Assessing the potential risk of crayfish introductions in South Africa

by

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DECLARATION

I, Lee-Anne Botha declare that the thesis, which I hereby submit for the degree Master of Science (Zoology) at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signature:

Date: 08 July 2021

DISCLAIMER

This thesis consists of chapters prepared as stand-alone chapters that have been submitted or are intended for submission for publication purposes to different journals. As a result, unavoidable repetitions and/or overlaps may occur between chapters.

GENERAL ABSTRACT

Alien freshwater crayfish have been translocated into regions outside their native range causing negative impacts on biodiversity and human well-being. These negative impacts have necessitated the need to control and manage their movement and utilization, partly through risk analysis protocols. Consequently, this study used recently developed protocols to assess potential current and future impacts of introduced crayfish in South Africa. These included the Environmental Impact Classification Scheme for Alien Taxa (EICAT) and the Socio-economic Impact Classification Scheme for Alien Taxa (SEICAT) for assessing environmental and socio-economic impacts and the Risk Analysis Framework for Alien Taxa (RAAT). Fourteen freshwater crayfish species with an invasion history were evaluated for potential impacts and invasion risk in South Africa. The EICAT and SEICAT assessments indicated that only three species (21%): red swamp crayfish (*Procambarus clarkii*), rusty crayfish (*Faxonius rusticus*), and signal crayfish (*Pacifastacus leniusculus*) had documented environmental impacts in their alien range. The remaining 11 species (79%) had no documented evidence of impacts and were classified as Data Deficient (DD), such that a closely related species with similar traits (e.g., feeding behaviour) and documented evidence of impact was used to infer their potential impacts. Most environmental impacts were associated with competition, predation, the transmission of diseases, and structural changes to ecosystems. Their magnitude varied from minor to massive. SEICAT assessments were also affected by a general lack of socio-economic data in the alien range, and most socio-economic impacts were associated with transmission of diseases, disruption in recreational activities, and the compromisation of employment opportunities, with the magnitude varying from minor to moderate. The RAAT framework was then used to assess the potential risk of the 14 alien freshwater crayfish species that have been introduced outside their native range. Of these, species (86%) pose a high-risk of invasion into South Africa, of which four species, marron (*Cherax cainii* and *C. tenuimanus*), *P. clarkii*, and redclaw crayfish (*Cherax quadricarinatus*) are already present in the country, but they have different introduction status. *Cherax cainii* and *C. tenuimanus* are present but not established, *P. clarkii* is established but not invasive, while *C. quadricarinatus* is invasive. Based on their introduction status and ecological traits, the ease of management for each of these species was scored as medium. Permit records indicate that *C. cainii* and *C. tenuimanus* are likely confined to aquaculture facilities. The current known distribution of *P. clarkii* in the wild is localised to two localities within Mpumalanga and Free State Provinces. Therefore, eradication is highly feasible. *Cherax quadricarinatus* is already widespread in the Inkomati River and adjacent river systems in Mpumalanga Province and is still spreading, and the most appropriate control is to minimise its further spread. Recommendations from the risk analyses of 5 species do not agree with the current listing under the South African Alien and Invasive Species (A&IS) Regulations because of no occurrence data in the country. Management plans should aim at identifying and preventing the introduction of potentially harmful invasive crayfish species, and maximise the potential benefits of less harmful species.

Key words: Alien freshwater crayfish, invasions, Alien and Invasive Species (A&IS) Regulations, impact assessments, management, EICAT, SEICAT, RAAT, South Africa.

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All honour and glory to God

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CHAPTER 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

Biological invasions are an increasing problem globally and are known to cause a significant loss of biodiversity, pose a significant threat to ecosystems and the services they provide, and affect human livelihoods and health (Kumschick and Richardson 2013; van Wilgen and Wilson 2018). Despite increasing awareness of the negative impacts of biological invasions, the number of alien species introductions is still increasing (Simberloff et al. 2013; Seebens et al. 2017). This is mainly as a result of increasing global trade and travel that has amplified the opportunities for species to be introduced into areas where they are not native (Perrings et al. 2005; Seebens et al. 2017). These opportunities can be classified as pathways of introduction, which are processes that lead to human-facilitated movement of alien taxa from one geographic area to another (Hulme et al. 2008; Faulkner et al. 2016; IUCN 2017). There are several pathways through which species have been intentionally or accidentally introduced globally (Hulme et al. 2008; CBD 2010). Alien species have been intentionally introduced to meet various societal needs such as agriculture, aquaculture, sport fishing, hunting, ornamental, and pet trade (Hulme et al. 2008; Essl et al. 2015). For example, the global trade on exotic ornamental plants has contributed to the introduction of many invasive plant species (Hulme et al. 2008; McGeoch et al. 2016). Similarly, in the Czech Republic, 53% of alien plants that have naturalized were primarily introduced for ornamental purposes (Perrings et al. 2005). Many invertebrates and exotic birds are also introduced as a result of the pet trade industry where some species may escape, whereas others are intentionally released into the wild as unwanted pets (Patoka et al. 2014a; Seebens et al. 2017). It has been suggested that as the demand in agriculture, tourism, and the global trade increases, so will the number of alien species as all of these sectors serve as pathways and vectors for introductions into new areas (Perrings et al. 2005; Essl et al. 2015; Seebens et al. 2017).

Accidental introductions have mainly occurred as a result of escapees from confinement (e.g., from aquaculture, research and breeding facilities), and contamination of goods or transport material (e.g., plant pests introduced with imported produce and aquatic organisms released through the ballast water of ships) (Hulme et al. 2008; Essl et al. 2015; McGeoch et al. 2016; IUCN 2017).

1.2 Evaluating impacts of alien species

Despite the socio-economic benefits derived from most of these introductions, some of the alien taxa have become invasive and caused adverse ecological impacts in areas of introduction (Simberloff et al. 2013; Zengeya et al. 2017). This has drawn attention to the need to control and manage the movement of invasive species as part of the Aichi Biodiversity targets set by the Convention on Biological Diversity (CBD) (CBD 2014). The Aichi Biodiversity Target 9 stated that "*By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated and measures are in place to manage pathways to prevent their introduction and establishment*". Consequently, studies have been undertaken to evaluate the impacts of alien species to prioritise the management of these species leading to the development of various protocols to try and screen potentially harmful species (Kumschick et al. 2012; Nentwig et al. 2016; Zengeya et al. 2017; Greta et al. 2019). However, these studies are often done using different methods or do not include all the components of the invasion process and are therefore not easily comparable across taxa and geographic regions (Kumschick and Richardson 2013). For example, simple terminology and how impacts are classified are different across protocols and can become misleading. This can result in alien species being classified incorrectly or the species being scored high risk which may not be a true reflection of the actual impacts (Lodge et al. 2000; Simberloff et al. 2013; Wilson et al. 2020). Some of the impacts caused by alien crayfish have been assessed by using impact scoring schemes and several expert opinion assessments have also been undertaken (Holdich et al. 2009; Gherardi et al. 2007; Lodge et al. 2012). However, some of the reviews were done more than 10 years ago and should therefore be updated. For example, Holdich et al. (2009) reviewed alien crayfish introductions in Europe and their history of invasion, and further discussed the emerging alien crayfish and their potential impacts based on documented impacts in their alien range. In South Africa, a similar assessment was undertaken to evaluate the potential impacts of alien crayfish species that were present in the country (de Moor 2002). This assessment was also based on expert opinion because no impacts have been recorded when the review was done (de Moor 2002). Consequently, the predictions were drawn from impacts recorded elsewhere (de Moor 2002).

Lodge et al. (2012) did a review at a global scale discussing the alien crayfish with known impacts and the need for additional studies for the data deficient species that have the potential to cause negative impacts when introduced. This is not surprising due to limited data available on some species with which to perform adequate impact assessments (Holdich et al. 2009; Lodge et al. 2012). They further also highlighted that the impacts recorded were skewed towards developed countries and species with a long history of introductions. Several studies have recorded the harmful ecological impacts caused by alien crayfish, and results from such studies are used to inform risk assessments. However, these studies have been done at different scales and using different methods making it difficult to draw conclusions and estimate the magnitude of impacts (Lodge et al. 2012; Simberloff et al. 2013).

There is therefore, a critical need for a standardised method to incorporate negative impacts caused by alien taxa into risk assessments (Kumschick and Richardson 2013). The Environmental Impact Classification Scheme for Alien Taxa (EICAT) is a simple, objective and transparent method of assessing alien taxa based on the magnitude of documented impacts in their alien ranges (Blackburn et al. 2014; Hawkins et al. 2015). The EICAT scheme has also been adopted by the International Union for Conservation of Nature (IUCN) and has been published as a standard (IUCN 2020). A similar framework, Socio-Economic Impact Classification of Alien Taxa (SEICAT) was also developed to classify how biological invasions affect human social-economic well-being (Bacher et al. 2017). These protocols however, need to be revised continuously to improve their proficiency as a tool for decreasing the rate of introductions, spread, and invasion in new areas (Blackburn et al. 2014; Bacher et al. 2017; Kumschick et al. 2020a).

1.3 Risk analysis

A risk analysis comprises four main components that include: 1) risk identification; 2) risk assessment; 3) risk management; and 4) risk communication (Kumschick et al. 2020a; Figure 1.1). Prevention is often the most cost-effective method to manage biological invasions, however, is not always possible, and therefore, management measures often try to identify and prevent the introduction of potentially harmful species while allowing for the introduction and utilisation of less harmful species (Kumschick et al. 2020a). Thus, a risk analysis considers both pre- and post-border introductions, the possible implications, and also provides an opportunity for the public domain and all stakeholders to provide input into potential management options (Kumschick et al 2020a).

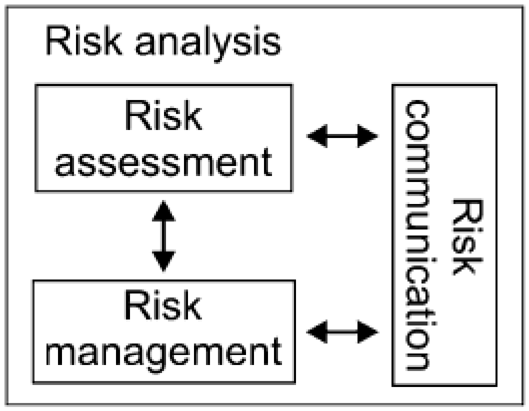

Figure 1.1 The four components of the risk analysis framework for alien taxa as described by Kumschick et al. (2020a). Risk identification is undertaken prior to the formal risk analysis and is therefore not included in the figure.

Risk identification

The risk of biological invasions is assessed through: 1) invasion pathways; 2) area of invasion; and 3) species that will determine what the risk assessment will evaluate and the appropriate management actions needed (Kumschick et al. 2020a). In situations where a species is the risk, the assessment will comprise of likelihood of introduction, establishment and spread (Kumschick et al. 2020a). The history of invasion and the negative impacts caused will also form part of risk analysis (Kumschick et al. 2020a).

Risk assessment

A risk assessment represents a protocol that is used to assess the likelihood of entry, establishment, and spread of alien taxa into a given area, and the potential negative impacts that are likely to occur as a result of the invasion (Kumschick et al. 2020a). Several approaches to undertake risk assessment have been suggested and these include trait-scoring, statistical, decision tree, rapid screening, mechanistic and detailed approaches (Keller and Kumschick 2017). For example, the trait scoring approach is a deductive approach of identifying species with specific traits that are likely to aid a species' establishment and also identify species that are likely to cause higher impacts (Keller and Kumschick 2017). Examples where this approach has been applied include: 1) the Aquatic Species Invasiveness Screening Kit (AS-ISK), formerly known as the Freshwater Invertebrate Invasiveness Scoring Kit (FISK) that was designed for assessing alien species in aquatic ecosystems (Greta et al. 2019); and 2) the Australian Weed Risk Assessment (AWRA) that represents the most widely used tool to screen alien plants in terrestrial ecosystems (Gordon et al. 2010; Kumschick and Richardson 2013).

The rapid screening approach considers two aspects of the alien species, namely: 1) climate suitability; and 2) history of invasion (Keller and Kumschick 2017). A major tenet of the approach is to match the similarity between the environments (usually climate) of an alien species in its native and introduced range. If the environment is similar, the likelihood of establishment is usually considered high, other factors (e.g., species interactions) not withstanding (Keller and Kumschick 2017). The rapid screening approach can be extremely useful where resources and information are limited and the results could filter species of high risk for more detailed risk analysis (Faulkner et al. 2014). For example, Faulkner et al. (2014) used the rapid screening approach to create a watch list of alien species that could potentially be introduced into South Africa. The study used climate matching, history of invasion, and propagule pressure to predict the invasion potential of alien species into South Africa (Faulkner et al. 2014). It identified and flagged approximately 400 alien species that had a high risk potential for being invasive in South Africa (Faulkner et al. 2014).

Unlike the other methods, the mechanistic approach does not solely focus on the traits of the alien species but includes other facets of the invasion process (i.e., introduction, establishment, spread and invasion) and the potential impacts (Keller and Kumschick 2017). It is based on the notion that if the invasive species cannot cross barriers (i.e., borders) or if environmental conditions are not optimal, the species will be considered low risk despite its history of invasion (Keller and Kumschick 2017).

The risk assessment approaches are based on different premises as highlighted above, and the decision on which to apply depends on the circumstances and purposes (Kumschick et al. 2020a). For example, the potential of introduction and spread of alien crayfish in several countries has been done using different risk assessment tools (Westman 2002; Peay et al. 2010;

Soes and Koese 2010; Lodge et al. 2012), such as using different approaches to assess all pathways associated with crayfish introductions (Chucholl 2013; Patoka et al. 2014a, 2014b; Faulkes 2015a, 2015b). For example, some studies assessed crayfish and its potential impacts using the Non-Native Organism Risk Assessment Scheme, a mechanistic approach that was designed to screen alien species in Europe (Peay et al. 2010). The scheme is divided into two components, namely: 1) Evaluating ecological traits to judge the invasion potential of an organism; and 2) a detailed assessment covering the stages of the invasion stages (i.e., entry, establishment, spread and impact) (Peay et al. 2010). In South Africa, AS–ISK which is a trait-scoring method that was designed for assessing alien species in aquatic ecosystems (Greta et al. 2019), was used to assess the risk of four crayfish species in South Africa (*Cherax* species, *C. cainii, C. destructor, C. quadricarinatus and C. tenuimanus*; Zengeya unpublished data). However, most of the impacts recorded for alien crayfish have been done by undertaking traditional impact studies and not through formal risk assessments. For example, there have also been a number of experimental studies on the rusty crayfish (*Faxonius rusticus*) and red swamp crayfish (*Procambarus clarkii*) in Wisconsin and Delaware, USA (Gherardi and Daniels 2004; Kreps et al. 2012) and long-term monitoring programs on *F. rusticus* and the signal crayfish (*Pacifastacus leniusculus*) in Trout Lake, Wisconsin and Riofrio River, Texas, USA to evaluate the impacts in recipient areas of introduction (Wilson et al. 2004; Dana et al. 2010).

Risk management

Risk management involves a process where the information gathered from the risk assessment is used to aid in developing management strategies by evaluating various methods that can be used to manage the species and the efficacy of each depending on the resources available (Kumschick et al. 2020a). By identifying the ease of management, alien species can be flagged as high or low risk that could aid in pre-border control by preventing the import of harmful species (Kumschick et al. 2020a). If the alien species is already present in the area, management options include eradication for localized species and containment for widespread species (Kumschick et al. 2020a). For example, some crayfish species are susceptible to biocides that can be used to eradicate established populations that occur at a few localized sites (Gould 2005; Ballantyne et al. 2019). However, biocides should be used in moderation because they are not species-specific and often affect native fauna (Manfrin et al. 2019). For open stream conditions, there is some evidence that physical barriers can discourage further spread of alien crayfish without disrupting upstream migration of freshwater fish (Krieg et al. 2021). Other physical methods such as intensive trapping have also yielded positive results, however these can become costly when implemented for long periods (Manfrin et al. 2019).

Risk communication

Risk communication involves a process where all stakeholders are continuously consulted throughout the risk analysis process to ensure they understand why recommendations were made and to provide them with an opportunity to raise any concerns or provide their own input (Kumschick et al. 2020b). When management plans for a socio-economically important species are developed, relevant stakeholders should be involved in the process to ensure that the impacts of the alien species are managed without compromising the benefits derived from the species that could ultimately affect human livelihoods (Bacher et al. 2017; Zengeya et al. 2017). Such situations for example, include the removal of alien trees in communities that harvest for firewood and the removal of alien fish that are targeted by recreational anglers (Zengeya et al. 2017). Local and international conferences, working groups, and municipal and community meetings create ideal platforms for stakeholder engagements as they collectively target members of the public, scientists, enthusiasts, policy-makers, and local communities.

Risk analyses in South Africa

In South Africa, the South African National Biodiversity Institute (SANBI) is an entity that is responsible for monitoring and managing aspects that may affect the overall biodiversity of the country. This includes monitoring species and the conservation status of all listed threatened or protected species and listed ecosystems. It also monitors and reports on the status of the alien species that are present in the country (van Wilgen and Wilson 2018). The institute has developed a Risk Analysis framework to inform the listing and management of alien taxa under the National Environmental Management: Biodiversity Act (NEM:BA (2004), and Alien and Invasive Species (A&IS) Regulations (2020). All alien species are managed under this Act where they are listed in different categories and managed accordingly (van Wilgen and Wilson 2018; Kumschick et al. 2020b). This framework is comprehensive as it covers all the stages across the invasion continuum from the pathway of introduction to the species' ability to establish and spread (Blackburn et al. 2011; Kumschick et al. 2018; Kumschick et al. 2020b). By using this framework, the process will confirm whether a species is listed in the correct category and provides evidence of the potential invasion risks and ecological impacts (Kumschick et al. 2018; Kumschick et al. 2020a).

The information gathered could be used to support recommendations and prevent future introduction of potentially harmful species that are not yet present in the country, by regulating import permits (Kumschick et al. 2020a). This prevents the importation of potentially invasive and harmful species with high risk while allowing the importation of beneficial species with low risk (Kumschick et al. 2018; Kumschick et al. 2020a). The information gathered also creates a platform for the development of adequate management plans to mitigate the risks when species are imported for any restricted activity under the NEM:BA and A&IS Regulations. The Risk Analysis framework also offers an overview of the management implications of alien species listed and the evidence-based information provided could be used to underpin management decisions (Kumschick et al 2020b).

1.4 STUDY RATIONALE

Freshwater crayfish are a diverse group of decapods with over 600 species and are among the most translocated group of freshwater invertebrates globally (Crandall and Buhay 2008; Mrugała et al. 2015). Crayfish have been introduced mainly for aquaculture and the pet trade industry (Holdich et al. 2009; Soes and Koese 2010; Lodge et al. 2012; Patoka et al. 2014b). They are highly fecund, tolerant to wide environmental conditions, have no larval stages, making them ideal for aquaculture (Holdich et al. 2009; Gherardi et al. 2011; Lodge et al. 2012). Some have different colour morphs, are small in body size, and these characteristics make them aesthetically appealing as pets (Patoka et al. 2014b; Mrugała et al. 2015). Currently, alien crayfish occur on all continents except Antarctica and have caused negative impacts in some areas of introduction (Gherardi 2007; Holdich et al. 2009; Gherardi et al. 2011; Lodge et al. 2012).

Four crayfish have been introduced into South Africa, and these include: 1) marron crayfish (*Cherax cainii*); 2) yabby crayfish (*C. destructor*); 3) redclaw crayfish (*C. quadricarinatus*) that are all native to Australia; and 4) red swamp craysfish (*Procambarus clarkii* that is native to the USA (de Moor 2002; Nunes et al. 2017a). To date, only *C. quadricarinatus* and *P. clarkii* have managed to establish populations in the country, with *C. cainii* being restricted to aquaculture facilities (Nunes et al. 2017a). There are no records of the

C. destructor being present in the wild (Nunes et al. 2017a). Naturalised populations of the *C. qudricarinatus* are more widespread and have established populations in the lower Phongola in KwaZula Natal Province (du Preez and Smit 2013; Figure 1.2). *Cherax quadricarinatus* have also established populations in the Inkomati River catchment in Mpumalanga Province and are continuing to spread into adjacent river systems (de Moor 2002; Nunes et al. 2017b; Figure 1.2). Naturalised populations of *P. clarkii* are known to occur at two sites: 1) Driehoek Farm located 10 km from the town of Dullstroom in Mpumalanga Province; and 2) Mimosa Dam in the Free State Province (Nunes et al. 2017c; Figure 1.2). *Cherax cainii* is the only freshwater crayfish that is legally permitted for aquaculture in South Africa, while the utilisation of the other crayfish species is strictly prohibited (de Moor 2002; Nunes et al. 2017a).

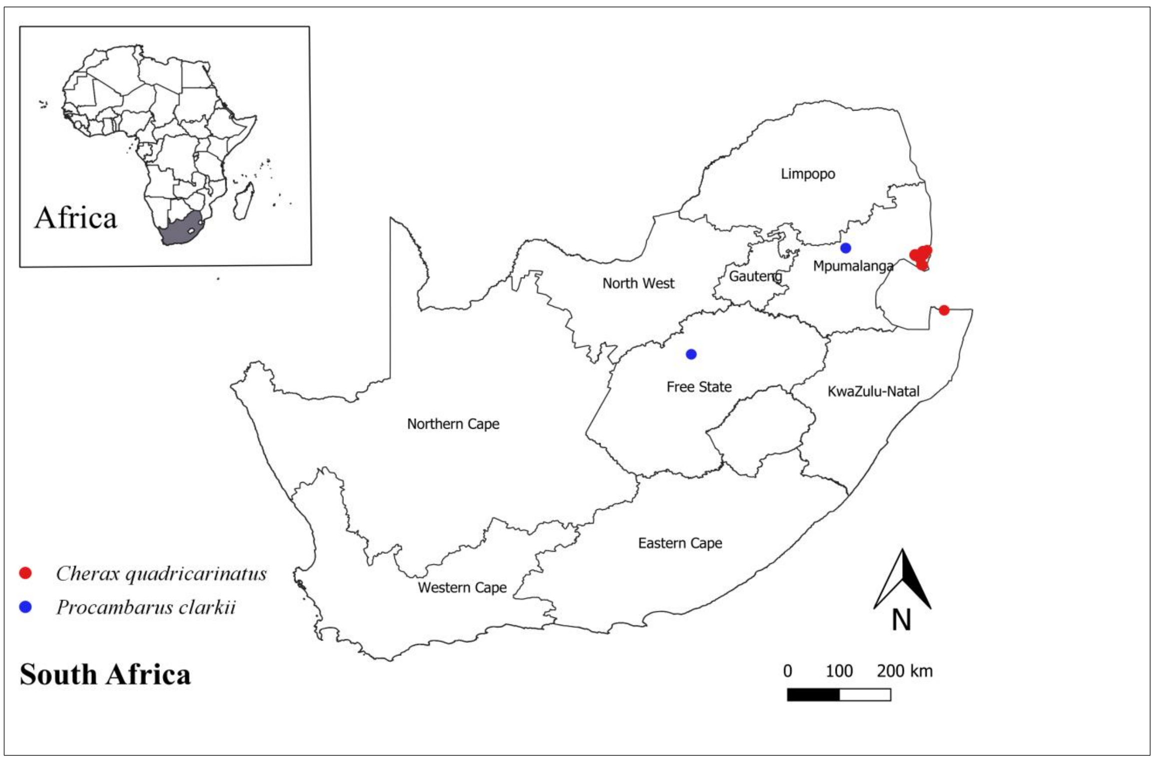

Figure 1.2: The locations of naturalised alien freshwater crayfish populations in South Africa.

Studies on crayfish in South Africa are limited to a few studies highlighting their introduction events and distribution (de Moor 2002; Nunes et al. 2017a; 2017b), and their potential as vectors of parasites (du Preez and Smit 2013; Nelwamondo 2016; Tavakol et al. 2021). Emerging crayfish species are common in the pet trade industry and aquaculture therefore, still require further research due to their potential negative impacts (Soes and Koese 2010; Lodge et al. 2012;

Patoka et al. 2014a). The life-history traits of crayfish allow them to establish and spread at a rapid rate (Byron and Wilson 2001; de Moor 2002; Gherardi and Acquistapace 2007), and can negatively impact an ecosystem through various mechanisms such as competition, predation, hybridisation, and the spread of their associated pathogens and parasites (Rebelo and Cruz 2005; Twardochleb et al. 2013; Loureiro et al. 2015; Jackson et al. 2016). Assessing the impacts of these species is a complex process, and evidence of these impacts can sometimes only become apparent at a later stage (Nystrom et al. 2007; Dunoyer et al. 2014; Magoulick and Piercey 2016; Marufu et al. 2018).

Given the above background, the present study is directed at undertaking a formal Risk Analysis of all invasive freshwater crayfish in South Africa using frameworks that consists of a range of different parameters to provide evidence of such risks. A Risk Analysis process is therefore, necessary and the frameworks used to assess impacts (EICAT and SEICAT) and risks of invasions (RAAT) offer simple, objective, and transparent process of identifying risk associated with the introduction of different alien species and it also allows for the comparative analysis across different regions and taxonomic groups (Kumschick et al. 2020b). This is to ensure that the science based risk analysis process inform on the development of appropriate management strategies for alien crayfish species aready in the country and or species that are likely to be introduced (Kumschick et al. 2020b).

1.5 AIMS OF STUDY

The general aim of this study therefore, is to identify the risks associated with the introductions of alien freshwater crayfish in South Africa by:

1) Evaluating and providing evidence for the potential impact of invasive crayfish using the standardized EICAT and SEICAT frameworks;

2) Evaluating the risk of invasion by alien freshwater crayfish using the Risk Analysis framework developed for South Africa; and

3) Providing some management recommendations and mitigation measures to prevent future introductions, and mimise impacts asoociated with alien species that are aready present in the country.

1.6 RESEARCH PREDICTION

Biological invasion studies are limited to a few taxonomic groups and geopraphical areas. Following the same pattern as seen for other taxa, the present study therefore predicts that the impact assessments will classify most species as Data Deficient (DD).

1.7 THESIS APPROACH

Information on impacts caused by alien freshwater crayfish is limited to a few species and in addition, the limited studies available were done using different methods and are not easily comparable across taxa and geographic areas (Soes and Koese 2010; Lodge et al. 2012). A way to alleviate this problem is to use standardized methods that can be used across different taxa and geographic regions. In this thesis, the negative environmental and socio-economic impacts were assessed using two impact classification schemes, the Environmental Impact Classification Assessment for Taxa (EICAT; Blackburn et al. 2014) and socio-Socio-Economic Impact Classification Assessment for Alien Taxa (SEICAT; Bacher et al. 2017), respectively.

In addition, the negative impacts associated with crayfish introductions have necessitated the need to control and manage their movement and utilization (Lodge et al. 2000; Patoka et al. 2018). This has been achieved in part through the development of risk analysis protocols to identify and prevent the introduction of potential harmful species while allowing the introduction of less harmful but beneficial species (Kumschick et al. 2020a). This study used the recently developed risk analysis framework of alien taxa (RAAT; Kumschick et al. 2018) to evaluate the risk posed by alien crayfish if they were introduced into South Africa. Risk analysis can also be used to guide the current regulations, underpin management decisions and to flag and prevent potential harmful species from being introduced into South Africa (Kumschick et al. 2020b). It can also be used to recommend management options to reduce the extent and impact of alien crayfish species that are already present in South Africa (Lodge et al. 2000). A database of freshwater crayfish species that are currently known to be invasive or have establsihed populations when introduced in areas outside their native range was compiled from the literature and global databases. These species were then evaluated for potential impacts and invasion risk to South Africa. The impact assessments are global in scope because all recorded impacts in their invaded range were used. The risk analysis however, was restricted to South Africa.

1.8 THESIS OUTLINE

The first part of this thesis (Chapter 2) assesses the negative environmental and socio-economic impacts caused by alien invasive freshwater crayfish in areas of introduction using EICAT and SEICAT impact classification schemes, and the impact mechanisms are also identified, and their magnitude evaluated. Chapter 3 evaluates the risks associated with alien crayfish introductions in South Africa and provides recommendations for the listing categories of alien crayfish under South Africa's NEM:BA and A&IS Regulations where required. Chapter 4 provides a general discussion where the key findings of the study are highlighted and discussed and outlines the current gaps and areas that require further research in alien freshwater crayfish.

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CHAPTER 2

ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACT ASSESSMENTS OF ALIEN FRESHWATER CRAYFISH IN THEIR GLOBAL INVASIVE RANGE: IMPLICATIONS FOR SOUTH AFRICA

2.1 ABSTRACT

Freshwater crayfish have been widely introduced into areas outside of their native range for aquaculture and aquarium trade. However, some crayfish introductions have led to negative impacts in areas of introduction leading to the development of assessment protocols to identify and prevent the introduction of potential harmful species. However, there have been proposals to classify impacts caused by alien species using standardized methods for assessing environmental impacts. This study therefore used recently developed protocols, the Environmental Impact Classification for Alien Taxa (EICAT) and Socio-Economic Impact Classification for Alien Taxa (SEICAT) to assess the impacts caused by freshwater crayfish in their global alien range. Fourteen alien freshwater crayfish species that are currently known to be invasive, have been introduced, or established in their global alien range were selected and impact assessments were unertaken. The results from the EICAT assessments indicated that only three species: red swamp crayfish (*Procambarus clarkii*), rusty crayfish (*Faxonius rusticus*), and signal crayfish (*Pacifastacus leniusculus*) had documented environmental impacts in their alien range while the remaining species were classified as Data Deficient (DD). The EICAT impacts were associated with competition, predation, the transmission of diseases, and structural changes to ecosystems and the magnitude of these impacts varied from minor to massive. The SEICAT assessment also revealed that information on non-environmental impacts of alien crayfish species is limited to a few species (*P. calrkii*, *F. rusticus*, *P. leniusculus*). The most dominant mechanisms in which the crayfish affected human well-being were transmission of diseases, disruption in recreational activities, and alien freshwater crayfish compromising job opportunities. The magnitude of these impacts varied from minor to moderate. There is an urgent need to undertake additional studies on impacts caused by crayfish in their alien range particularly South Africa due to the information being limited to a few species.

Keywords: Crayfish, freshwater invasions, assessment frameworks, human well-being, management, EICAT, SEICAT, Global invasive range, South Africa

2.2 INTRODUCTION

2.2.1 Evaluation of impacts caused by alien species

Alien species can cause harmful impacts in recipient areas of introduction that can lead to declines in populations of native species and adverse impacts on human well-being (Lodge et al. 2012; Simberloff et al. 2013). Consequently, impact assessment frameworks have been developed to assess potential environmental and non-environmental impacts that alien species are likely to cause in areas where they are introduced (Kumschick and Richardson 2013; Zengeya et al. 2020). These could be used to identify and prevent the introduction of potentially harmful species. Examples of impact assessment frameworks that assess environmental impacts include an invasive species assessment protocol to evaluate non-native plants for their impact on biodiversity (Morse et al. 2004), a bio-pollution assessment scheme (Olenin et al. 2007), a generic ecological impact assessment of alien species in Norway (Sandvik et al. 2013), and the Environmental Impact Classification Scheme of Alien Taxa (EICAT; Blackburn et al. 2014, Hawkins et al. 2015). There is only one framework that specifically focuses on non-environmental impacts, the Socio-Environmental Impact Classification Scheme of Alien Taxa (SEICAT; Bacher et al. 2017), but there are a few frameworks that assess both environmental and non-environmental impacts and these include a conceptual framework for prioritisation of invasive alien species for management according to their impact (Kumschick et al. 2012), a review of impacts of invasive alien marine species on ecosystem services and biodiversity (Katsanevakis et al. 2014), the General Impact Scoring System (GISS; Nentwig et al. 2016), and an Invasive Species Effects Assessment Tool (In SEAT; Martinez- Cillero et al. 2019).

A major challenge in the implementation of these different frameworks to classify and assess impacts of alien species is that they are often not easily comparable because they were done using different methods (Kumschick and Richardson 2013; Zengeya et al. 2020). For example, some of the assessment protocols only target a specific taxon or address one specific part of the invasion process, and some are specific to certain geographic areas, and are, therefore, not comprehensive enough to make well-informed management recommendations (Blackburn et al. 2014; Kumschick et al. 2017; Vanderhoeven et al. 2017).

One way to alleviate this problem is to standardize the way impacts are classified and assessed in alignment with international best standards (Blackburn et al. 2014; Wilson et al.

2020). This has been achieved in part through the proposal to use EICAT and SEICAT frameworks as global standards because they can be used to classify impacts of alien species across all taxa and different geographical scales (e.g., national, regional, and global scales) (Kumschick et al. 2020; Wilson et. 2020). As a result, EICAT has recently been adopted as an International Union for the Conservation of Nature (IUCN) product and published as a standard (IUCN 2020). The EICAT framework is based on published evidence and assessments done using the framework are easily comparable between taxa and regions because they are done using simple, objective, and transparent methods that minimise bias (Blackburn et al. 2014). EICAT classifies impacts based on 12 mechanisms that vary from direct impacts on individual native species such as competition, predation, and hybridisation to chemical, physical or structural impacts on the ecosystem (Blackburn et al. 2014, Hawkins et al. 2015. In addition, EICAT classifies impacts into five levels of the impact (i.e., Minimal Concern, Minor, Moderate, Major and Massive) based on the magnitude and organisational level of species affected (Blackburn et al. 2014, Hawkins et al. 2015). For example, impacts classified as of minimal concern do not affect the performance of a native species, moderate impacts lead to a reduction in population size of at least one native species but do not lead to extirpation and or extinction, while massive impacts lead to irreversible community changes such as species extinction (Blackburn et al. 2014, Hawkins et al. 2015). Similarly, the SEICAT framework assesses non-environmental impacts by evaluating how alien species adversely affect human well-being (Bacher et al. 2017). Alien species are known to affect the daily lives of humans indirectly (e.g., crustaceans damaging fishing nets) or directly (e.g., getting stung by invasive wasps) (Gherardi et al. 2011a; Bacher et al. 2017). Therefore, SEICAT is structured to assess impacts of an alien species on several facets of human well-being such as safety, material and immaterial assets, health, and social, spiritual, and cultural relations (Bacher et al. 2017). The impacts are then classified based on their magnitude into five levels of the impact (i.e., Minimal Concern, Minor, Moderate, Major and Massive) (Bacher et al. 2017).

Several EICAT assessments have been done for a number of taxa at global assessments initiatives for amphibians (Kumschick et al. 2017), bamboos (Canavan et al. 2019), gastropods (Kesner and Kumschick 2018), mammals (Hagen and Kumschick 2018) and some invertebrates (Nelufule 2018). A few taxa have EICAT assessments at a national level for South Africa and these include a few species of grasses (Visser et al. 2017), trees (Hirsch et al. 2020; Jansen et al.

2020; van Wilgen et al. unpublished data), invertebrates (van Wilgen et al. unpublished data), and fish (Marr et al. 2017). Socio-economic impacts of alien species have been largely neglected (Kumschick and Richardson 2013), and there are a few global assessments for amphibians (Bacher et al. 2017), birds (Evans et al. 2020), and marine fishes (Galanidi et al. 2018). In South Africa, SEICAT has been applied to gastropods (Kesner and Kumschick 2018), mammals (Hagen and Kumschick 2018), and trees (Jansen et al. 2020).

2.2.2 Freshwater crayfish introductions

Freshwater crayfish are very diverse with over 600 species divided into three families (Crandall and Budhay 2008). They are among the most translocated freshwater invertebrates and are now present on all continents except Antarctica (Crandall and Buhay 2008; Lodge et al. 2012; Twardochleb et al. 2013). Freshwater crayfish have been primarily introduced for aquaculture; however, they have also become popular in the aquarium trade industry (Holdich 1993; Patoka et al. 2018). For example, the red swamp crayfish (*Procambarus clarkii*) contributes at least 85% of the world's crayfish production and in 2003, the USA produced 33 498 tonnes valued at approximately $ 48.6 million US while China produced 723 207 tonnes (valued at >$344 240 000 US million) in 2015 (Wang et al. 2018). The aquarium trade is another important pathway of introduction and crayfish are known to be sold in various countries despite strict regulations and policies in place to manage the introduction of alien species (Lodge et al. 2000; Patoka et al 2018). Approximately 120 crayfish species out of the 600 known species are available for sale as pets (Chucholl 2013; Yasuda and Wada 2015). Germany is known to be the main importer of non-indigenous crayfish into Europe followed by the Czech Republic (Chucholl 2013; Yasuda & Wada 2015). In Germany alone, 123 crayfish species are available for sale, of which 105 species are of North American origin (Chucholl 2013; Faulkes 2015).

The majority of crayfish introductions is intentional and unintentional resulting in their release into the wild (Holdich et al. 2009; Chucholl 2013; Yasuda and Wada 2015), as has been the case in many countries, such as in Spain and the United Kingdom (Holdich 1993; Gherardi 2007; Holdich et al. 2009). Alien crayfish are known to escape from aquaculture facilities, and some are released into the wild as unwanted pets by owners enabling crayfish to spread into new areas (Patoka et al. 2014; Mrugała et al. 2015). Crayfish are mobile and are therefore not restricted to waterways and can easily migrate overland to colonise new areas (Barbaresi and

Gherardi 2000). Furthermore, crayfish are naturally known to be hardy species for their high tolerance to a wide variety of environmental conditions and have managed to invade many areas outside of its native range where they have caused harmful impacts (Gherardi 2007; Holdich et al. 2009).

Impacts caused by introduced crayfish are limited to a few, mainly North American species, and there is therefore a need to assess impacts caused by other introduced crayfish species (Holdich et al. 2009; Lodge et al. 2012). For example, the redclaw crayfish (*Cherax quadrcarinatus*) that is native to Australia, has been widely introduced for both aquaculture and the aquarium trade, however, studies in its invaded range have been limited in scope to introduction events (Ahyong and Yeo 2007; Nunes et al. 2017a), distributional records (Nunes et al. 2017b; Douthwaite et al. 2018), and trophic ecology (Marufu et al. 2018). The marbled crayfish (*Procambarus fallax f. virginalis*) has established populations in Madagascar, however, to date there are no records of its impacts (Feria and Faulkes 2011; Faulkes 2015). Although several studies have documented the harmful ecological impacts caused by some alien crayfish, these impacts were not assessed using formal assessment protocols and it is not easy to estimate the magnitude of the impacts (Lodge et al. 2000; Nunes et al. 2017a). Furthermore, these studies are not easily comparable because they were done using different methods (Lodge et al. 2000; Peay et al 2010; Soes and Koese 2010).

The use of standardised and evidence-based methods to assess the impacts of alien species will help improve the confidence levels in the information used to inform management interventions (Blackburn et al; 2014; Bacher et al; 2017; Wilson et al. 2020). For example, impact assessments could be used to identify and prioritise species that should be targeted for management to prevent the introduction and/or minimise the impacts of harmful species while allowing the introduction and utilisation of less harmful but beneficial species (Lodge et al. 2000; Kumschick et al. 2020). In addition, the use of objective and transparent methods helps minimise bias and contentions around the negative impacts caused by the species and the need to manage them (Blackburn et al. 2014; Wilson et al. 2020).

The main objective of this study was to assess and classify the environmental and non-environmental impacts of freshwater crayfish in their global alien range using formal impact assessment frameworks such as EICAT and SEICAT.

The study predicted that most the alien freshwater crayfish will be Data Deficient (DD as a result of the limited information available.

2.3 METHODS

2.3.1 Species selection

A database with all crayfish species was compiled from the primary literature, the International Union for Conservation of Nature (IUCN) Red List (www.iucnredlist.org/), and the Global Biodiversity Information Facility (GBIF) (www.gbif.org/en/). The invasion status of the crayfish species was quantified based on data from the primary literature, the Centre for Agriculture and Bioscience International (CABI) Invasive species compendium (www.cabi.org/isc), the Global Invasive Species Database (GISD) (www.iucngisd.org/gisd/), and the Non-Indigenous Aquatic Species (NAS) (nas.er.usgs.gov). Invasion status was defined according to the different stages of the unified framework (see Blackburn et al. 2011), and species were grouped in four broad categories: 1) not introduced = species that have no record of introduction to areas outside their native range; 2) introduced = species that are introduced to a country but are not naturalized in the wild; 3) established = species that have established in the wild but are not yet invasive; and 4) invasive = species with self -sustaining populations that have spread from initial sites of introduction.

For both EICAT and SEICAT, an extensive literature review of impact studies was undertaken using Google Scholar (https://scholar.google.co.za/) and Web of Science (http://apps.webofknowledge.com) search engines. The search thread **invasive*crayfish** or **impacts*species name** were used. The relevant literature was compiled and recorded impacts were then assessed and classified using procedures outlined for EICAT (Blackburn et al. 2014; Hawkins et al. 2015) and SEICAT (Bacher et al. 2017). Detailed information on the literature used to assign scores is available in Appendices 2.1 and 2.2.)

2.3.2 EICAT

EICAT assessment has five main impact categories that include: 1) Minimal Concern (MC) - where the alien species have impacts but not to the extent where the fitness of a native species is affected; 2) Minor (MN) - where impacts reduce the fitness of one or more native taxa; 3) Moderate (MO) - where impacts are on populations of one or more taxa; 4) Major (MR) - where impacts are at a community level but are reversible; and 5) Massive (MV) - where impacts lead to community-level changes and are irreversible (Blackburn et al. 2014; Hawkins et al. 2015). The magnitude of the environmental impacts were scored using the magnitude of impacts across 12 impact categories that included: 1) Competition - where alien species compete with native taxa for shared resources; 2) Predation - where the alien taxa are predatory on native taxa; 3) Hybridisation with native fauna leading to deleterious impacts; 4) Disease transmission to native species; 5) Parasitism - where parasites and pathogens are transmitted to native taxa causing negative impacts; 6) Poisoning/toxicity - where alien taxa are toxic through ingestion, inhalation or contact; 7) Bio-fouling - where the accumulation of alien taxa on wet surfaces lead to harmful impacts; 8) Grazing/herbivory/browsing - where the feeding behaviour of alien taxa in their global alien range are detrimental to native plant species; 9,10 & 11) Chemical, physical or structural impacts on ecosystems - where the alien taxa change various characteristics and regimes in their invaded range leading to negative impacts; and 12) Interaction with other alien species in their alien range facilitating deleterious impacts on native species (Blackburn et al. 2014; Hawkins et al. 2015).

A confidence score was assigned to the assessments as: 1) Low; 2) Medium; and 3) High (Hawkins et al. 2015). The scores were determined by the data used for the impact assessments (Hawkins et al. 2015). For example, when the data used were only inferred, the sources used are unreliable and contain contradictory information, a low confidence score was assigned (Hawkins et al. 2015). A medium confidence score was allocated when there was ambiguity in some of the data but there was also a number of direct observational evidence available (Blackburn et al. 2011; Hawkins et al. 2015). Good quality data sources and direct observational evidence to support the impact assessment were assigned a high confidence score (Hawkins et al. 2015). The region where studies were undertaken was included to estimate the extent of introduced and established ranges. This is needed to evaluate if the impacts are at local, national or global scales (Blackburn et al. 2014; Hawkins et al. 2015).

2.3.3 SEICAT

SEICAT evaluates how alien taxa affect the livelihoods of humans or deter them from participating in activities that are imperative for their well-being (Bacher et al. 2017). The impact categories reflect the magnitude of impact the alien species has on human well-being Bacher et al. 2017). SEICAT also has five impact categories that include: 1) Minimal Concern (MC) - where no impacts are recorded despite the availability of relevant studies concerning their impact on human well-being; 2) Minor (MN) - where the presence of alien taxa impact human well-being according to the categories and make it difficult to participate in normal human activities; 3) Moderate (MO) - where alien taxa cause a reduction in human activity such as fewer participants and location change, but it remains active; 4) Major (MR) - where human activity disappears in invaded areas, but this change is reversible when alien taxa are removed within a decade; and 5) Massive (MV) - where impacts result in the total disappearance of human activity and changes are usually irreversible (Bacher et al. 2017).

SEICAT assessment classifies the impact on human well-being using four categories 1) Safety - where the presence of alien taxa affect human safety (e.g., bee/wasp stings) or security from disasters, inducing flooding); 2) Material and immaterial assets - where alien taxa impact human livelihoods by compromising employment opportunities; 3) Health - where alien taxa are poisonous or harbor zoonotic diseases that may compromise humans' immune system; and 4) Social, spiritual and cultural relations - where the presence of alien taxa may prevent humans to perform certain ceremonies (Bacher et al. 2017). Four mechanisms were identified through which alien freshwater crayfish can impact human well-being to assist with the classification and these included: 1) burrowing activities that may include inducing flooding; 2) damage to fisheries that may include competing with native fish reducing stock and recreational activities; 3) predation on fish eggs; and 4) transmission of diseases.The same confidence scoring rationale used in EICAT above (Blackburn et al. 2011; Hawkins et al. 2015) was also used in SEICAT. The region where studies were undertaken was also noted to estimate the extent of introduced and established ranges.

2.4 RESULTS

A database of 658 species was created of which 14 crayfish species whose invasion status was categorized as introduced, established and invasive were then selected for the impact assessments (see Supporting Information Table 2.1). The majority of the material used to quantify the impacts in these assessments was from laboratory experiments validated by field surveys and long-term monitoring programs because of the complexities involved when trying to identify the underlying mechanisms responsible for these impacts.

2.4.1 EICAT

Three out of 14 alien freshwater crayfish species, red swamp crayfish (*P.clarkii*), rusty crayfish (*Faxonius rusticus*), and signal crayfish (*P. leniusculus*) showed recorded impacts. The rest of the species were all classified as Data Deficient (DD) (Table 2.1). The majority (18 of 44) of documented impacts were assessed as moderate, 30% as minor, 23% as major and 7% as massive (Figure 2.1a). The environmental impacts recorded were associated with six mechanisms that included predation followed by competition, grazing, hybridisation, transmission of diseases and structural changes to ecosystems through burrowing or changing water systems from clear to turbid conditions (Figure 2.1b). Most of the impact studies obtained a confidence score of medium to high because the impacts were identified through long-term studies and experimental studies validated by field surveys that represent direct observations. Impact studies were limited to two regions, Europe (27 studies) and North America (16 stuides).

Table 2.1 Environmental Impact Classification for Alien Taxa (EICAT) and Socio-Economic Impact Classification for Alien Taxa (SEICAT) assessments of 14 alien freshwater crayfish that are currently known to be invasive, established, or have been introduced in areas outside their native range.

		EICAT				**SEICAT**			
Species	**Invasion status**	Maximum impact	Mechanism(s)	Confidence level	Region(s) where impacts were recorded	Maximum impact	Mechanism(s)	Confidence level	Region(s) where impacts were recorded
Smooth marron (***Cherax cainii***)	Introduced	DD	–	–	–	DD	–	–	–
Yabby (***Cherax destructor***)	Established	DD	–	–	–	DD	–	–	–
Redclaw crayfish (***Cherax quadricarinatus***)	Invasive	DD	–	–	–	DD	–	–	–
Hairy marron (***Cherax tenuimanus***)	Introduced	DD	–	–	–	DD	–	–	–
Calico crayfish (***Faxonius immunis***)	Introduced	DD	–	–	–	DD	–	–	–
Kentucky River crayfish (***Faxonius juvenilis)***	Established	DD	–	–	–	DD	–	–	–
Spiny-cheek crayfish (***Faxonius limosus***)	Invasive	DD	–	–	–	DD	–	–	–
Rusty crayfish (***Faxonius rusticus***)	Invasive	MR	Predation	Medium	USA	MO	Social activites	Low	USA
Virile crayfish (***Faxonius virilis***)	Invasive	DD	–	–	–	DD	–	–	
Signal crayfish (***Pacifastacus leniusculus)***	Invasive	MV	Transmission of disease	High	Europe	MN	Material assets	Medium	Europe
Narrow-clawed crayfish (***Pontastacus leptodactylus***)	Invasive	DD	–	–	–	DD	–	–	–
White river crayfish (***Procambarus acutus acutus)***	Introduced	DD	–	–	–	DD	–	–	–
Red swamp (***Procambarus clarkia***)	Invasive	MV	Predation	High	Europe	MO	Material assets	Medium	Europe
Marbled crayfish (***Procambarus fallax f. virginalis***)	Established	DD	–	–	–	DD	–	–	–

Invasion status was based on the unified framework (Blackburn et al. 2011) and was grouped in three level descriptors: 1) introduced = species that are introduced to a country but are not naturalized in the wild, 2) established = species that have established in the wild but are not yet invasive, and 3) invasive = species with self-sustaining populations that have spread from initial sites of introduction. Impacts for EICAT are described as follows: 1) MC = discernible impacts, but not deleterious to individuals; 2) MN = fitness of individuals is reduced; 3) MO = declines in population sizes of at least one species; 4) MR = local extinctions of at least one species; 5) MV = irreversible changes to community composition or extinctions; and 6) DD = Data Deficient. Impacts for SEICAT are described as follows: 1) MC = discernible impacts, but not deleterious to individual persons; 2) MN = well-being of individual people is reduced; 3) MO = change to human activity sizes; 4) MR = local disappearance of an activity; 5) MV = irreversible disappearance of an activity; and 6) DD = Data Deficient. Impact classifications and mechanisms/constituents of human well-being refer to the maximum impact reported. Detailed information on the literature used to assign scores is available in Appendices 2.1 and 2.2).

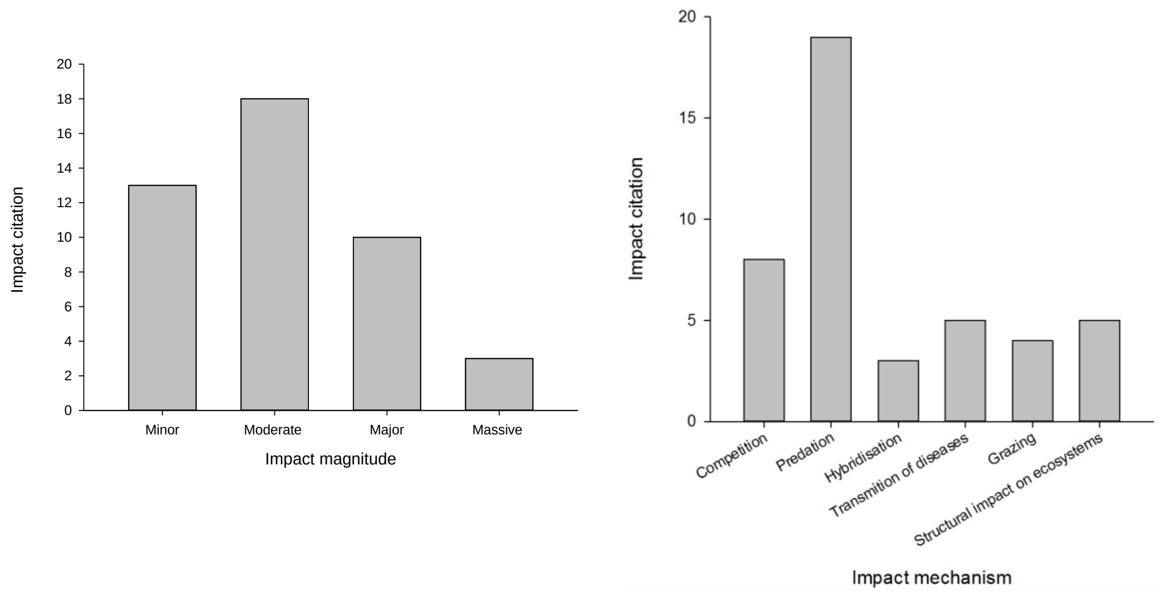

Figure 2.1: The (a) magnitude and (b) impact mechanisms associated with environmental impacts caused by freshwater crayfish in their global alien range as assessed using the Environmental Impact Classification for Alien Taxa (EICAT) scheme.

2.4.2 SEICAT

Similar to the EICAT, only three species *F. rusticus*, *P. leniusculus, and P. clarkii* had recorded impacts in their alien range. The no impact records were found for the other 11 species and they were all classified as Data Deficient (DD). Eight out of the 13 studies that documented socio-economic impacts were assigned an impact magnitude score of moderate, and the remainder were classified as minor impacts (Figure 2.2a). These impacts were mainly associated with impacts on material and immaterial assets (38%), social, spiritual and cultural activities (38%), and human health (23%) (Figure 2.2b). Most (54%) of the assessed impacts had a medium confidence score, while 46% had a high confidence scores and only one had a low confidence score. Most of the impacts (9 out 13) were recorded in Europe, and only a few from Africa and North America (Table S2.1).

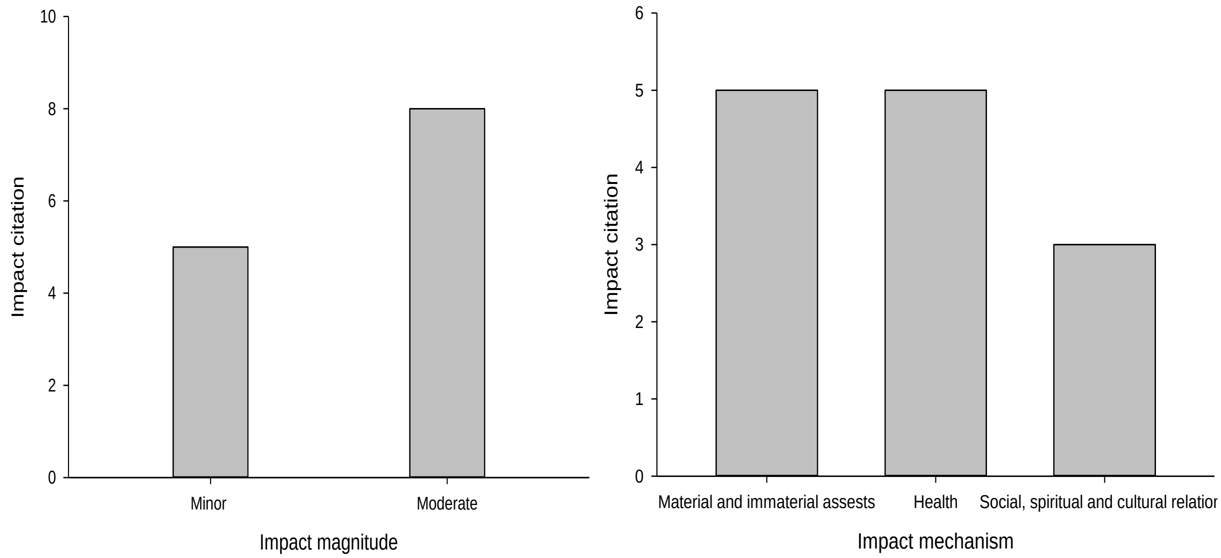

Figure 2.2: The (a) magnitude and (b) impact mechanisms associated with non-evironmental impacts caused by alien freshwater crayfish on human well-being in their global introduction range as assessed using the Socio-Economic Impact Classification for Alien Taxa (SEICAT) scheme.

2.5 DISCUSSION

This study assessed and classified the environmental and non-environmental impacts caused by alien freshwater crayfish in their global alien range using formal impact assessment frameworks such as EICAT and SEICAT. This is the first time where such formal impact assessment tools have been used to assess impacts caused by alien freshwater crayfish. The study predicted that majority of the alien cryfish species will be Data Difficent (DD) and the results from the impact assessments classified 11 out of the 14 alien crayfish species as Data Deficient (DD). Most of the crayfish that are known to have been introduced outside their native ranges are yet to become invasive and their impacts are largely not documented.

Environmental impacts

The environmental impact assessments indicated that for the few crayfish species that have documented evidence of impacts, the impacts occurred through various mechanisms such predation, competition, grazing, hybridisation, transmission of diseases and structural changes to ecosystems. The magnitude of the impacts varied from minor to massive. Crayfish are omnivores and it is not surprising that predation is one of the mechanisms leading to the decline of many native species in areas of introduction (Ficetola et al. 2011; Lodge et al. 2012; Girdner et al. 2018). Freshwater species such as amphibians and molluscs are greatly affected by alien freshwater crayfish resulting in moderate to major impacts (Wilson et al. 2004; Mathers et al. 2016). For example, the presence of red swamp crayfish (*Procambarus clarkii*) in wetlands of northern Italy contributed to a decline in the abundance of larvae of native amphibians (Ficetola et al. 2011). Higher densities of rusty crayfish (*Faxonius rusticus*) altered and reduced population sizes of snail communities in Wisconsin Lake, USA (Wilson et al. 2004). The Mazima newt (*Taricha granulosa*) has almost disappeared in areas where signal crayfish (*Pacifastacus leniusculus*) has been introduced in Crater Lake, USA (Girdner et al. 2018). Fish species are also frequently preyed upon by invasive crayfish in various areas of introduction. For example, introduced crayfish are known to predate on trout in the Great Lakes, USA (Jonas et al. 2005), and on salmonid fish in Yorkshire, England (Peay et al. 2009).

Competition was another significant mechanism through which introduced crayfish triggered impacts in introduced areas. For example, it has been reported that *F. rusticus* is displacing its congeners, the virile crayfish (*F. virilis*) and the northern clearwater crayfish (*F. pronpinquus*) in freshwater systems where they occur in sympatry through competition for resources such as food and shelter in the USA (Hill et al. 1995; Kitchell and Roth 2005). *Faxonius rusticus* possesses larger chelae, giving it a competitive advantage when interacting with conspecifics and this often leads to increased predation rates and or reproductive interference for the less aggressive crayfish through competitive exclusion from suitable habitats (Kitchell and Roth 2005). Similarly, *P. leniusculus* was assessed as causing major impacts as it readily out-competes the native noble crayfish (*Astacus astacus*) in Finland and the white-clawed crayfish (*Austropotamobius pallipes*) in Yorkshire, UK (Westman et al. 2002; Dunn et al. 2009). *Procambarus clarkii* is known to be very aggressive and experimental studies have shown that when it occurs in sympatry with other conspecifics, it usually initiates interactions, however whether this aggressive behaviour leads to competitive exclusion still needs to be validated in the wild (Gherardi and Daniels 2004; Barbaresi and Gherardi 2008; Meira et al. 2019).

Grazing alters community composition and structure (Roth et al. 2006), such as changing ecosystems from macrophyte-dominated areas with clear water, to turbid phytoplankton-dominated areas (Matsizaki et al. 2009). For example, grazing and non-consumptive stalk-cutting by *P. clarkii* have caused major impacts in Lake Chozas in north-western Spain leading to a reduction in macrophyte communities and a decline in populations of invertebrates, amphibians, and waterfowl (Rodriguez et al. 2003). Similar excessive grazing by *F. rusticus* in Lake Michigan, USA caused major impacts through the reduction of macrophyte abundance that led to an 80% decline in native species richness (Wilson et al. 2004).

Crayfish are also known to harbour parasites and are vectors of many diseases such as crayfish plague (Holdich et al. 2009; Longshaw 2011). North American crayfish are all vectors of crayfish plague, a disease caused by the parasitic oomycete, *Aphanomyces astaci* (Longshaw 2011; Lodge et al. 2012). Both *P. clarkii* and *P. leniusculus* were found to cause massive impacts because they have been implicated as vectors of crayfish plague that reduced populations of native European crayfish species such as *A. astacus*, *A. pallipes* and the stone crayfish (*Austropotamobius torrentium*) in Germany (Churcholl and Schimpf 2016; Souty-Grosset et al. 2016) and England (Almeida et al. 2014). In South Africa there is evidence of co-introductions of parasites with alien crayfish, however, no studies have been undertaken to evaluate the impacts of these parasites on native fauna (Avenant-Oldenwage 1993; du Preez and Smit 2013; Nelwamondo 2016; Tavakol et al. 2016).

Chemical, physical or structural impact on ecosystems was associated with *P. clarkii* and *P. leniusculus* because of their burrowing activities that can cause moderate structural damage to riverbanks and increase bank erosion (Guan 1994; Holdich et al. 2009; Haubrock et al. 2019). *Pacifastacus leniusculus* is considered to be a non-burrowing species, although in its invaded range, it constructs burrows under rocks and riverbanks (Dana et al. 2010). In Europe, it has been observed that these burrows can reach high densities, and can have a moderate impact on riverbank geomorphology, causing them to collapse (Holdich et al. 2009). For example, on the River Lark in the UK, burrowing by *P. leniusculus* has been reported to cause erosion at the rate of 1 m per annum (Guan 1994). Burrowing activities by *P. clarkii* can cause moderate impacts through a decrease in water quality by bioturbation leading to increased turbidity and influx release of nutrients from sediments, often leading to algal blooms (Angeler et al. 2001; Yamamoto 2010). The impaired water quality also affects the quality of the habitats for other aquatic fauna (Angeler et al. 2001; Rodriguez et al. 2003). For example, increased turbidity can impede the foraging and respiratory processes of fish (Rodriguez et al. 2003). Burrowing activities by *P. clarkii* have also been implicated in causing structural damage to riverbanks and increasing bank erosion, and causing damage to water retention infrastructure such as dam walls and dykes (Souty-Grosset et al. 2016).

It is noteworthy that occasionally more than one mechanism may contribute to environmental impacts (Westman et al. 2002). For example, alien crayfish may reduce population sizes of native amphibians through direct predation on larvae and eggs or reproductive interference by removing suitable spawning sites such as macrophytes through grazing or excluding them from shelter leading to differential predation (Ficetola et al. 2011).

Socio-economic impacts

Socio-economic impacts are not well-documented because of the general lack of evidence. For this study, the impacts recorded for the magnitude of impacts varied from minor to moderate because it was difficult to assess the extent of the impacts (Souty-Grosset et al. 2006; Lodge et al. 2012). The impacts associated with farming and fishery industries are easier to evaluate and to get information on because the monetary value and losses are often calculated (Keller et al. 2008; Marbuah et al. 2014). Issues such as human health and social activities however, are more challenging to assess because events are often simply not reported, there is a general lack of interest or there is a lack of health services (Lodge et al. 2012; Souty-Grosset et al 2016). This study found documented evidence for non-environmental impacts for only three species (*P. leniusculus, P. clarkii* and *F. rusticus*) out of the 14 species assessed.

Pacifastacus leniusculus is known to be an ideal species for aquaculture and has been introduced in Europe to alleviate the exploitative pressure on native crayfish (Holdich 1993). This introduction has however, contributed to further decline in native crayfish populations through competition and transmission of diseases (Westman et al. 2002; Holdich et al. 2009). For example, the indigenous *A. astacus* has been replaced by *P. leniusculus* due to its rapid spread in areas of introduction (Dana et al. 2010). *Astacus astacus* is considered to be more valuable than *P. leniusculus* and generates higher revenue; hence a decline in *A. astacus* has affected livelihoods through reduced income (Johnsen and Taugbol 2010; Marbuah et al. 2014). However, because the magnitude of the economic loss caused by *A. astacus* displacement by *P.*

leniusculus has not been formally quantified, an impact score of minor magnitude was assigned (Johnsen and Taugbol 2010; Marbuah et al. 2014).

Infected *P. clarkii* also caused a tularemia out-break (caused by *Francisella tularensis*) in central Spain (Anda et al. 2001). The disease causes hand injuries that are associated with coming in contact with contaminated water or sediment at fishing sites or when cleaning caught crayfish (Anda et al. 2001). *Procambarus clarkii* often inhabits agricultural fields and their burrowing activities can cause damage to infrastructure such as irrigation canals and dam walls (Lodge et al. 2012; Acre and Diéguez-Uribeondo 2015). Grazing causes crop damage and reduces yield (Anastácio et al. 2005). In Europe for example, *P. clarkii* affects rice production through field water loss, damage to rice fields and ditches, direct consumption of rice seed and plants, and clogging of pipes leading to moderate impacts (Souty-Grosset et al. 2016). *Procambarus clarkii* also affects the fishing industry by damaging gill nets and spoiling the fish caught in nets by feeding on them before the nets are retrieved (Gherardi et al. 2011a). It has been reported in Italy that damage caused by *P. clarkii* vary between €139,179 and €1,167,680 per annum (Gherardi et al. 2011b). This includes damage to angling, fisheries, aquaculture, and irrigation ditches (Gherardi et al. 2011b). An impact of moderate magnitude was assigned due to the ambiguity in the information available.

Faxonius rusticus invasions can disrupt recreational activities in the invaded range (Keller et al. 2008). This can ultimately affect the well-being of humans because they can no longer participate in these activities (Keller et al. 2008). In Vilas County, USA, *F. rusticus* has reduced sport fish populations through egg predation and/or competition with juveniles (Keller et al. 2008). Consequently, this leads to an estimated annual loss of $1.5 million (US) (Keller et al. 2008). An impact score of moderate magnitude was assigned as it was assumed that the revenue lost was due to partial abandonment of activity.

2.6 CONCLUSION

Although only three alien freshwater crayfish had recorded impacts, the literature provides ample evidence of some negative impacts caused by crayfish in their invaded range. This was further reflected by the impact assessments and agrees with expert opinion that there is reason for concern (Gherardi 2011; Lodge et al. 2012). The magnitude of impact scores assigned to the environmental impacts was mostly major as opposed to massive because it has been observed that with the removal of alien crayfish, many of these impacts are reversible (Hansen et al. 2013).

Most of the recorded impacts were from species that are known to be invasive than from those in other stages of the introduction-naturalisation-invasion continuum (Lodge et al. 2012). While impacts have not been documented for those who are not invasive, it is unlikely that this is a true reflection of their impacts (Holdich et al. 2009; Lodge et al. 2012). Therefore, additional research is required to fill this information gap because the rate of introduction is increasing (Holdich et al. 2009; Lodge et al. 2012; Nunes et al 2017a). Impacts from invasive species are likely to be more noticeable because they are likely to have been introduced for longer periods and have had the opportunity to spread in large numbers from sites of introduction (Pysek et al. 2008; Holdich et al. 2009; Evans et al. 2020). Conversely, the socio-economic impacts in this study were associated with the three species with known environmental impacts. This could be due to the assumption that invasive species with reported environmental impacts are also likely to cause socio-economic impacts, neglecting the species that are currently Data Deficient (DD) (Pysek et al. 2008; Evans et al. 2020). It is further noted that most of the environmental impacts were recorded at a global scale with very few observed in South Africa and many other developing countries (de Moor 2002; Lodge et al. 2012; Evans et al. 2020). The recorded impacts were unevenly distributed and skewed towards Europe and the USA. This agrees with the notation that there is a research bias towards specific geographic regions and taxonomic groups in invasion ecology (Pyšek et al. 2008). Region bias is one of the challenges in biological invasions, and it has been noted that developing countries are not well-represented (Pysek et al. 2008; Logde et al. 2012). This could be due to the insufficient resources available to undertake impact studies because research is highly dependent on funding which may not be allocated towards invasion research in these countries, and consequently impacts caused by alien species may go undetected (Lodge et al 2012; Pysek et al. 2008; Evans et al. 2020; Measy et al. 2020).

In South Africa, crayfish studies are limited to co-introductions (Nunes et al. 2017a,b), and transmission of parasites (see Weyl et al. 2020) and mechanisms that offer native crabs some resistance to these invaders (South et al. 2020). However, impacts from these invasions still need to be formally evaluated (Lodge et al. 2012; Nunes et al. 2017a). This has been observed for many other alien taxa in South Africa (van Wilgen and Wilson 2018). The same applies to the non-environmental impacts where the need is even greater (Marbuah et al. 2014; Evans et al. 2020). Impact studies from alien crayfish should therefore be prioritized, as many introduced crayfish have no documented evidence of impacts but share similar traits with a few of the invasive crayfish that have recorded impacts, and therefore the potential of crayfish introductions to cause negative impacts is high (Holdich et al. 2009, Gherardi 2010).

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CHAPTER 3

RISK ANALYSIS OF ALIEN FRESHWATER CRAYFISH IN SOUTH AFRICA

3.1 ABSTRACT

Freshwater crayfish are a diverse group of decapods and introductions outside their native range are rapidly increasing. It is therefore important to identify the risks involved with their introduction to anticipate the potential impacts and to prioritize management actions accordingly. In this study, we assessed the risks associated with the introduction of alien freshwater crayfish in South Africa using the South African-developed Risk Analysis for Alien Taxa framework (RAAT) to propose appropriate recommendations to guide the regulations responsible for managing alien species. The framework consists of three broad categories that include risk assessment, risk management and risk communication. Fourteen alien freshwater crayfish species were identified to have the invasion potential based on their global invasion history. Of these 80% were considered to be high risk for invasion if introduced into South Africa. Four out of the 14 crayfish species, the smooth marron (*Cherax cainii*), the redclaw (*C. quadricarinatus*), the hairy marron (*C. tenuimanis*), and red swamp (*Procambarus clarkii*) are already present in South Africa and ease of management for each was scored medium based on their introduction status. Five of the risk analyses recommend changes in the current listing category of alien crayfish species under the South African Alien and Invasive Species (A&IS) regulation, because there are no records to indicate that they are present in the country. Once established, managing freshwater crayfish becomes challenging and costly because of their hardy nature. Management plans should, therefore, aim to identify and prevent the introduction of potentially harmful invasive crayfish species and maximise the potential benefits from less harmful species. This is especially important as prevention is often much easier and considerably less costly. The information generated in this risk analysis study can be used for making well-informed management decisions to regulate and prioritise high-risk alien freshwater crayfish species.

Keywords: freshwater invasions, Risk Analysis, Alien Taxa framework, Alien and Invasive Species (A&IS) Regulations, management, South Africa.

3.2 INTRODUCTION

Biological invasions are a significant problem globally and currently many countries have a growing number of invasive species (Pysek et al. 2020). The primary reason for the alien species introductions has been to meet societal needs such as the provision for food, raw materials such as timber, ornamental horticulture species, and the pet trade industry (Hulme et al. 2008). Some of these introduced species have become invasive and have been implicated in causing adverse effects on biodiversity, ecosystem functioning, human livelihood and human health (Simberloff et al. 2013). Due to the negative impacts associated with some of these introductions of invasive species, there is a critical need to control and manage the movement and utilization of alien species in South Africa (Faulkner et al. 2016; Kumschick et al. 2020a). This is especially pertinent as the number of established alien species has strongly increased worldwide during the past two centuries (Seebens et al. 2017) mainly as a result of increased connectivity through increased travel and trade (Seebens et al. 2018).

In South Africa, biological invasions are managed through the Alien and Invasive Species Regulations (A&IS Regulations 2020) of the National Environmental Management: Biodiversity Act (NEM:BA) (Act 10 of 2004). The rationale behind the regulations is to restrict the importation of high-risk alien species, reduce their populations, the extent and impact of well-established invaders to regulate the movement and the utilization of alien species, and interventions aimed to eradicate species that occur in low numbers over limited areas, in order to manage the invasions (van Wilgen and Wilson et al. 2018; Kumshick et al.2020a).

The implementation of these regulations and control measures, however, have been contentious because of disagreements between stakeholders and conservation authorities on the benefits and negative impacts caused by alien species and their proposed control measures (Woodford et al. 2017; Zengeya et al. 2017). This in part reflects challenges associated with the consultative process that was used when the regulations were drafted (Kumschick et al. 2020a). Although the A&IS Regulations of 2014 were developed in consultation with experts, the recommendations made and the decisions taken however, were not clearly documented (see Kumschick et al. 2020a). Consequently, there have been some contestations on the merits of the evidence used to develop some of the interventions (van Wilgen and Wilson 2018).

A process was therefore initiated retrospectively to develop a framework to provide evidence for listing species with reference to the A&IS Regulations of 2014 in a consistent and transparent manner in South Africa (Kumschick et al. 2020b). This South African-developed framework, termed Risk Analysis for Alien Taxa (RAAT) outlines a normative process to assess an alien taxon's likelihood of invasion, realised and potential impacts, and options for management in a given area (Kumschick et al. 2018; 2020b). It specifically attempts to align with major international developments in dealing with the classification of pathways of introduction (Hulme et al. 2008), the introduction-naturalisation-invasion continuum (Blackburn et al. 2011), and formal assessments for environmental (Blackburn et al. 2014; Hawkins et al. 2015) and non-environmental impacts of alien taxa (Bacher et al. 2017). In addition, the RAAT framework can also be applied consistently across taxa, regions and realms, explicitly sets out uncertainties, and provides decision-makers with information both on the risks posed and on what can be done to mitigate or prevent impacts (Kumschick et al. 2020b). The RAAT framework has already been tested and applied to support decisions regarding the listing of several alien taxa under the South Africa's regulations on biological invasions (Kumschick et al. 2020b). Notably, recommendations from some of the risk analyses do not agree with the current listing under the A&IS Regulations (Kumschick et al. 2020b). This may be due to a lack of sufficient evidence available to support the need for some species to be regulated, or there are no occurrence data available for species currently listed or eradication is not feasible as validated by field surveys (Kumschick et al. 2020a).

The present study applied the RAAT framework to undertake a risk analysis of alien freshwater crayfish in South Africa. Globally, freshwater crayfish have been widely distributed and are now present on all continents except Antarctica (Westman 2002; Lodge et al. 2012). Crustaceans are considered one of the most successful taxonomic groups among aquatic alien invasive species (Gherardi et al. 2011a; Chucholl 2016), and crayfish, in particular, have caused negative environmental and socio-economic impacts in their invaded range (Westman et al. 2002; Gherardi et al. 2011b; Lodge et al. 2012). The pet trade and aquaculture industries are considered to be the primary pathways of introduction for alien crayfish (Holdich 1993; Chucholl 2013; Patoka et al. 2014a). Introductions through aquaculture are often well-regulated compared to the pet trade industry, where introduction often go undetected because of the idiosyncratic human behavior of circumventing regulations in order to meet the high demand of popular ornamental species despite restrictions prohibiting such introductions (Patoka et al. 2014b; Faulkes 2015; Patoka 2018). Management actions directed at alien freshwater crayfish can therefore be complex because they are perceived to have both benefits and negative impacts (Holdich 1993; Westman et al. 2002; Lodge et al. 2012).

Four non-native species have been introduced in South Africa for aquaculture, and these included smooth marron crayfish (*Cherax cainii*), yabby crayfish (*C. destructor*), redclaw crayfish (*C. quadricarinatus*), and red swamp crayfish (*Procambarus clarkii*) (Nunes et al. 2017a). The *Cherax* species are native to Australia and *P. clarkii* is from North America. In South Africa, *C. cainii* and *C. destructor* are considered introduced but not naturalised, while *C. quadricarinatus* and *P. clarkii* are invasive (Nunes et al. 2017a; van Wilgen and Wilson 2018). *Cherax cainii* is the only freshwater crayfish that is legally permitted for aquaculture in South Africa, while the utilisation of the other crayfish species is currently prohibited because of potential negative impacts. (de Moor 2002; Nunes et al. 2017a).

Alien crayfish therefore, represent good model species to assess using a standardized protocol such as the RAAT framework to quantify the potential risk posed by alien crayfish introductions in South Africa in a transparent and objective manner and prevent contentions around their management (Kumschick et al. 2020b). In addition, the RAAT framework creates an opportunity for scientists and policymakers to collaborate to develop knowledge transfer processes, comprehensive informed management decisions, and policy frameworks (Kumschick et al. 2020b). This allows for the prioritization of potentially harmful invasive species to undergo comprehensive risk analysis before introductions are permitted and has the potential to support bio-security schemes to reduce the rate of introductions of harmful freshwater crayfish species and permit the importation of species that pose minimum risk (Lodge et al. 2016; Patoka et al. 2018).

The general objective of the present study, therefore, was to undertake a formal risk analysis of alien freshwater crayfish in South Africa. Specifically, the study intends to:

1) Identify alien freshwater crayfish that have an invasion history and have the potential to become invasive if introduced into South Africa; and

2) Provide formal science-based risk analyses to support policy decision-makers on the risks posed by alien crayfish introduction and recommended potential mitigation measures to prevent the introduction of harmful species and to minimize impacts.

3.3 METHODS

Risk Analysis for Alien Taxa (RAAT) Framework

A risk analysis was undertaken using the South African Risk Analysis for Alien Taxa (RAAT) framework as outlined by Kumschick et al. (2018; 2020b). The RAAT framework consists of the following four components: 1) risk identification; 2) risk assessment; 3) risk management; and 4) risk communication (Kumschick et al. 2018).

Risk identification: Biological invasions present various risks that can be broadly grouped in terms of species, pathways, and areas (Kumschick et al. 2020a). In this study, the risks associated with biological invasions from alien crayfish were identified in terms of species (Kumschick et al. 2020a). A database with all freshwater crayfish species was compiled from the published literature, the International Union for Conservation of Nature (IUCN) Red List (www.iucnredlist.org/), and the Global Biodiversity Information Facility (GBIF) (www.gbif.org/en/) The invasion status of the freshwater crayfish species was quantified using data from the published literature, the Centre for Agriculture and Bioscience International (CABI) Invasive species compendium (www.cabi.org/isc), the Global Invasive Species Database (GISD) (www.iucngisd.org/gisd/), and the Non-Indigenous Aquatic Species (NAS) (nas.er.usgs.gov). Invasion status was defined according to the different stages of the unified framework (see Blackburn et al. 2011), and species were grouped in four level descriptors: 1) not introduced = species that have no record of introduction to areas outside their native range; 2) introduced = species that are introduced to a country but are not naturalized in the wild; 3) established = species that have established in the wild but are not yet invasive; and 4) invasive = species with self -sustaining populations that have spread from initial sites of introduction. Crayfish species whose invasion status was categorized as introduced, established and invasive in their global alien introduction range were then assessed using the risk assessment, risk management and risk communication protocols outlined below.

Risk assessment: This step evaluated the likelihood of a particular crayfish species being introduced, establishing and spreading in South Africa, and the consequences (negative impacts) thereof (Kumschick et al. 2020b). Information on environmental and socio-economic impacts was derived from the impact assessments done in Chapter 2, and in cases where a species had no documented impacts, it was classified as Data Deficient (DD), and a closely-related species was instead chosen to infer the potential impacts (Kumschick et al. 2020b)**.** The risk score was calculated using the outcomes of the assessment of: 1) likelihood of introduction; 2) establishment and spread and 3) potential to cause negative impacts (consequences) (Kuschick et al. 2020b).

Probability scores for the likelihood of entry into the country, establishment, and spread were assigned to each respective parameter where the lowest probability was when chances of an event occurring was extremely unlikely ($P = 0.000001$) and the highest probability was when the chances were probable ($P = 1$) (Kumschick et al. 2018; 2020b). The highest score of each sub-section was then multiplied to get an overall probability for the likelihood a particular crayfish species being introduced, establishing, and spreading in the country (Kumschick et al 2020b).

The potential to cause negative impacts (i.e., consequences) was estimated using the impact classification schemes for environmental (EICAT) and non-environmental (SEICAT) impacts which classify and assess impacts in terms of the mechanisms' impact (e.g., competition, predation, and hybridization), and magnitude of the observed impacts (Kumschick et al. 2020). Magnitude of impacts was classified into five categories that range from Minimal Concern (MC) to Massive (MV) (Kumschick et al. 2020b). The highest scores for the consequence and likelihood sections were then used to determine the risk (Kumschick et al. 2018; 2020b). The risk score was categorized as either low, medium, or high (Kumschick et al. 2018; 2020b).

Management: This step included the evaluation of the best management options for the freshwater crayfish species that are known to be present in South Africa to mitigate spread and impacts while allowing utilization (Kumschick et al. 2020b). In South Africa, alien taxa are managed under the Alien and Invasive Species (A&IS) Regulations which comprise of lists (i.e., notices) for regulated species and the management and control option for each listed species (van Wilgen and Wilson 2018). The management options are grouped into four categories: 1) Category 1a) species that should be eradicated; 2) Category 1b) species that should be controlled as part of national programmes, and cannot be traded or allowed to spread; 3) Category 2) species that have the same restrictions as Category 1b species but a permit can be issued to allow utilization under specific conditions that aim to prevent spread and minimize impacts; and 4) Category 3) species that can be utilized without a permit but they cannot be traded or further propagated and should be controlled in the way they occur in biodiversity-sensitive areas such as protected areas or riparian zones (Kumschick et al. 2020a) . These regulation categories apply only to species that are already present in the country and permits are required for new introductions into the country and these are only allowed if a risk analysis is performed and indicates that the alien species is of low risk (Kumschick et al. 2020a). Possible management interventions are evaluated, to allocate the ease of management score of low, high, and medium (Kumschick et al. 2020b).

Risk communication and recommendations: This included the collation and summary of the complete background information of the RAAT framework process to make recommendations for management, regulations, and stakeholder engagement with relevant stakeholders (Kumschick et al. 2020b).

3.4 RESULTS

Risk identification

Fourteen alien freshwater crayfish species whose invasion status was categorized as introduced, established and invasive in their global alien introduction range were selected for risk analysis in South Africa (Supporting Information Table 2.1). These included five *Faxonius* species: calico crayfish (*F. immunis*), Kentucky River crayfish (*F. juvenilis*), spiny-cheek crayfish (*F. limosus*), rusty crayfish (*F rusticus*), and virile crayfish (*F. virilis*); two *Procambarus* species: White River crayfish (*P. acutus*); and red swamp crayfish (*P. clarkii*); and signal crayfish (*Pacifastacus leniusculus*) that are native to North America; narrow clawed crayfish (*Pontastacus leptodactylus*) which is native to Europe; and four *Cherax* species: smooth marron (*C. cainii*), hairy marron (*C. tenuimanus*), yabby crayfish *(C. destructor*), and redclaw crayfish (*C. quadricarinatus*) that are native to Australia. The marmorkrebs crayfish (*Procambarus fallax f. virginalis*) has an unknown native distribution. For detailed distribution of alien crayfish species, see Appendices S3.1 to S3.14.

Risk assessment

Likelihood of entry

Six species (*C. cainii, C. quadricarinatus, C. tenuimanus, P. leniusculus, P. clarkii and P. fallax f. virginalis*) were assigned a score of probable for likelihood of entry into South Africa (Table 3.1). Three of the six species (*C. cainii*, *C. quadricarinatus* and *P. clarkii*) have documented records of being present in the country while there are no formal occurance records of *P. fallax f. virginalis* and *P. leniusculus,* there is anecdotal evidence that they are likely present in the country through the pet trade. In addition, recent import permit records indicate that *C. tenuimanus* may be present in the country, however, this still needs to be confirmed because of the taxonomic uncertainty of whether the species imported was *C. cainii* or *C. tenuimanus* (Table 3.1). Three species (*C. destructor*, *F. rusticus* and *F. virilis)* were assigned a score of fairly probable because of their availability in the global pet trade industry. The likelihood of entry for the remainder of the assessed species was scored as unlikely for *F. immunis* and very unlikely for *F. juvenilis*, *F. limosus*, *P. leptodactylus,* and *P. acutus* because there are no known records of the species in South Africa or in neighbouring countries (see Supportting Information Appendix 3.1 to 3.14 for detailed risk analyses).

Table 3.1 A summary of the risk analysis results for 14 alien crayfish species known to be invasive or have been introduced in areas outside their native range. LIK = Likelihood; CON = Consequences; MAN = Management. The current and recommended listings are also included to indicate where change of listing has been proposed. MR = Major; MV = Massive.

Species	Native region	Invasion status in South Afica	LIK	CON	Risk	MAN	Current listing in South Africa	Recommended listing
Smooth marron (*Cherax cainii*)	Australia	Introduced	Probable	MR	High	Medium	2	2
Yabby (*Cherax destructor*)	Australia	Not present	Fairly probable	MR	High	NA	1a	Remove from list
Redclaw crayfish (*Cherax quadricarinatus*)	Australia	Invasive	Probable	MR	High	Medium	1b	1b
Hairy marron (*Cherax tenuimanus*)	Australia	Introduced	Probable	MR	High	Medium	2	2/remove from list
Calico crayfish *(Faxonius immunis)*	North America	Not present	Unlikely	MR	High	NA	Not listed	No change
Kentucky River crayfish (*Faxonius juvenilis*)	North America	Not present	Very unlikely	MR	Medium	NA	Not listed	No change
Spiny-cheek crayfish (*Faxonius limosus*)	North America	Not present	Very unlikely	MR	High	NA	1a	Remove from list
Rusty crayfish (*Faxonius rusticus*)	North America	Not present	Fairly probable	MR	High	NA	1a	Remove from list
Virile crayfish (*Faxonius virilis*)	North America	Not present	Fairly probable	MR	High	NA	Not listed	No change
Signal crayfish (*Pacifastacus leniusculus*)	North America	Not present	Probable	MV	High	NA	1a	Remove from list
Narrow-clawed crayfish (*Pontastacus leptodactylus*)	Europe	Not present	Very unlikely	MV	High	NA	1a	Remove from list
White River crayfish (*Procambarus acutus*)	North America	Not present	Very unlikely	MR	Medium	NA	Not listed	No change
Red swamp crayfish (*Procambarus clarkii*)	North America	Invasive	Probable	MR	High	Medium	Not listed	1a
Marmokrebs (*Procambarus fallax* f. *virginalis*)	Unknown	Not present	Probable	MR	High	NA	Not listed	No change

Consequence

Twelve of the 14 species (*C. cainii*, *C. destructor*, *C. quadricarinatus*, *C. tenuimanus*, *F. immunis*, *F. limosus*, *F. rusticus*, *F. virilis*, *P. leniusculus*, *P. leptodactylus*, *P. clarkii*, *and P. fallax f. virginalis*) scored high in the risk category. These species have the potential to cause major to massive environmental impacts through various mechanisms, such as competition, predation and the transmission of diseases. The species also pose moderate risk to human well-being as they are known to affect recreational activities, human livelihood, and food security through their negative impacts on fisheries. The remaining two species (*F. juvenilis* and *P. acutus*) obtained a medium risk score because of their overall risk and ease of management scores.

Management and listing recommendations

Three out of four species (*C. cainii, C. quadricarintaus,* and *C. tenuimanus*) that are known to occur in South Africa are currently listed under the NEM:BA A&IS Regulations, which implies there is an obligation to manage them. Five of the assessed species (*F. immunus*, *F. juvenilis F. virilis, P. acutus,* and *P. fallax f, virginalis*) are not present in the country and therefore not listed currently on the A&IS regulations. However, *P. clarkii* is also not listed in the regulations but there is evidence that there are localized populations in the country and should therefore be listed as a Category 1a species. In contrast, five species (*C. destructor*, *F. limosus*, *F. rusticus, P. leniuculus*, *and P. leptodactylus*) are listed under Category 1a but there is no evidence that they are present in the country and they should be removed from the list of regulated species. It is uncertain if there are two marron species (*Cherax cainii* and *C. tenuimanus*) in South Africa and the list should be up-dated when the identity of the species present in the country is confirmed. The ease of management for the four crayfish species (*C. cainii, C. tenuimanus*, *C. quadriacrinatus* and *P. clarkii*) that are known to be present in South Africa was scored as medium. The two marron species (*C. cainii, C. tenuimanus*) are likely confined to aquaculture facilities because there are no known naturalised populations in the country and *P. clarkii* is localised to two known locations in Mpumalanga and Free State Provinces therefore, eradication is still highly feasible. *Cherax quadricarinatus* is already widespread in the Inkomati River and adjacent river systems and is still spreading. Eradication is no longer feasible and control methods should rather focus on minimising spread.

3.5 DISCUSSION

This study undertook a formal risk analysis of alien freshwater crayfish in South Africa. It specifically intended to identify alien freshwater crayfish that have an invasion history and have the potential to become invasive if introduced into South Africa and to provide policy decision-makers with information both on the risks posed and on what can be done to mitigate or prevent impacts. It identified 14 crayfish species that have global invasion history of which 12 species were classified as a high risk because of their potential to cause major to massive impacts in recipient areas of introduction.

Risk assessment

Likelihood

The likelihood of entry into South Africa for most (64%) of the assessed species varied from fairly probable to probable because there is some evidence that the species are present in the country in the pet trade, aquaculture facilities and or neighbouring countries (Nunes et al. 2017a; Madzivanzira et al. 2020). However, the level of confidence in some of the evidence is low and requires verification through follow up studies. For example, there is reliable evidence that the redclaw crayfish (*Cherax quadricarinatus*) and the red swamp crayfish (*Procambarus clarkii*) are present, but it is unclear if smooth marron crayfish (*C. cainii*) and or the hairy marron (*C. tenuimanus*) are present because introduction records of marron crayfish into South Africa and elsewhere in the world prior to 2002 incorrectly referred *Cherax cainii* as *C. tenuimanus* (Austin and Ryan 2002). For this reason, follow up surveys are required to confirm the genetic identity of the species utilised by the aquaculture facilities, and the current distribution in the country (Austin and Ryan 2002; Zengeya and Wilson 2020). Many of the crayfish introductions elsewhere in the world were because of accidental or intentional release by owners as unwanted pets (Belle et al. 2011; Patoka et al 2014b; Faulkes 2015). Several crayfish species assessed in this study scored probable and fairly probable for likelihood of introduction because they are popular species in the pet trade industry in other countries (Chucholl 2013; Patoka 2014a; Faulkes 2015) and there is anecdotal evidence that they may be present in the pet trade in South Africa (Nunes et al. 2017a). For example, *Procambarus virginalis f. fallax* was first discovered in the pet trade in Germany and is now widespread in Madagascar (Jones et al. 2009; Faulkes

2010). This species poses a significant threat in areas of introduction as it reproduces through pathogenesis and there is no information available on its place of origin and potential impacts in invaded areas (Jones et al. 2009). It is closely-related to *P. clarkii* and can cause similar negative environmental impacts in its invaded range (Feira and Faulkes 2011; Lodge et al. 2012). Bio-security policies can be strengthened with the use of risk analysis, for example, propagule pressure is known to be an important determinant for the establishment of alien species (Seebens et al. 2017; Patoka et al. 2018). Australia and New Zealand have managed to reduce the number of invasions by reducing propagule pressure through risk analysis of imports and implementing apporapriate interventions to intercept potential harmful species at port of entry (Simberloff 2005; Lodge et al. 2016). The pet trade industry is a cause for concern, particularly in South Africa because the movement of crayfish has not been evaluated (de Moor 2002; Nunes et al. 2017a; Madzivanzira et al. 2020).

Consequence

The risk analyses from this study further highlighted that crayfish have the potential to cause major to massive environmental and socio-economic impacts. This agrees with previous reviews (e.g., de Moor 2002; Souty-Grosset et al. 2006; Holdich et al. 2009; Lodge et al. 2012; Acre and Diéguez-Uribeondo 2015). However, for most of the crayfish species, their impacts had to be inferred because of lack of documented evidence to assess the impacts in South Africa and globally (de Moor 2002; Lodge et al. 2012). For a few species such as the rusty crayfish (*Faxonius rusticus*), *P. clakii* and the signal crayfish (*Pacifastacus leniusculus*) there was evidence that alien crayfish species can cause declines in populations of native species through mechanisms such as competition, predation, and the transmission of diseases (Hill et al 1995; Wilson et al. 2004; Ficetola et al. 2011; Longshaw 2011; Lodge et al. 2012). For example, *F. rusticus* has competitively displaced native freshwater crayfish and fish (Klocker and Strayer 2004; Jonas et al. 2005; Keller et al. 2008). *Faxonius rusticus* is an omnivore and direct predation and intensive grazing have contributed to a decline in populations of freshwater invertebrates and macrophyte communities (Roth et al. 2006; Bobledyk and Lamberti 2008). It has also been implicated in disrupting recreational activities, leading to some economic loss.

Pacifastacus leniusculus introductions have contributed to the decline of populations of native crayfish species such as the endangered noble crayfish (*Astacus astacus*) through the transmission of crayfish plague in Germany (Chucholl and Schrimpf 2016). *Pacifastacus leniusculus* has also been implicated in out-competing and displacing other crayfish species, habitat modification through burrowing and predation on invertebrates and fish eggs (Guan 1994; Pockl and Peckny 2002; Crawford et al. 2006). *Procambarus clarkii* has been implicated in causing major impacts on native communities through competition and predation leading to decreased abundance and local extirpation of native species (Cruz et al. 2006; Barbaresi and Gherardi 2008; Jackson et al. 2016). It is also known to cause habitat loss and habitat modification through intensive grazing and stalk cutting of aquatic macrophytes that provide food, refuge and spawning sites (i.e., reproductive interference) for fish and other aquatic fauna (Rosenthal et al. 2005; Cruz et al. 2006). *Procambarus clarkii* is also known to cause socio-economic impacts such as damaging bait and nets for recreational anglers (Gherardi et al. 2011b; Chucholl 2016).

Crayfish in general often occur in high densities, reach maturity at a young age and are highly fecund (Lodge et al. 2000, Gherardi et al. 2011a). All these life history traits make alien crayfish ideal species for invading recipient areas of introduction (Gherardi 2007; Lodge et al. 2012). In addition, they are polytrophic and therefore, they can cause strong alterations in multiple trophic levels of invaded ecosystems (Nyström et al. 2001, Gherardi 2007). Therefore, although the majority of the assessed species had no recorded impacts, they are likely to cause similar impacts as those observed from crayfish species that have documented impacts and share similar functional traits (Holdich et al. 2009; Lodge et al. 2012). For example, although *C. tenuimanus* has no documented evidence of impacts, it shares similar traits with *P. clarkii*; both species are functional omnivores that have the potential to cause multiple impacts at different levels of the food web. It is therefore likely that *C. tenuimanus* can cause similar impacts to that of *P. clarkii* in areas of introduction.

Risk management

Managing crayfish is challenging and although there are several methods that have been used to control alien populations of crayfish, the identification of an appropriate method is often context-specific. For example, the use of biocides is often effective for localized populations in dams and ponds (Hein et al. 2006; Ballantyne et al. 2019; Peay et al. 2019) but it is not effective for widespread species because of the large doses of treatment required and higher potential of adverse effects on non-targeted species (Freeman et al. 2010; Gherardi et al. 2011a; Recsetar and Bonar 2015). For example, localized populations of *P. leniusculus* in Scotland (Ballentyne et al. 2019) and *C. cainii* in New Zealand (Gould 2005) were successfully eradicated through the use of biocides (Manfrin et al. 2019). Other methods have also been used to eradicate alien crayfish populations, these include the use of manual trapping and predatory fish to control *F. rusticus* in Wisconsin, USA (Hein et al. 2006), and the use of biological control agents such as crayfish plague to control small populations of *C. destructor* (Holdich et al. 2009; Peay 2010). Another study investigated the effect of trapping on population abundance of invasive *P. clarkii* and found that continuous trapping increased the growth rate creating a positive feedback loop (Loureiro et al. 2018). It was further suggested that, one intensive trapping event may yield better results for controlling populations of invasive crayfish compared to continuous trapping events (Loureiro et al. 2018).

All three species (*C. cainii*, *C. quadricarinatus* and *P. clarkii*) that are known to be present in South Africa were assigned a medium score for ease of management. *Procambarus clarkii* is known to occur at two locations in South Africa and is restricted to dams, therefore eradication can still be evaluated for this species using a combination of methods (Nunes et al 2017b). *Cherax quadricarinatus* is more widespread and eradication is no longer feasible. It would be more practical to focus management efforts to preventing further spread (Nunes et al. 2017c). The two marron species (*C. cainii* and *C. tenuimanus*) are likely still restricted to aquaculture facilities as there are no known naturalized populations in the country (CapeNature, unpublished data). However, the introduction records of marron into South Africa and elsewhere in the world prior to 2002, incorrectly referred *Cherax cainii* as *C. tenuimanus* (Austin and Ryan 2002). It is uncertain if one or both species have been introduced into the country and follow up surveys are required to confirm the genetic identity of the species utilised by the aquaculture facilities, and their current distribution in the country. There are management protocols in place for the farming of marron in the Western Cape Province that aim to minimise the risk of the species to escape from confinement and establishing in the wild (CapeNature, unpublished data). Similar protocols should be adopted by the other provinces in the country. If the species escape from confinement, rapid incursion response using biocides, as observed in other countries such as New Zealand, can be highly effective at eradicating localised populations (Gould 2005). In addition, in the event that any of the maroon species escape confinement, it is very unlikely that they will spread rapidly due to their low tolerance to a wide range of environmental conditions compared to *C. quadricarinatus* and *P. clarkii* (Byrant and Pappas 2007; Nunes et al. 2017a).

Listing recommendations

Based on the results from the risk analyses in this study, it is recommended to add *P. clarkii* on the list of regulated species as a Category 1a because it is present in the country at localized locations that can be targeted for eradication. The risk analyses furthermore recommended removing several from the list (*C. destructor*, *F. limosus*, *F. rusticus*, *P. lenisuculus*, and *P. leptodactylus*) because they are not present in South Africa but should be flagged to prevent future introductions. The risk analysis framework offers a simple, objective, and transparent process of identifying the risk associated with the introduction of crayfish species (Kumschick et al. 2020b). This evidence-based protocol can be extremely useful to screen potentially harmful species, inform policy-makers, and underpin management decisions (Andersen et al. 2004; Dana et al. 2014; Vanderhoeven et al. 2017). The results from these risk analyses can be used to allow the importation of low-risk crayfish for restricted use, and as a precautionary measure, prohibit the introduction of all the high-risk crayfish species which is recommended. However, given that the global rate of introductions is still increasing (see Seebens et al. 2017; Patoka et al. 2018), the protocols that have been developed and implemented may not be effective or the public is not complying. In South Africa, there is a critical need to assess the movement of alien crayfish through the pet trade as there is some anecdotal evidence that some of the species that were assessed have a high invasion risk in South Africa are already present in the country.

3.6 CONCLUSION

The RAAT framework has been tested and revised numerous times to avoid inconsistencies and uncertainty among the relevant assessors (Kumschick et al. 2020). It has been applied to assess various alien taxa in South Africa and in some cases recommended a change in the listing for some species (Kumschick et al. 2020b). Similarly, this study identified the majority of alien freshwater crayfish species as a high risk for invasion and recommended addition of one species and a removal of five species (*C. destructor*, *F. limosus*, *F. rusticus*, *P. lenisuculus*, and *P. leptodactylus*) based on evidence of their occurance in the country. Species that are not present in the country are regulated through an importation permit that can only be issued once a risk analysis has been undertaken and species are considered as low to medium risk (Kumschick et al. 2020). This study provides relevant information for the prioritization of the high-risk alien crayfish and support management plans where efforts should be directed. However, given that there are only a few alien freshwater crayfish species present in South Africa, the primary aim should be to prevent the introduction of new high risk species. Therefore, this study recommends that permit application for the importation of these species should not be permitted. The risk analyses have identified the relevant pathways of introduction that should be prioritized and assessed to make well-informed science-based decisions to regulate alien taxa accompanied by strict implementation measures.

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CHAPTER 4

GENERAL DISCUSSION

The general aim of this thesis was to identify the risks associated with crayfish introductions in South Africa. This was achieved by using the internationally-developed formal frameworks to assess environmental (Environmental Impact Classification for Alien Taxa (EICAT); Blackburn et al. 2014; Hawkins et al. 2015) and non-environmental impacts (Socio-Economic Impact Classification for Alien Taxa (SEICAT); Bacher et al. 2017) of alien crayfish in Chapter 2. In Chapter 3, the risk posed by alien crayfish introductions into South Africa was then assessed using the recently developed Risk Analysis for Alien Taxa framework (RAAT; Kumschick et al. 2018). These protocols follow international best standards and are based on documented evidence (Wilson et al. 2020). The EICAT framework has been adopted by the IUCN and published as an international standard (IUCN 2020). Freshwater crayfish are ideal taxa to assess potential impacts and risks involved with their introduction because they have been widely introduced globally for aquaculture and the pet trade (Perez et al. 2003; Holdich et al. 2009). They are well-suited and highly sought-after aquaculture species because they are hardy and can tolerate a wide range of trophic and ecological adaptations (Masser and Rouse 1997). They also possess adaptive life history traits such as multiple spawning events, high fecundity, fast growth rates and parental care (Ghanawi and Saoud 2012). However, these life-history traits also predispose them to be invasive in areas of introduction (Westman et al. 2002; Lodge et al. 2012).

4.1 IMPACT ASSESSMENTS

Different protocols have historically been used to assess the negative impacts caused by alien freshwater crayfish in their invaded range (Peay et al. 2010; Gherardi 2011a). However, a major limitation of the results from these assessments is that they are not comparable because the studies used different methods. For example, previous studies on freshwater crayfish invasions have included studies on introduction dynamics (Lodge et al. 2000; Holdich et al. 2009; Gherardi 2011a), meta-analyses of impacts caused in their global invasive range (Westman et al. 2002; Gherardi 2006; Twardochleb et al. 2013). In addition, some studies have used species distribution models (SDMs) and risk assessment protocols to assess the invasion risk posed by crayfish introductions (Feria and Faulkes 2011; Larson and Olden 2012; Chucholl 2016). However, none of these studies undertook a formal impact assessment using standardized protocols that classify the impacts and associated mechanisms (Savini et al. 2012; Laverty et al. 2015). This study used standardized protocols to classify the environmental (EICAT) and non-environmental (SEICAT) impacts of alien freshwater crayfish to avoid the problems of comparing impacts using different methods. It evaluated the negative impacts of 14 alien freshwater species that are known to have been introduced outside their native range.

This study has provided evidence that alien freshwater crayfish have the potential to cause significant impacts in recipient areas of introduction. The magnitude of environmental impacts varied from moderate to massive and minor to moderate for non-environmental impacts. For example, the North American crayfish species have been studied extensively due to their long history of introductions and one such species, the red swamp crayfish (*Procambarus clarkii*) is considered to be one of the most invasive (Holdich et al. 2009; Gherardi 2011a; Manfrin et al. 2019). The EICAT assessments identified the leading impact mechanisms to be competition, predation, transmission of diseases, and grazing. For example, Klocker and Strayer (2004) showed that rusty crayfish (*Faxonius rusticus*) out-competes its native congeners, the northern clearwater crayfish (*F. ponpinquus*) and the virile crayfish (*F. virilis*) for shared resources due to its aggressive behavior. Similar results were found in areas where invasive signal crayfish (*Pacifastacus leniusculus*) occur in sympatry with native white-clawed crayfish (*Austropotamobius pallipes*) resulting in differential predation of the latter because of competitive exclusion from shelters (Dunn et al. 2009). Native species are readily preyed on by alien crayfish and studies have verified that uninvaded areas have a higher diversity compared to invaded sites (Lodge et al. 1994; Bobledyk and Lamberti 2008; Galib et al. 2020). Predation by *P. clarkii* had major impacts on amphibian populations in Spain, resulting in a total community collapse (Cruz and Rebelo 2005; Cruz et al. 2008). Alien crayfish expose native fauna to diseases and parasites that could affect their overall health (Edgerton et al. 2002; Longshaw 2011). For example, *P. clarkii* and *P. leniusculus* have been implicated in the transmission of crayfish plague that caused devastating impacts in Europe resulting in the collapse of native freshwater crayfish communities (Holdich and Reeve 1991; Souty-Grosset et al. 2016).

Socio-economic impact assessments focus on human well-being and how the alien species affects related issues such as livelihoods, farming practices, and recreational activities (e.g., Westman et al. 2002; Laverty et al. 2015). The main mechanisms of impact identified in this study were competition, predation, transmission of diseases, grazing and structural changes to the envrionment. Some alien freshwater crayfish construct burrows in rice fields that can affect crop yields, leading to a loss in revenue (Souty-Grosset et al. 2016). Their burrows can also compromise bank morphology and accelerate the soil erosion process, making invaded areas susceptible to flooding (Guan 1994; Haubrock et al. 2019). The presence of alien freshwater ecosystems also threatens human livelihoods by replacing native species with higher economic value (Marbuah et al. 2014). Recreational activities such as angling are also affected because alien crayfish damage nets and prey on popular fish species resulting in some economic loss (Keller et al. 2008; Peay et al. 2009; Gherardi et al. 2011b). Alien crayfish can cause human health issues, for example when poorly cooked crayfish are consumed (Edgerton et al. 2002; Lane et al. 2009) or when handling infected crayfish (Anda et al. 2001). There is still a knowledge gap regarding the socio-economic impacts of most alien freshwater crayfish. Most studies cover negative environmental impacts because they are fairly well-documented and consequently, there is limited information on socio-economic impacts which was also the case in this study. Assessing the associated socio-economic impacts such as human health and social activities is more challenging (Keller et al. 2008; Marbuah et al. 2014). Following the same pattern as seen for other taxa, the study predicted that majority of the alien cryfish species will be data difficent and the results from the impact assessments classified 11 out of the 14 alien crayfish species as DD. Most of the crayfish that are known to have been introduced outside their native ranges are yet to become invasive and their impacts are largely not documented.

4.2 RISK ANALYSIS FOR ALIEN TAXA

To manage alien taxa properly, sufficient information is required to develop adequate management plans and regulations that can be achieved through various protocols such as risk analyses to evaluate the potential risks associated with alien species. The RAAT framework offers an opportunity to quantify the potential risk posed by alien crayfish introductions in South Africa in a transparent and objective manner and prevent controversies around their management (Lodge et al. 2012; Kumschick et al. 2020b). In addition, the RAAT framework creates an opportunity for scientists and policy-makers to collaborate in order to develop comprehensive informed management decisions and policy frameworks (Hulme et al. 2008; Lodge et al 2012; Patoka 2018). The RAAT framework was used to identify potentially harmful alien freshwater crayfish in order to prevent their introduction, and to recommend appropriate management interventions.

Chapter 3 assessed the potential risk of 14 alien crayfish introductions into South Africa. The risk was evaluated by identifying species with known invasion history, undertaking a risk assessment to assess the likelihood of invasion (i.e., entry, establishment, and spread) and potential impacts, evaluating possible management options, and lastly, consolidating the information in the communication component of the assessment (Kumschick et al. 2020b). The risk assessment identified the pet trade industry as a noteworthy pathway of introduction and most likely the most difficult to regulate (Chucholl 2013; Patoka et al. 2018). Various new species have historically been discovered in the pet trade industry with no record of origin, for example, marmorkrebs crayfish (*Procambarus fallax f. virginalis*) (Faulkes 2010; 2015), and some alien crayfish species are sold under an incorrect name (Lodge 2000; Faulkes 2015). Persistent propagule pressure is one of the determining factors for a successful invasion (Seebens et al. 2017; Essl et al. 2020), and the pet trade is a continuous contributor to the pool of alien crayfish species that could potentially be introduced into South Africa (Chucholl and Wendler 2016). Apart from human-aided vectors, crayfish can also disperse naturally to other areas through connected waterways (Nunes et al. 2017a; Krieg et al. 2021.), and migrate overland to new areas (Gherardi 2006; Thomas et al. 2019). Some can burrow to survive extreme heat conditions (Gherardi 2006). All these factors contributed to many of the species obtaining a score of probable in crossing all the stages of invasion (i.e., likelihood of entry, establishment, and spread) (Blacburn et al. 2011; Kumschick et al. 2020b). The consequence component used EICAT and SEICAT frameworks, and was assessed using the information from Chapter 2 following Kumschick et al. (2018; 2020b).

The management of alien crayfish is complex because of the potential economic benefits that could be derived from their utilisation and therefore, managing the impacts becomes a challenge (Manfrin et al. 2019). Implementing control measures can also become challenging because they occur in sympatry with other indigenous freshwater fauna, are mobile, and are therefore, not restricted to waterways (Gherardi 2007; Thomas et al. 2019). Some also burrows, for example, the yabby crayfish (*Cherax destructor*; Withnall 2000), the signal crayfish (*P. leniusculus;* Guan 1994), and the red swamp crayfish (*P. clarkii;* Gherardi 2006; Haubrock et al.

2019) that could impede some control methods (Nunes et al. 2017b). The only control method with a good success rate in combating crayfish is biocides (Gherardi 2011a; Manfrin et al. 2019; Peay et al. 2019). However, the biocides used are not target-specific, and can affect other freshwater fauna (Ballentyne et al. 2019; Manfrin et al. 2019). Thus, it is only recommended for species with localised distribution such as those occurring in small ponds, limiting the impacts on other freshwater organisms (Gould 2005; Sandonnen 2019). Traditional methods include electrofishing, intensive trapping, and introducing natural predators (Manfrin et al. 2019). However, to increase the efficacy rate, these methods are usually used in combination (Hein et al. 2006; Manfrin et al. 2019; Garcia-de-Lomas et al. 2020). Some studies caution against using trapping as the only control method because results indicate that this method may be body size-selective, removing adults only and consequently, juveniles grow rapidly due to lack of competition, creating positive feedback loop (Manfrin et al. 2019; Chadwick et al. 2020). Loureiro et al. (2018) found similar results and recommended intensive trapping instead of continuous removal methods when management options are evaluated for *P. carkii*. In South Africa, an attempt to eradicate *P. clarkii* 22 years ago at the Driehoek Farm in the Mpumalanga Province was not successful (Nunes et al. 2017b). Although the eradiation method remains unknown, *P. clarkii* burrows and mechanical methods alone, would not have been effective in the removal of individuals (Nunes et al. 2017b). It is also highly likely that the eradication attempt was successful and the results from this survey could be an indication of a new invasion, however, this needs to be verified. The RAAT framework assigned a high-risk score to 80% of the species that have been assessed, suggesting that risk of invasion by alien freshwater crayfish in South Africa is high because of the impacts they caused in areas of introduction outside their native range.

Species of concern

Three alien crayfish crayfish, *F. rustisus*, *P. leniusculus,* and *P. clarkii* had information on impacts. Several other species especially in the genera *Cherax*, *Faxonius* and *Procambarus* have been introduced and some have managed to establish populations in the wild, but there was no information on their impacts in areas of introduction and they were classified as Data Deficient (DD) (Holdich et al. 2009; Lodge et al. 2012). The risk posed by the Data Deficeint species was assessed using closely-related species with similar traits (e.g. feeding ecology, breeding)

(Kumschick et al. 2020). Species from Australia, *C. destructor*, and *C. qudricarinatus* are popular in the aquaculture and aquarium industries (Dedium et al. 2018). *Cherax destructo*r has established populations in central Italy and other regions in Australia (Coughran and Daly 2012; Mrugala et al. 2016), whereas *C. quadricarinatus* is more widespread (Lodge et al. 2012). Crayfish are known to harbour various diseases and parasites (see Edgerton et al. 2002), for example temnocephela worms are associated with commercially important crayfish species in the genus *Cherax* (Longshaw 2011). More importantly, heavily infested specimens have already been identified in South Africa, where the native freshwater crabs were also infected (Avenant-Oldewage 1993; Tavakol et al. 2016; 2021). Mrugala et al. (2016) also found that *C. destructor* shows some resistance when infected with crayfish plague making it a potential vector and threat to other crayfish species that are highly susceptible to the disease. *Procambarus fallax f. virginalis* was discovered in the pet trade industry in Germany is now widespread in Madagascar and has also established populations in the Netherlands (Feira and Faulkes 2011; Chucholl et al. 2012). There is little information available on this species because its native origin is unknown (Chucholl and Pfeiffer 2010), and its ecological information such as thermal tolerance was determined from experimental studies and current distributional records (Faulkes 2010). Due to the limited information available, predicting the likelihood of invasion and potential impacts of *P. fallax f. virginalis* is challenging, and if like its closely-related species, *P. clarkii*, it is likely to cause harmful impacts (Faulkes 2010; Chucholl et al. 2012).

4.3 INTERVENTIONS

The development of policies is highly dependent on the information available to make well-informed decisions (Lodge et al. 2000; Sandonnen 2019). Implementing regulations for biological invasions, in general, is a challenge and poorly enforced because of various factors (Patoka et al. 2018; Sandonnen 2019). Several studies have advocated for the white/blacklist approach where alien species are thoroughly screened before any introductions are permitted (Lodge 2000; Hulme et al. 2008). Species considered low-risk would typically be on the whitelist, and those with the potential to become invasive would be blacklisted and any movement strictly prohibited (Patoka et al. 2018). Policies developed for this purpose ideally target pathways of introductions (Simberloff et al. 2013; Marbuah et al. 2014). South Africa is also adopting a similar approach, where the risk analyses will form the basis of evidence to inform management of alien species (Kumschick et al. 2020a). For alien freshwater crayfish, aquaculture is simpler to regulate due to permit requirements in South Africa (Kumschick et al. 2020a) compared to the pet trade and live bait industries (Distefano et al. 2009; Patoka et al. 2018). Various studies have reported that these industries are generally not well-regulated and where regulations have been developed, they are not enforced adequately (Lodge et al. 2000; Distefano et al. 2009). Most of the shop-owners in these industries do not comply with restrictions or bans and continue to sell alien species (Distefano et al. 2016). Generally, these owners do not know what species they are selling, or they identify them incorrectly (Distefano et al. 2009; Berube and Kraft 2010; Kilian et al. 2012). Several alien crayfish species are available to buy online and in pet shops even though there is no legal documentation of their introduction in South Africa (de Moor 2002; Nunes et al. 2017c; Madzivanzira et al. 2020). From the information available, there is no indication whether the movement of crayfish species through these industries has been evaluated to fully anticipate the level of risk they pose as pathways of introduction (Nunes et al. 2017c; Madzivanzira et al. 2020). However, proper risk assessments are needed where impacts and the likelihood of invasion are quantified to support policies and management plans (Lodge et al. 2012; Simberloff et al. 2013). The RAAT framework is one example of such a tool used to assess impacts and their magnitudes and outline the mechanisms associated with these impacts based on scientific evidence (Kumschick et al. 2020b).

4.4 MANAGEMENT RECOMMENDATIONS AND FUTURE STUDIES

Alien freshwater crayfish introductions should be limited to species that pose low to medium risk (Lodge et al. 2000). Alien crayfish populations are usually discovered when they have established, and eradication is often no longer feasible (Gherardi 2011a; Lodge et al. 2012). For this reason, management plans should be developed for the respective alien crayfish populations according to their invasion status and the range (Lodge et al. 2000). For example, the red swamp crayfish (*P. clarkii*) populations in South Africa are restricted to two localities, and are ideal for eradication initiatives (Gherardi 2011a; Nunes et al. 2017b Manfrin et al. 2019). Eradication is likely to be feasible for localized populations as demonstrated elsewhere (e.g., Gould 2005; Ballantyne et al. 2019). Eradication methods should also consider some aspects of the species ecology. For example, *P. clarkii* constructs burrows and some mechanical control methods such as partial de-watering of invaded ponds/dams will not be effective because the species can seek refuge in burrows (Holdich and Reeve 1991; Gherardi 2011a; Manfrin et al. 2019). The redclaw crayfish (*Cherax quadricarinatus*) is widespread in the Inkomati River in Mpumalanga Province where it has become invasive (Nunes et al. 2017a South et al 2020), therefore, management efforts for *C. quadricarinatus* should be directed towards the control and prevention of further spread (de Moor 2002; Nunes et al. 2017a). Methods such as the use of barriers could be explored to assist in slowing down the current spread and should consider their mobility to counter overland migration (Thomas et al. 2019; Krieg et al. 2021). The introduction of alien species is regulated through a permit system, however based on the results of the risk analyses; it is highly recommended that permit applications for the importation of species that are considered as to be high risk should not be granted.

Alien freshwater crayfish species occupy vacant niches in areas where there are no native crayfish species, and in such cases other decapods such as native species of crabs could be at risk from the crayfish invasions (Lodge et al. 2012; Jackson et al. 2016). For example, Jackson et al. (2016) demonstrated that alien crayfish invasions can lead to niche constriction and declines in population sizes of native crabs. Further studies in South Africa and other areas are required in invaded areas to monitor the impacts on native freshwater crab populations and identify the mechanisms responsible and ultimately the magnitude of these impacts (Savvides et al. 2015; Zeng et al. 2019). Experiments have indicated that competition may be one impact mechanism because alien crayfish were dominant in aggressive interactions and occupied shelters more than native crabs (Savvides et al. 2015). Although both crayfish and crabs are omnivores, alien crayfish may be more flexible than native crabs when limited food resources are available because of the decrease in diet breadth observed in the latter (Jackson et al. 2016). Another concern in South Africa is the transmission of diseases to native decapods and other freshwater fauna because both species present in the wild are vectors of parasites and diseases (Edgerton et al. 2002; Tavakol et al. 2016). Studies are needed to determine if any native decapods are susceptible to these pathogens such as the crayfish plague. This disease could have similar devastating impacts as reported in Europe, where native crayfish populations are still struggling to recover (Holdich and Reeve 1991; Edgerton et al. 2002)

4.5 CONCLUSION

This study is the first to undertake impact assessments using EICAT and SEICAT and to use the RAAT framework to assess the risk of alien freshwater crayfish in South Africa. Both these frameworks provided sufficient information on impacts and why the introduction of alien crayfish in South Africa should be of concern. The life-history traits of alien freshwater crayfish predispose them to adapt rapidly to environmental conditions in areas of introduction and aid their establishment and spread (Gherardi et al. 2007; Lodge et al. 2012). Three out of four species that are known to occur in South Africa are currently listed under the NEM:BA A&IS Regulations, which implies there is an obligation to manage them. However, the red swamp crayfish (*P. clarkii*) is not listed on the regulations but there is evidence that there are localized populations in the country and should therefore be listed as a Category 1a species (Kumschick et al. 2020b). In South Africa, the populations of alien crayfish species that are currently localized to a few locations should be eradicated urgently to avoid secondary dispersal. For the most part, public awareness is pivotal to help combat further spread because current sites can also act as a source for secondary dispersal (Nunes et al. 2017c). The public should be sensitized about the illegality of using and selling the alien crayfish species as live bait and pets (de Moor 2002; Nunes et al. 2020c). The release of alien crayfish into the wild as unwanted pets can accelerate the dispersal rate, as reported in other countries (Kilian et al. 2012; Chucholl 2013; Faulkes 2015). In addition, the pet trade industry is of great concern because the movement of alien crayfish has not been evaluated but there is some evidence that they are present in the industry (Nunes et al. 2017c). Therefore, some crayfish species may be present in South Africa but remain undocumented (Nunes et al. 2017c; Madzivanzira et al. 2020). There is an urgent need to enforce regulations rigorously to prevent the introductions and spread of alien crayfish. Where possible, the results from these studies could be used for the development of better control methods, policies and improve management plans for alien freshwater crayfish in South Africa and beyond.

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APPENDICES

Supporting Information Table S2.1 A list of freshwater crayfish species that have a history of introduction to areas outside there respective native range compiled from the published literature, the International Union for Conservation of Nature (IUCN) Red List (www.iucnredlist.org/), the Centre of Agriculture and Bioscience International (CABI): Invasive Species Copendium (https://www.cabi.org/ISC/) , and the Global Biodiversity Information Facility (GBIF) (www.gbif.org/en/). Invasion status was defined according to the different stages of the unified framework (see Blackburn et al. 2011), and species were grouped in four broad categorieslevel descriptors: 1) not introduced = species that have no record of introduction to areas outside their native range,; 2) introduced = species that are introduced to a country but are not naturalized in the wild, 3) established = species that have established in the wild but are not yet invasive,and 4) invasive = species with self -sustaining populations that have spread from initial sites of introduction. A total; of 14 species were assessed of which 11 had no documented evidence of introduction outside there native range and are not shown.

Species	Native region	Global alien range	Introduction status	Sources
Cherax cainii	South-West Australia	U.S.A, Japan, China, Chile, New Zealand, the Caribbean, Malawi, Zimbabwe and South Africa	**Introduced** U.S.A, Japan, China, Chile, New Zealand, the Caribbean, Malawi, Zimbabwe and South Africa	CABI, 2021. *Cherax cainii* [original text by Uma Sabapathy Allen]. In: Invasive Species Compendium. Wallingford, UK: CAB International. www.cabi.org/isc. GBIF.org (06 August 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.jjvau7
Cherax destructor	Southeast and central Australia	China, Italy, South Africa, Spain, Western Australia and Zambia	**Introduced** Italy, South Africa, Spain, Western Australia and Zambia **Established**- Europe (Spain)	CABI, 2021. *Cherax destructor* [original text by Uma Sabapathy Allen]. In: Invasive Species Compendium. Wallingford, UK: CAB International. www.cabi.org/isc. GBIF.org (06 August 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.uk1pbf

Species	Native region	Global alien range	Introduction status	Sources
Cherax quadricarintaus	northern Australia and Papua New Guinea	Asia Africa: Morocco, Zamba, Asia: China, Indonesia, Israel, Japan, Malasia, Philipines, Singapore, Taiwan, Thailand, Australia: New South Wales, Western Australia, Samoa, Europe: Greece,Italy, Spain, United Kingdom, North America, South America	**Introduced**– Asia Africa: Morocco, Zamba, Asia: China, Indonesia, Israel, Japan, Malasia, Philipines, Singapore, Taiwan, Thailand, Australia: New South Wales, Western Australia, Samoa, Europe: Greece,Italy, Spain, United Kingdom, North America, South America, **Established**– Jamaica, Mexico, Puerto Rico, United States (California) **Invasive**– Africa: South Africa	CABI, 2021. *Cherax quadricarinatus* [original text by Clive Jones]. In: Invasive Species Compendium. Wallingford, UK: CAB International. www.cabi.org/isc. Austin, C.M., Jones, C. & Wingfield, M. 2010. *Cherax quadricarinatus*. *The IUCN Red List of Threatened Species* 2010: e.T4621A11041003. https://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T4621A11041003.en GBIF.org (06 August 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.dkmivh
Cherax tenuimanus	south west of Western Australia	Australia, South Africa	**Introduced**- Australia, South Africa	CABI, 2021. *Cherax tenuimanus.* In: Invasive Species Compendium. Wallingford, UK: CAB International. www.cabi.org/isc. GBIF.org (06 August 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.tvqoxp
Faxonius immunis	Canada and United States	Germany and United States	**Introduced**– Europe: Germay, United States: Vermont, Rhode Island, Massachusetts, New Hampshire **Established**- Europe: Germany	Adams, S., Schuster, G.A. & Taylor, C.A. 2010. *Orconectes immunis*. *The IUCN Red List of Threatened Species* 2010: e.T153925A4564415. https://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T153925A4564415.en. Chucholl C. 2009. The \`Newcomer´ *Orconectes immunis* Keeps Spreading in the Upper Rhine Plain. *Crayfish News* 31**:** 4–5. GBIF.org (06 August 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.mpnsbl

Species	Native region	Global alien range	Introduction status	Sources
Faxonius juvenilis	Canada (New Brunswick, Quebec); United States (Connecticut, Delaware, District of Columbia,	France	Established: Europe: France	Adams S, Schuster GA Taylor, CA. 2010. *Orconectes juvenilis*. *The IUCN Red List of Threatened Species* 2010: e.T153954A4568495. https://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T153954A4568495.en. Chucholl C, Daudey T. 2008. First record of *Oroconectes juvenilis* in eastern France: update to the species identity of a recently introduced orconectid crayfish. *Biological Invasions* 3: 105–107. GBIF.org (06 August 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.oko8m1
Faxonius limosus	Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island,Vermont, Virginia, West Virginia)	Austria; Belgium; Czech Republic; France Germany; Hungary; Italy, Lithuania; Luxembourg; Montenegro; Morocco; Netherlands; Poland; Russian Federation Switzerland; United Kingdom	**Introduced**– Africa: Morocco, Europe: Bulgaria, Estonia, Latvia, Montenegro, North America: United States (Maine, NewHampshire) **Invasive**–Europe: Austria, Belarus, Belgium, Croatia, Czech Republic, France, Germany, Hungary, Italy, Lithuania, Netherlands, Poland, Romania, Central Russia, Serbia, Slovakia, Slovenia, Switzerland, United Kindom, North America:	CABI, 2021. *Faxonius limosus* [original text by Elena Tricarico]. In: Invasive Species Compendium. Wallingford, UK: CAB International. www.cabi.org/isc. Alekhnovich, A., Buřič, M. (2017): NOBANIS – Invasive Alien Species Fact Sheet – Orconectes limosus. – From : Online Database of the European Network on Invasive Alien Species – NOBANIS www.nobanis.org GBIF.org (06 August 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.7eml1s
Faxonius rusticus	Ohio River drainage, United States of America	Canada, Lake Michigan, United States of America	**Introduced**– North America: United Stated (Alabama, Colorado, Conneticut, Kentucky, Maine, Maryland, New Mexico, New Jersey, Nebraska, Nevada, North Carolina, Oregon, South Dakota, Vermont, West Virginia,Wyoming. **Invasive**– North America: Canada, United States (Michigan, Minnesota, New York, Ohio, Pennylvania, Winsconsin)	CABI, 2021. *Faxonius rusticus* [original text by Elena Tricarico]. In: Invasive Species Compendium. Wallingford, UK: CAB International. www.cabi.org/isc. GBIF.org (06 August 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.fiugct

Species	Native region	Global alien range	Introduction status	Sources
Faxonius virilis	USA and CanadaMissouri, Mississippi, Ohio, and Great Lakes drainages of the United States	**Europe**: Netherlands, United Kingdom, **North America**: Wyoming, West Virginia, Vermont, Utah, Tennesee, Rhode Island, Pensylvania, New Mexico, New Hampshire, Montana, Massachusettes, Maryland, Kansas, Idaho, Connecticut, Colorado, California, Arizona, Alabama, Mexico,	**Introduced-** North America: United States (Mexico, Conneticuit, Kansas, Massachusetts, New Hampshire, New Mexixo, Pennsylvania, Rhode Island, Tennese, Vermont, Virginia) **Invasive** – Europe: Netherlands, United Kingdom, North America (Alabama, Airizona, California, Colorado, Idaho, Maryland, Montana, New Burnswick, Utah, Washington, Wyoming)	CABI, 2021. *Faxonius virilis* [original text by Adam Ellis]. In: Invasive Species Compendium. Wallingford, UK: CAB International. www.cabi.org/isc. GBIF.org (06 August 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.dwmjne
Pacifastacus leniusculus	North-western U.S.A. and south-western Canada	Austria; Belgium; Cyprus; Denmark; Finland; France; Germany; Greece; Italy; Japan; Latvia; Lithuania; Luxembourg; Netherlands; Poland; Portugal; Russian Federation; Spain; Sweden; Switzerland; United Kingdom	**Introduced-** Asia: Japan, Hokkaido. Europe: Austria; Belgium; Cyprus; Denmark; Finland; France; Germany; Greece; Italy; Japan; Latvia; Lithuania; Luxembourg; Netherlands; Poland; Portugal; Russian Federation; Spain; Sweden; Switzerland; United Kingdom **Invasive-** North America: California	CABI, 2021. *Pacifastacus leniusculus* [original text by Uma Sabapathy Allen]. In: Invasive Species Compendium. Wallingford, UK: CAB International www.cabi.org/isc. GBIF.org (06 August 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.ic4smn

Species	Native region	Global alien range	Introduction status	Sources
Pontascacus leptodactylus	Austria; Azerbaijan; Belarus; Bosnia and Herzegovina; Bulgaria; Croatia; Georgia; Greece; Hungary; Iran, Islamic Republic of; Israel; Kazakhstan; Kyrgyzstan; Moldova; Romania; Russian Federation; Serbia (Serbia); Slovakia; Turkey (Turkey-in-Asia, Turkey-in-Europe); Turkmenistan; Ukraine	Armenia, Belgium, Czech Republic, Denmark, Finland, France, Germany, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Spain, Switzerland, United Kingdom (Great Britain), Uzbekistan	**Introduced:** Armenia, Belgium, Czech Republic, Denmark, Finland, France, Germany, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Spain, Switzerland, United Kingdom (Great Britain), Uzbekistan **Invasive**: Europe: United Kingdom	CABI, 2021. *Pontastacus leptodactylus* [original text by Uma Sabapathy Allen]. In: Invasive Species Compendium. Wallingford, UK: CAB International www.cabi.org/isc. GBIF.org (06 August 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.apkolt
Procambarus acutus	Coastal plain from Maine to Georgia, and from the Florida panhandle to Texas, and Minnesota to Ohio.	Belize; Brazil; Chile; China; Colombia; Costa Rica; Cyprus; Dominican Republic; Ecuador; Egypt; France; Georgia; Germany; Italy; Japan; Kenya; Mexico; Netherlands; Philippines; Portugal; South Africa; South Sudan; Spain; Sudan; Switzerland; Taiwan; Uganda; United Kingdom; United States of America (in the States of Alabama, Arizona, Arkansas, California, Hawaii, Idaho, Indiana, Maryland, Nevada, New, North Carolina, Ohio, Oregon, South Carolina, Utah, Virginia, West Virginia - Present - Origin uncertain); Venezuela (Bolivarian Republic); Zambia	**Introduced**– Africa: Egypt, Europe: Netherlands, North America: California, Connecticut, Maine, Massachusetts, Rhode Island	CABI, 2021. *Procambarus acutus [*original text by Francesca Gherardi]. In: Invasive Species Compendium. Wallingford, UK: CAB International www.cabi.org/isc. GBIF.org (06 August 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.pjcti6

Species	Native region	Global alien range	Introduction status	Sources
Procambarus clarkii	North eastern Mexico and South-central U.S.A	Belize; Brazil; Chile; China; Colombia; Costa Rica; Cyprus; Dominican Republic; Ecuador; Egypt; France; Georgia; Germany; Italy; Japan; Kenya; Mexico; Netherlands; Philippines; Portugal; South Africa; South Sudan; Spain; Sudan; Switzerland; Taiwan; Uganda; United Kingdom; United States of America (in the States of Alabama, Arizona, Arkansas, California, , Hawaii, Idaho, , Indiana, Maryland, Nevada, , North Carolina, Ohio, Oregon, South Carolina, , Utah, Virginia, West Virginia Venezuela (Bolivarian Republic); Zambia	**Introduced**– ***Africa***: Sudan, Asia: Georgia, Phillipines, Israel, Singapore, Taiwan. ***Europe:*** Belgium, Germany; Netherlands; Poland; Azores, Canary Islands. North America– Alaska, Belize; Costa Rica; Dominican Republic, Floria, Georgia, Idaho, Indiana, New York, North Carolina, Puerto Rico, South Carolina, Utah Winsconsin, ***South America***: Brazil; Ecuador, Venezuela **Invasive**– ***Africa***: Egypt; Kenya; South Africa; Uganda; Zambia, ***Asia***: China; Guangdong; Hong Kong; Hubei Jiangsu Japan. ***Europe***: Cyprus; France; Italy; Portugal, Spain, Switzerland; United Kingdom, ***North America***: Airizona, California, Colorado, Hawaii, Maryland, Mississippi, Mexico, Nevada, New Mexico, Ohio, Oregon	CABI, 2021. *Procambarus clarkii* [original text by Jay Huner]. In: Invasive Species Compendium. Wallingford, UK: CAB International www.cabi.org/isc. GBIF.org (06 August 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.xklcqe
Procambarus fallax f virginalis	Unkown	Madagascar, Europe, Japan, Netherlands, Italy	**Introduced**– Africa: Madagascar ,Asia: Hokkaido, Europe: Austria, Germany, Italy, Netherlands **Present in pet trade**– North America: United States **Invasive**– Africa: Madagascar	CABI, 2021. *Procambarus f. virginalis* [original text by Christoph Chucholl]. In: Invasive Species Compendium. Wallingford, UK: CAB International www.cabi.org/isc. GBIF.org (06 August 2019) GBIF Occurrence Download https://doi.org/10.15468/dl.7auosf

Appendix 2.1 A summary of the impact assessment of alien crayfish species done using the Environmental Impact Classification of Alien Taxa (EICAT) and the relevant literature cited. Impact scores, from highest to lowest are: 1) Massive (MV); 2) Major (MR); 3) Moderate (MO), 4) Minor (MN); 5) and Minimal Concern (MC).

Species	Impact mechanisms	Impact	Impact score	Reference	Region	Confidence score
Faxonius rusticus	Competition	Outcompete native crayfish – decline in abundance	MO	Bobledyk and Lamberti 2008	USA	Medium
		Competitive exclusion	MO	Hill and Lodge 1994	USA	Medium
		Outcompete native species	MO	Garvey and Steiin 1993	USA	Medium
		Displacing native congeners	MO	Taylor and Redmer 1996	USA	Medium
		Competitive exclision	MO	Berman and Moore 2003	USA	Medium
	Grazing	Reduced macrophyte abundance and diversity	MR	Wilson et al. 2004	USA	High
		Reduced macrophyte abundance	MO	Rosenthal et al. 2006	USA	Medium
	Hybridisaion	Hybridise with native species	MN	Alcella et al. 2014	USA	Medium
		Hybridise with native species	MN	Perry et al.2002	USA	Medium
		Hybridise with native species	MN	Perry et al 2002	USA	Medium
	Predation	Decline in snail diversity	MR	Kreps et al. 2012	USA	High
		Decline lake trout fry	MO	Jonas et al. 2005	USA	High
		Decrease in invertebrate abundance	MO	Wilson et al. 2004	USA	High
		Predate on eggs- reproductive inteferene	MN	Baldrige and Lodge 2013.	USA	Medium
Pacifastacus leniusculus	Competition	Displacing native crayfish	MR	Almeida et al. 2014	Europe	High
		Competitive exclusion	MR	Westman et al. 2002	Europe	High
		Displacing native crayfish species, competitive exclusion	MO	Dunn et al. 2009	Europe	Medium
	Strcuctural changes	Burrowing has led to the collapse of river banks	MO	Guan et al. 1994	Europ	Medium
	Predation	Decline in invertebrate numbers	MR	Mathers et al. 2016	Europe	High

Species	Impact mechanisms	Impact	Impact score	Reference	Region	Confidence score
Pacifastacus leniusculus		Decline in invertebrate numbers	MO	Crawford et al. 2006	Europe	High
		Decline in newt numbers	MO	Girdner et al. 2018	USA	High
		Decline in mollusc numbers	MO	Meira et al 2020	Europe	High
		Decline in mussel numbers	MO	Sousa et al. 2020	Europe	High
		Decline in invertebrate richness and abundance	MO	Galib et al. 2020	Europe	High
		Affect salmanoit recruition	MN	Peay et al. 2009	Europe	Medium
	Transmission of diseases	Tranmission of crayfish plague led to decline in numbers and local extiction	MV	Chucholl and Schrimpf 2016.	Europe	High
		Local dissaopearance of native crayfish	MV	Almeida et al. 2014	Europe	Medium
		Tranmit diseases to native species	MR	Weinlader and Furer	Europe	Medium
		Crayfish transmission to crabs	MN	Svaboda et al. 2014	Europe	Low
Procambarus clarkii	Grazing	Reduce macrophyte species	MR	Donato et al. 2018	Europe	Medium
		Reduced macrophye abundabce	MO	Rodriguez et al. 2003	Europe	Medium
	Predation	Exclude amphibians from breeding sites	MR	Cruz and Rebelo 2005	Europe	High
		Collapse in amphibian population	MR	Cruz et al. 2008	Europe	High
		Displace newts in areas of introduction	MR	Gamradt and Katz 1996	USA	High
		Reduce amphibian numbers	MO	Cruz et al. 2006	Europe	High
		Reduced abundance two amphibian species	MO	Ficetola et al. 2011	Europe	Medium
		Mosquito and lymph larvae	MN	Bucciarelli et al. 2019	Europe	High
		Reduce invertebrate numbers	MN	Meira et al. 2020	Europe	High
		Predates on native amphibians	MN	Banci et al. 2013	S. America	High
	Structural impact on ecosystem	Change water from clear to turbit	MN	Rodriguez et al. 2003	Europe	High
		Burrowing may reduce levee stability	MO	Acre and Diéguez Uribeondo 2015	Europe	Medium
	Structural impact on ecosystem	Burrowing damage dam walls and irrigation structures	MN	Correia and Fereira 2005	Europe	Medium
	Structural impact on ecosystem	Burrowing may reduce levee stability	MN	Haubrock et al. 2019.	Europe	Low
	Transmission of diseases	Reduced native crayfisg populations	MV	Gherardi 2010	Europe	Medium

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Appendix 2.2 A summary of the impact assessment using the Socio-Economic Impact Classification for Alien Taxa (SEICAT) and the relevant literature cited. Impact scores, from highest to lowest are: 1) Massive (MV); 2) Major (MR); 3) Moderate (MO); 4) Minor (MN); and 5) Minimal Concern (MC).

Species	Constituent of human well-being	Activity	Impact score	Reference	Region	Confidence score
Faxonius rustcus	Social, spiritual and cultural activities	Competition/ Predation– Reduce sport fish population	MN	Keller et al. 2008	USA	Low
Pacifastacus leniusculus	Material and immaterial assets	Competition/ Predation –Replacing aquaculture species	MO	Holdich et al. 2009	Europe	Low
	Social, spiritual and cultural activities	Competition/ Predation –Affect sport fish population	MN	Peay et al. 2009	Europe	Low
Procambarus clarkii	Material and immaterial	Damange to rice fields	MO	Gherardi et al. 2011	Europe	Medium
		Burrowing/ grazing- Decrease in rice production and clog pipes	MO	Gherardi et al. 2011	Europe	Medium
		Decrease rice production	MN	Anastácio et al. 2005	Europe	Medium
		Predation– Affects the fishing industry by damaging gill nets and spoiling the fish caught in the nets	MO	Gherardi et al. 2011	Africa	Medium
	Health	Transmission of disease	MO	Lane et al. 2009	USA	High
		Transmission of disease	MO	Anda et al. 2011	Europe	High
		Procambarus clarkii serves as vector for several parasites and diseases some of which are zoonotic, for example the rat lungworm *Angiostrongylus cantonensis* that causes meningitis, and the nematode *Gnathostoma spinigerum* that causes human gnathostomiasis	MN	Putra et al. 2018	Indonesia	Low
		It accumulates cyanobacteria toxins and heavy metals that can be transferred to its consumers, above all birds but also humans included.	MN	Gherardi et al. 2011	Europe	Low
		Transmission of disease	MO	Souty-Grosset et al. 2016	Europe	Low
	Social, spiritual and immaterial assets	Competition/ Predation –disrupt recreational activities (Angling)	MO	Gherardi et al. 2011	Europe	Low

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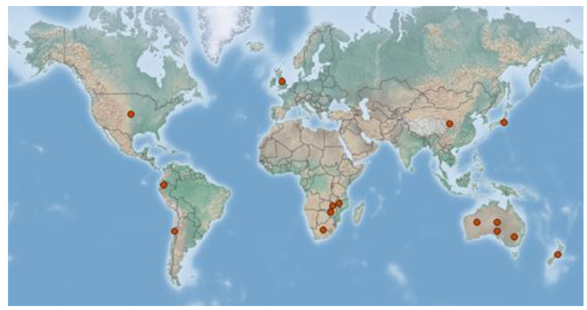
Appendix 3 Risk analyses reports of 14 alien freshwater crayfish that are currently known to be invasive, established, or have been introduced in areas outside their native range. The reports are presented as prepared for submission to the South African Alien Species Risk Analysis Review Panel (ASRARP), a committe that is tasked with reviewing risk analyses attached to import applications and listing of species under national legislation to ensure they are scientifically robust and take into account the best available evidence (see Kumschick et al. 2020 for details). ASRARP is an independent body and its members consist of scientists and taxon experts working working various issues on biological invasions. The committee provides recommendations to an interdeaptmental panel set up by the Department of Forestry, Fisheries and the Environment that is tasked with granting import permits and or approving changes to regulations on biological invasions.

Appendix 3.1 Risk analysis report for Smooth marron (*Cherax cainii*).

Risk Analysis Report

<table>
<tr><td>Taxon:
Cherax cainii Austin and Ryan, 2002</td><td>Area:
South Africa</td></tr>
<tr><td>Compiled by:
Lee-Anne Botha</td><td>Approved by:</td></tr>
<tr><td>Picture of Taxon

http://www.fish.wa.gov.au/Species/Marron/Pages/default.aspx</td><td>Alien distribution map

Sourced from CABI (2019)</td></tr>
<tr><td>Risk Assessment summary:
The marron, Cherax cainii was described in 2002 after a taxonomic revision revealed that previously known populations of C. tenuimanus were not homogenous but instead consisted of two genetically-distinct species, C. tenuimanus restricted to the Margaret River in Western Australia and C. cainii that is widespread and widely utilised for aquaculture in Australia. Introduction records of marron in South Africa prior to 2002 refer to C. tenuimanus but recent import permit records indicate that both species are likely present in the country, but this still needs to be genetically verified. In addition, there are no known naturalised populations in the country but the potential for intentional and accidental release from aquaculture facilities into the wild is high. Escapees are able to disperse overland into adjacent river systems to colonise new areas. There is a lack of documented evidence of environmental and socio-economic impacts caused by C. cainii in its alien range. Procambaus clarkii (red swamp crayfish) a closely related species that has documented evidence of impacts in areas of introduction was used to infer the potential impacts of C. cainii. Both species are functional omnivores and have the potential to cause multiple impacts at different trophic levels of the food web. Procambarus clarkii has been implicated in causing major impacts on native communities through competition and predation leading to decreased abundance and local extirpation of native species. It is also known to cause habitat loss and modification through intensive grazing and stalk cutting of aquatic macrophytes that provide food, refuge and spawning sites (i.e., reproductive interference) for fish and other aquatic fauna. It is therefore, likely that C. cainii will cause similar impacts in areas of introduction.</td><td>Risk score:
High</td></tr>
<tr><td>Management options summary:
There are management protocols in place for the farming of marron in the Western Cape Province that aim to minimise the risk of escape from confinement and naturalisation. Similar protocols should be adopted by the other provinces in the country. In the event that the species escapes and, incursion response using biocides, as observed in New Zealand can be highly effective at eradicating localised populations. Therefore, early detection and response is crucial to prevent further spread.</td><td>Ease of management:
Easy</td></tr>
</table>

Recommendations: *Cherax cainii* is currently listed as Category 2 under NEM:BA regulations; the results from this Risk Anlaysis supports this listing. Should *C. cainii* manage to escape, establish populations and become widespread; it should be moved to Categories 1a or 1b.	**Listing under NEM:BA A&IS lists of 2014 as amended 2020:** 2
	Recommended listing category: 2

1. Background

BAC1 Name of assessor(s)		
Name of lead assessor	**Lee-Anne Botha**	
Additional assessor (1)		
Additional assessor (2)		
BAC2 Contact details of assessor (s)		
Lead assessor	Organisational affiliation: Department of Zoology and Entomology, University of Pretoria and The South African National Biodiversity Institute (SANBI).	
	email: u18389164@tuks.co.za	
	Phone: 072 833 7952	
Additional assessor (1)	Organisational affiliation:	
	email:	
	Phone:	
Additional assessor (2)	Organisational affiliation:	
	email:	
	Phone:	
BAC3 Name(s) and contact details of expert(s) consulted		
Expert (1)	Name: Dr Tsungai Zengeya	
	email: T.Zengeya@sanbi.org.za	
	Phone: 021 799 8408	
Expert (2)	Name:	
	email:	
	Phone:	
Comments: Dr Tsungai Zengeya works for the South African National Biodiversity Institute (SANBI). His research interests are in freshwater ecology and biological invasions. He provided comments and inputs throughout the compilation of this risk analysis that improved its quality.		
BAC4 Scientific name of *Taxon* under assessment		
Taxon name: *Cherax cainii*		Authority: Austin and Ryan, 2002
Comments: *Cherax tenuimanus* was originally described by Smith in 1932 from the Margaret River in Western Australia (Austin and Ryan 2002). Examination of marron populations from different river systems in Australia however revealed two genetically distinct marron species, *C. tenuimanus* that is restricted to the Margaret River, Western Australia, and *C. cainii* which is widespread within south-west of Western Australia and other areas in South Australia and Victoria because of extensive introductions for aquaculture (Austin and Ryan 2002).		

References: Austin CM, Ryan SG. 2002. Allozyme evidence for a new species of freshwater crayfish of genus *Cherax* Erichson (Decapoda: Parastacidae) form the south-west of Western Australia. *Invertebrate Systematics* 16: 357–367.	
BAC5 Synonym(s) considered	
Synonyms: None	
Comments: *Cherax cainii* and *C. tenuimanus* were initially classified as one, thus literature records prior to 2002 could be referring to either one of the two species (Austin and Ryan 2002). For this risk analysis, information on both species was used.	
References: Austin CM, Ryan SG. 2002. Allozyme evidence for a new species of freshwater crayfish of genus *Cherax* Erichson (Decapoda: Parastacidae) form the south-west of Western Australia. *Invertebrate Systematics* 16: 357–367.	
BAC6 Common name(s) considered	
Common names: smooth marron/marron	
Comments: *Cherax cainii* has two common names: smooth marron and marron (Austin and Ryan 2002; Beatty et al. 2004).	
References: Austin CM, Ryan SG. 2002. Allozyme evidence for a new species of freshwater crayfish of genus *Cherax* Erichson (Decapoda: Parastacidae) form the south-west of Western Australia. *Invertebrate Systematics* 16: 357–367. Beatty SJ, Morgan DL, Gill HS. 2004. Biology of a translocated population of the large freshwater crayfish, *Cherax cainii* Austin & Ryan, 2002 in a Western Australian River. *Crustaceana* 77:1329–1351.	
BAC7 What is the native range of the *Taxon*? (add map in Appendix BAC7)	
Response: South-West Australia	Confidence: High
Comments: *Chrerax cainii* is native to south-west Australia (Austin and Ryan 2002; Beatty et al. 2004).	
References: Austin CM, Ryan SG. 2002. Allozyme evidence for a new species of freshwater crayfish of genus *Cherax* Erichson (Decapoda: Parastacidae) form the south-west of Western Australia. *Invertebrate Systematics* 16: 357–367. Beatty SJ, Morgan DL, Gill HS. 2004. Biology of a translocated population of the large freshwater crayfish, *Cherax cainii* Austin & Ryan, 2002 in a Western Australian River. *Crustaceana* 77: 1329–1351.	
BAC8 What is the global alien range of the *Taxon*? (add map in Appendix BAC8)	
Response: U.S.A, Japan, China, Chile, New Zealand, the Caribbean, Malawi, Zimbabwe and South Africa.	Confidence: Medium
Comments: Globally, *C. cainii* has been introduced for aquaculture in several countries but there is no evidence of naturalised populations in any of the areas of introduction (Lawrence and Jones 2002; Beatty et al. 2004; CABI 2019).	
References: Beatty SJ, Morgan DL, Gill HS. 2004. Biology of a translocated population of the large freshwater crayfish, *Cherax cainii* Austin & Ryan, 2002 in a Western Australian River.*Crustaceana* **77**: 1329–1351. Lawrence C, Jones C. 2002. *Cherax*. In: Holdich DM (ed.) Biology of freshwater crayfish. Blackwell Science, U.K CABI. 2019. Invasive species compendium. Available from URL. https://www.cabi.org/isc/datasheet/89136	

BAC9 Geographic scope = the *Area* under consideration		
Area of assessment: South Africa		
Comments: Geographic scope of assessment is South Africa.		
BAC10 Is the *Taxon* present in the *Area*?		
Response: Yes		Confidence: Medium
Comments: *Cherax cainii* is likely to be present in South Africa because there are import permits records that indicate that it was introduced for aquaculture but there are no known naturalised populations (Zengeya and Wilson 2019). A few aquaculture farms in Eastern and Western Cape are reportedly rearing marron but it is not clear which of the two species (*C. cainii* and/or *C. tenuimanus*) is being farmed (Austin and Ryan 2002; de Moor 2002; Nunes et al. 2017). It is assumed to be *C. cainii* because it's is widely utilised for aquaculture whereas *C. tenuimanus* seems to be largely restricted to the Margaret River, Australia (Austin and Ryan 2002). There is therefore is a need for follow up studies to genetical verify the identity of the species utilised.		
References: Austin CM, Ryan SG. 2002. Allozyme evidence for a new species of freshwater crayfish of genus *Cherax* Erichson (Decapoda: Parastacidae) form the south-west of Western Australia. *Invertebrate Systematics* 16: 357–367. de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future, *African Journal of Aquatic Science* 42: 309–323. Zengeya TA, Wilson JR. (eds.) 2020. The status of biological invasions and their management in South Africa in 2019. South African National Biodiversity Institute, Kirstenbosch and DSI-NRF Centre of Excellence for Invasion Biology, Stellenbosch.		
BAC11 Availability of physical specimen		
Response: No		Confidence in ID:
Herbarium or museum accession number:		
References:		
BAC12 Is the *Taxon* native to the *Area* or part of the *Area*?		
The *Taxon* is native to (part of) the *Area*.	No	Confidence: High
The *Taxon* is alien in (part of) the *Area*.	Yes	Confidence: High
Comments: *Cherax cainii* is native to Australia and are there no freshwater crayfish species native to South Africa (de Moor 2002; Nunes et al. 2017).		
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future, *African Journal of Aquatic Science* 42: 309–323.		
BAC13 What is the *Taxon*'s introduction status in the *Area*?		
The *Taxon* is in cultivation/containment.	Yes	Confidence: Medium
The *Taxon* is present outside of cultivation/containment.	Unknown	Confidence: Low
The *Taxon* has established/naturalised.	Unknown	Confidence: Low

The *Taxon* is invasive.	Unknown	Confidence: Low
Comments: *Cherax cainii* is likely present in the country because there are import permit records for its introduction for aquaculture, however there are no known naturalised populations (de Moor 2002; Nunes et al 2017; Zengeya and Wilson 2019).		
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. Zengeya TA, Wilson JR. (eds.) 2020. The status of biological invasions and their management in South Africa in 2019. South African National Biodiversity Institute, Kirstenbosch and DSI-NRF Centre of Excellence for Invasion Biology, Stellenbosch.		

BAC14 Primary (introduction) pathways		
Release	NA	Confidence:
Escape	Aquaculture	Confidence: Medium
Contaminant	NA	Confidence:
Stowaway	NA	Confidence:
Corridor	NA	Confidence:
Unaided	NA	Confidence:
Comments: Import permit records that indicate that *C. cainii* has been introduced for aquaculture in South Africa (de Moor 2002; Nunes et al. 2017; Zengeya and Wilson 2019).		
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. Zengeya TA, Wilson JR. (eds.) 2020. The status of biological invasions and their management in South Africa in 2019. South African National Biodiversity Institute, Kirstenbosch and DSI-NRF Centre of Excellence for Invasion Biology, Stellenbosch.		

2. Likelihood

LIK1 Likelihood of entry via unaided primary pathways	
Response: Probable	Confidence: High
Rationale: *Cherax cainii is* already present in the country (de Moor 2002; Nunes et al. 2017). However, if it were in neighbouring countries it would be difficult to stop natural dispersal (Nunes et al. 2017).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. https://www.cabi.org/isc/datasheet/89136	

LIK2 Likelihood of entry via human aided primary pathways	
Response: Probable	Confidence: High
Rationale: *Cherax cainii* has been introduced primarily for aquaculture purposes (de Moor 2002; Nunes et al. 2017).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past,	

present and potential future. *African Journal of Aquatic Science* 42: 309–323.

LIK3 Habitat suitability

Response: Fairly probable	Confidence: Medium

Rationale:

Cherax cainii occurs in deep perennial rivers and prefers sandy areas in rivers particularly where organic matter accumulates (Beatty et al. 2004). It requires structural diversity for shelter and refuge. Areas susceptible to *C. cainii* are cool permanent streams in the Highveld and in the southern and south-western Cape (de Moor 2002; Nunes et al. 2017).

References:

Beatty SJ, Morgan DL, Gill HS. 2004. Biology of a translocated population of the large freshwater crayfish, *Cherax cainii* Austin & Ryan, 2002 in a Western Australian River.*Crustaceana*77: 1329–1351.

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

LIK4 Climate suitability

Response: Fairly probable	Confidence: Medium

Rationale:

Cherax cainii has a thermal tolerance range of 8-29°C with an optimal range of 17-25°C (Bryant and Papas 2007). Growth ceases when temperature is <12.5 °C (Bryant and Papas 2007). The projected areas that are climatically suitable for *C. cainii* in South Africa are located mainly in the eastern part of the country and a few areas in the Western Cape (Nunes et al. 2017). The suitable areas were mainly restricted to upland areas of the Greater Berg, Kromme, Great Kei, Mzimvubu, uMngeni, Phongolo, Crocodile and Limpopo catchment areas (Nunes et al. 2017).

References:

Bryant D, Papas P. 2007. Marron *Cherax cainii* (Austin) in Victoria - a Literature review. Arthur Rylah Institute for Environmental Research. Technical Report Series 167.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

Zengeya TA. Risk assessment of *Cherax* sp in South Africa (Unpublished data).

LIK5 Unaided secondary (dispersal) pathways

Response: Unlikely	Confidence: Medium

Rationale:

There are no naturalised populations in South Africa or neighbouring countries that could act as sources for secondary dispersal (de Moor 2002; Nunes et al. 2017).

References:

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African Journal of Aquatic Science 27: 125–139.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

LIK6 Human aided secondary (dispersal) pathways

Response: Probable	Confidence: Medium

Rationale:

Cherax cainii is used for aquaculture and the potential for intentional release is high (de Moor 2002; Bryant and Papas 2007; Nunes et al. 2017).

References:

Bryant D, Papas P. 2007. Marron *Cherax cainii* (Austin) in Victoria – a literature review. Arthur Rylah Institute for Environmental Research Technical Report Series No. 167. (*Department of Sustainability and Environment: Heidelberg*).

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

3. Consequences

CON1 Environmental impact	
CON1a: Competition	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON1b: Predation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1c: Hybridisation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1d: Transmission of disease	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact	
References: L. Botha (Unpublished data).	
CON1e: Parasitism	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact	
References: L. Botha (Unpublished data).	
CON1f: Poisoning/toxicity	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1g: Bio-fouling or other direct physical disturbance	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1h: Grazing/herbivory/browsing	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON1i: Chemical, physical or structural impact on ecosystem	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1 Maximum environmental impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON2 Socio-economic impact	
CON2a: Safety	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data	
CON2b: Material and immaterial assets	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2c: Health	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2d: Social, spiritual and cultural relations	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2 Maximum socio-economic impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON3 Closely related species' environmental impact

CON3a: Competition	
Response: MR	Confidence: Medium
Rationale: *Procambarus clarkii* is very aggressive and usually out-competes native species for shelter and spawning sites, and these often leads to reproductive interference (Cruz et al. 2006; Lodge et al. 2012). For example, in areas were *P. clarkii* has been introduced , some amphibian species (e.g., *Bufo bufo*, *B. calamita*, *Rana* sp., *Taricha torosa* and *Triturus vulgaris*) have been excluded or displaced from their natural habitats, resulting in local extinctions through reproductive failure (Cruz et al. 2006; Lodge et al. 2012). In addition, as a result of direct competition, there has been a decrease in the distributional ranges and abundance of native crayfish populations (*Astacus astacus*, *Austropotamobius pallipes* and *A. torrentium*) in some areas in Europe and Japan (Cruz et al. 2006; Lodge et al. 2012). Furthermore, direct competition for food has caused dietary niche constriction and declines in populations of native crabs in some areas invaded by *P. clarkii* (Jackson et al. 2016).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338. Jackson MC, Grey J, Miller K, Britton, JR, Donohue I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology*, 85:1098–1107. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.	
CON3b: Predation	
Response: MR	Confidence: Medium
Rationale: In its invasive range, there is evidence that predation by *P. clarkii* can result in the local or population extinctions of at least one native species (Lodge et al. 2012; Souty-Grosset et al. 2016). For example, *P. clarkii* has been implicated in causing population declines of several species of fish and amphibians by reducing their breeding success through predation on eggs and larval amphibians (Cruz et al. 2006; Francesco et al. 2011). Indirect effects of predation can also cause trophic cascades that can lead to changes in ecosystem structure and function (Gherardi and Barbaresi 2008; Lodge et al. 2012). For example, predation on invertebrates can release algae from grazing pressure and lead to changes in the abundance and dominance of species in algal communities (Gherardi and Barbaresi 2008).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338. Ficetola GF, Siesa ME, Manenti R, Bottoni L, De Bernardi F, Padoa-Schioppa E. 2011. Early assessment of the impact of alien species: Differential consequences of an invasive crayfish on adult and larval amphibians. *Diversity and Distributions* 17:1141–1151. Gherardi F, Barbaresi S. 2008. Feeding opportunism of the red swamp crayfish *Procambarus clarkia*, an invasive species. *Freshwater crayfish* 16: 77–85. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON3c: Hybridisation	
Response: MC	Confidence: Low
Rationale:	

This is unlikely in South Africa because there are no native crayfish species (de Moor 2002; Nunes et al. 2017).

References:

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017b. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

CON3d: Transmission of disease

Response: MR	Confidence: High

Rationale:

Procambarus clarkii can harbour many pathogens, parasites, and diseases that can be transmitted to other congeneric species (Longshaw 2011; Lodge et al. 2012). There is evidence that transmission of diseases and parasites by *P. clarkii* to native species has caused local or population extinctions of at least one native species, leading to changes in community composition (Lodge et al. 2012). For example, *P. clarkii* is a vector of crayfish plague, a disease caused by the parasitic oomycete, *Aphanomyces astaci* (Aquiloni et al. 2011; Longshaw 2011; Souty-Grosset et al. 2016). In Europe, transmission of crayfish plague by *P. clarkii* to native crayfish species has been linked to a decline in populations of several native crayfish species of as *Astacus astacus*, *Austropotamobius pallipes* and *A. torrentium* (Holdich et al. 2009; Longshaw 2011). *Procambarus clarkii* can also harbour white spot syndrome disease – a viral infections of crustaceans, and fungal pathogens such as *Batrachochytrium dendrobatids* that causes chytridiomycosis – a lethal skin infection in amphibians (Longshaw 2011; McMahon et al. 2013).

References:

Aquiloni L, Martín MP, Gherardi F, Diéguez-Uribeondo J. 2011. The North American crayfish *Procambarus clarkii* is the carrier of the oomycete *Aphanomyces astaci* in Italy. *Biological Invasions* 13: 35–367.

Holdich, DM, Reynolds JD, Sibley P J. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. Knowledge and Management of Aquatic Ecosystems 11:394–395.

Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449 –472.

Longshaw M. 2011. Diseases of crayfish: A review. *Journal of Invertebrate Pathology* 106: 54–70.

McMahon TA, Brannelly LA, Chatfield MW, Johnson PT, Joseph MB, McKenzie VJ, Richards-Zawacki CL, Venesky MD, Rohr JR. 2013. Chytrid fungus *Batrachochytrium dendrobatidis* has non-amphibian hosts and releases chemicals that cause pathology in the absence of infection. *Proceedings of the National Academy of Sciences of the United States of America* 110: 210–215.

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON3e: Parasitism

Response: DD	Confidence: Low

Rationale:

No information is available to assess the level of impact.

References:

L. Botha (Unpublished data)

CON3f: Poisoning/toxicity

Response: MN	Confidence: Medium

Rationale:

See CON4c

References:

See CON4c	
CON3g: Bio-fouling or other direct physical disturbance	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON3h: Grazing/herbivory/browsing	
Response: MO	Confidence: Medium
Rationale: Grazing by *P. clarkii* can lead to habitat loss and modification through the removal of macrophytes. Habitat loss can lead to a decline in populations of species that utilise the macrophyte stands as a food source, nesting sites, and as refugia from predation (Rosenthal et al. 2005). *Procambarus clarkii* can also cause changes to community composition through trophic cascades (Gherardi and Aquistapace 2007; Souty-Grosset et al. 2016). For example, in Lake Chozas (northwest Spain), grazing by *P. clarkii* caused a reduction in macrophyte communities and this impact cascaded up the food chain with declines in invertebrates, amphibians, and waterfowl (Rodriguez et al 2003). Grazing can also cause changes to community composition and structure, such as changing ecosystems from macrophyte-dominated areas with clear water, to turbid phytoplankton-dominated areas (Matsizaki et al. 2009). Excessive grazing can also lead to accelerated rates of important processes such as litter breakdown and decomposition (Rosenthal et al. 2005; Gherardi and Aquistapace 2007).	
References: Gherardi F, Acquistapace P. 2007. Invasive crayfish in Europe: The impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. *Freshwater Biology* 52: 1249–59. Matsuzaki SS, Usio N, Takamura N, Washitani I. 2009. Contrasting impacts of invasive engineers on freshwater ecosystems: An experiment and meta-analysis. *Oecologia* 158: 673–686. Rodríguez CF, Bécares E, Fernández-Aláez M. 2003. Shift from clear to turbid phase in Lake Chozas (NW Spain) due to the introduction of American red swamp crayfish (*Procambarus clarkii*). *Hydrobiologia* 506: 421–26. Rosenthal SK, Lodge DM, Mavuti KM, Muohi W, Ochieng P, Mungai BN, Mkoji GM. 2005. Comparing macrophyte herbivory by introduced Louisiana crayfish (*Procambarus clarkii*) (Crustacea: Cambaridea) and native Dytiscid beetles (*Cybister tripunctatus*) (Coleoptera: Dytiscidae), in Kenya. *African Journal of Aquatic Science* 30: 157–62. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON3i: Chemical, physical or structural impact on ecosystem	
Response: MN	Confidence: Medium
Rationale: **Water quality**: *Procambarus clarkii* is often considered an ecosystem engineer due to its ability to change ecosystems through its burrowing activities (Souty-Grosset et al. 2016). For example, its burrowing activities can cause a decrease in the water quality through bioturbation leading to increased turbidity and influx release of nutrients from sediments, often leading to algal blooms (Angeler et al. 2001; Yamamoto 2010). The impaired water quality also affects the quality of the habitats for other aquatic fauna (Angeler et al. 2001; Rodriguez et al. 2003). For example, increased turbidity can impede foraging and respiratory processes of fish (Rodriguez et al. 2003). **Erosion**: Burrowing activities can cause structural damage to river banks and increase bank erosion, and also cause damage to water retention infrastructure such as dam walls and dykes (Souty-Grosset et al. 2016).	
References:	

Angeler DG, Sánchez-Carrillo S, García G, Alvarez-Cobelas M. 2001. The influence of *Procambarus clarkii* (Cambaridae, Decapoda) on water quality and sediment characteristics in a Spanish floodplain wetland. *Hydrobiologia* 464: 89–98.

Rodríguez CF, Bécares E, Fernández-Aláez M. 2003. Shift from clear to turbid phase in Lake Chozas (NW Spain) due to the introduction of American red swamp crayfish (*Procambarus clarkii*). *Hydrobiologia* 506: 421–26.

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

Yamamoto Y. 2010. Contribution of bioturbation by the red swamp crayfish *Procambarus clarkii* to the recruitment of bloom-forming cyanobacteria from sediment. *Journal of Limnology* 69: 102–111.

CON3k: Indirect impacts through interactions with other species

Response: DD	Confidence: Low

Rationale:
The information available is not sufficient to assess the level of impact.

References:
L. Botha (Unpublished data).

CON3 Closely related species' Maximum environmental impact (Figure S3)

Response: MR	Confidence: Medium

Rationale:
Direct predation and competition for food, shelter, and spawning sites have led to local extinctions and a decrease in the abundance of native amphibians and crayfish species (Cruz et al. 2006; Gherardi & Acquistapace 2007; Jackson et al. 2016). Impacts have been recorded in the Iberian Peninsula, Sweden, Italy (Gherardi and Acquistapace 2007), Japan, and U.S.A. (California) (Holdich et al. 2009; Lodge et al. 2012).

References:
Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338.

Gherardi F, Acquistapace P. 2007. Invasive crayfish in Europe: The impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. *Freshwater Biology* 52: 1249–59.

Holdich, DM, Reynolds JD, Sibley P J. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. Knowledge and Management of Aquatic Ecosystems 11:394–395.

Jackson MC, Grey J, Miller K, Britton,JR, Donohue, I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology*, 85:1098–1107.

Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449 –472.

CON4 Closely related species' socio-economic impact

CON4a: Safety

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data)

CON4b: Material and immaterial assets

Response: MO	Confidence: Low

Rationale: *Procambarus clarkii* often inhabits agricultural fields and their burrowing activities can cause damage to infrastructure such as irrigation canals and dam walls (Lodge et al. 2012; Arce and Diéguez-Uribeondo 2015). Burrowing activities can also alter soil hydrology leading to water loss. Grazing causes crop damage and reduces yield (Anastácio et al. 2005; Arce and Diéguez-Uribeondo 2015). In Europe for example, *P. clarkii* affects rice production through field water loss, damage to rice field banks and ditches, direct consumption of rice seed and plants, and clogging of pipes (Anastácio et al. 2005; Souty-Grosset et al. 2016).
References: Anastácio PM. Correia AM, Menino JP. 2005. Processes and patterns of plant destruction by crayfish: effects of crayfish size and developmental stages of rice. *Archiv für Hydrobiologie* 162: 37–51. Arce JA, Diéguez-Uribeondo J. 2015. Structural damage caused by the invasive crayfish *Procambarus clarkii* (Girard, 1852) in rice fields of the Iberian Peninsula: A study case. *Fundamental and Applied Limnology* 186: 259–269. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–472. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.
CON4c: Health

Response: MN	Confidence: Medium

Rationale: *Procambarus clarkii* can bio-accumulate toxins and metals from the environment (Gherardi et al. 2011; Alcorlo et al. 2016; Souty-Grosset et al. 2016). These pollutants are often harmful and can be transferred to higher food web levels through the consumption of affected crayfish by humans and predators such as otters, birds, and fish (Anda et al. 2001; Gherardi et al. 2011; Lodge et al. 2012). *Procambarus clarkii* serves as vector for several parasites and diseases some of which are zoonotic, for example the parasitic fluke flatworms (*Paragonimus* spp.) that causes lung fluke disease in humans, tularemia-causing bacterium *Francisella tularensis*, rat lungworm *Angiostrongylus cantonensis* that causes meningitis, and the nematode *Gnathostoma spinigerum* that causes human gnathostomiasis (Edgerton et al. 2002; Lane et al 2009; Souty-Grosset et al. 2016).
References: Alcorlo P, Otero M, Crehuet M, Baltanás A, Montes C. 2006. The use of the red swamp crayfish (*Procambarus clarkii* Girard) as indicator of the bioavailability of heavy metals in environmental monitoring in the River Guadiamar (SW Spain). *Science of the Total Environment* 366:380–390. Anda P, Segura del Pozo J, Díaz García JM, Escudero R, et al. 2001. Waterborne outbreak of tularemia associated with crayfish fishing. *Emerging Infectious Diseases* 7:575–82. Edgerton BF, Evans LH, Stephens FJ, Overstreet RM. 2002. Synopsis of freshwater crayfish diseases and commensal organisms. *Aquaculture* 206: 57–135. Gherardi F, Barbaresi S, Vaselli O, Bencini A. 2002. A comparison of trace metal accumulation in indigenous and alien freshwater macro-decapods. *Marine and Freshwater Behaviour and Physiology* 35:179–88. Lane MA, Barsanti MC, Santos CA, Yeung M, Lubner SJ, Weil GJ. 2009. Human paragonimiasis in North America following ingestion of raw crayfish. *Clinical and Infectious Diseases* 49: 55–61. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449-472.
CON4d: Social, spiritual and cultural relations

Response: MO	Confidence: Medium
Rationale: *Procambarus clarkii* affects the fishing industry by damaging gill nets and spoiling the fish caught in the nets (Gherardi et al. 2011).	
References: Gherardi F, Robert FJ, Kenneth BB, Mavuti M, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological Conservation* 144: 2585–2596.	
CON4 Closely related species' Maximum socio-economic impact (Figure S3)	
Response: MO	Confidence: Medium
Rationale: In its invaded range *P.clarkii* had caused harmful impacts in agricultural fields (Anastácio et al. 2005) and has disrupted some recreational activities leading to economic loss (Gherardi et al. 2011; Souty-Grosset et al. 2016).	
References: Anastácio PM. Correia AM, Menino JP. 2005. Processes and patterns of plant destruction by crayfish: effects of crayfish size and developmental stages of rice. *Archiv für Hydrobiologie* 162: 37-51. Gherardi F, Barbaresi S, Vaselli O, Bencini A. 2002. A comparison of trace metal accumulation in indigenous and alien freshwater macro-decapods. *Marine and Freshwater Behaviour and Physiology* 35:179–88. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78-93.	

CON5 Potential impact	
Response: MO	Confidence: Low
Rationale: In South Africa, there are no freshwater crayfish species but other closely related decapods such as crabs are likely to have broad habitat and trophic overlaps (de Moor 2002; Jackson et al. 2016). The outcome of such resource overlap between *C. cainii* and indigenous fauna is unknown, but given that *P. clarkii* has caused adverse impacts in other areas of introduction there is a cause of concern for possible impacts of *C. cainii* in South African river systems (de Moor 2002; Lodge et al. 2012). *Cherax cainii* is a functional omnivore and may have an impact on macroinvertebrates and macrophytes communities (de Moor 2002). Another major concern is the transmission of diseases to native decapods and other freshwater fauna (Tavakol et al. 2016). Known populations of *C. cainii* in South Africa are restricted to aquaculture facilities and there are no known naturalised populations in the wild. In the event that it manages to escape from such facilities, it's very unlikely that it will spread rapidly due to its low tolerance to a wide range of environmental conditions (Byrant and Pappas; Nunes et al. 2017).	
References: Bryant D, Papas P. 2007. Marron *Cherax cainii* (Austin) in Victoria – a literature review. Arthur Rylah Institute for Environmental Research Technical Report Series No. 167. (*Department of Sustainability and Environment: Heidelberg*). de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Jackson MC, Grey J, Miller K, Britton JR, Donohue I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology*, 85:1098–1107. Lodge DM, Deines A, Gherardi, F, Yeo, DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology Evolution Systematics* 43: 449–472. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past,	

present and potential future. *African Journal of Aquatic Science* 42: 309–323. Tavakol S, Luus-Powell WJ, Smit WJ, Baker C, Hoffman A, AlHalajian A. 2016. First introduction of two Australian Temnocephalan species into Africa with an alien host: Double Trouble. *Journal of Parasitology* 102: 653–658.

4. Management

MAN1 What is the feasibility to stop future immigration?	
Response: High	Confidence: Medium
Rationale: *Cherax cainii* is mainly used for aquaculture and there are no known populations in neighbouring countries (de Moor 2002; Nunes et al. 2017). However, if it were in neighbouring countries it would be difficult to stop natural dispersal (Nunes et al. 2017).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

MAN2 Benefits of the Taxon	
MAN2a Socio-economic benefits of the *Taxon*	
Response: Medium	Confidence: Low
Rationale: Production of crayfish in South Africa has had mixed success because of several challenges that have been encountered in trying to farm the species (Nunes et al. 2017). As a result, marron aquaculture has been mainly restricted to a few small scale aquaculture farms in Eastern Cape and Western Cape (Madzivanzira et al. 2020).	
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey, GJ, Weyl, OLF. 2017. Freshwater crayfish invasions In South Africa: past, present and potential future, *African Journal of Aquatic Science* 42: 309–323.	
MAN2b Environmental benefits of the *Taxon*	
Response: None	Confidence: Low
Rationale: No documented information available.	
References: L. Botha (Unpublished data).	

MAN3 Ease of management	
MAN3a How accessible are populations?	
Response: 0	Confidence: Low
Rationale: There are records of permit applications at CapeNature to import marron for aquaculture (Nunes et al. 2017). A follow up study needs to be undertaken to check if farms are still in production and to ascertain the identity of the species utilised (de Moor 2002; Burgess 2007; Nunes et al. 2017). There is uncertainty on the species utilised (see taxonomy notes)	
References: Burgess M. 2007. Pioneers of SA marron production. Farmer's Weekly Magazine. Mon30April2007 http://www.farmersweekly.co.za/article.aspx?id=520&h=Pioneers-of-SA-marron-production de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic*	

Science 27: 125-139.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

MAN3b Is detectability critically time-dependent?	
Response: 0	Confidence: Low

Rationale:

Cherax cainii can be detected throughout the year, although species seem to be more active at night (Bryrant and Papas 2007).

References:

Bryant D, Papas P. 2007. Marron *Cherax cainii* (Austin) in Victoria – a literature review. Arthur Rylah Institute for Environmental Research Technical Report Series No. 167. (Department of Sustainability and Environment: Heidelberg.

MAN3c Time to reproduction	
Response: 1	Confidence: Low

Rationale:

Cherax cainii reaches sexual maturity when two to three years (Beatty et al. 2004).

References:

Beatty SJ, Morgan DL, Gill HS. 2004. Biology of a translocated population of the large freshwater crayfish, *Cherax cainii* Austin & Ryan, 2002 in a Western Australian River. *Crustaceana* 77: 1329–1351.

MAN3d Propagule persistence	
Response: NA	Confidence: NA

Rationale:

Cherax cainii is an invertebrate.

References:

MAN3 Ease of management (SUM from Table S4)	
Response: Easy	Confidence: Low

Rationale:

There are no known wild populations in the country. It is assumed that *C. cainii* individuals are confined to aquaculture facilities in Eastern and Western Cape (de Moor 2002; Nunes et al. 2017; Madzivanzira et al. 2020). In addition, some provinces e.g. Western Cape has management plans in place to prevent escape and introduction into the wild (Nunes et al. 2017).

References:

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

MAN4 Has the feasibility of eradication been evaluated?	
Response: No	Confidence: Low

Rationale:

Currently there are no known wild populations in the country (de Moor 2002; Nunes et al. 2017). It is assumed that species are confined to aquaculture facilities, thus eradication feasibility could be evaluated if necessary (Nunes et al. 2017; Madzivanzira et al. 2020).

References:

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

MAN5 Control options and monitoring approaches available for the *Taxon*
Response: Yes
References: *Cherax cainii* is susceptible to use of biocides e.g. in New Zealand biocides have been used to control and eradicate marron crayfish (Gould 2005).

MAN6 Any other management considerations to highlight? (if yes, fill in Appendix MAN6)	
Response	No

5. Calculations

Likelihood = Fairly probable

Parameter	Likelihood	Stages	Final assessment
LIK1	1	P(entry) = 1	P (invasion) = 0.5
LIK2	1		
LIK3	0.5	P(establishment) = 0.5	
LIK4	0.5		
LIK5	0.027	P (spread) = 1	
LIK6	1		

Consequence = MR

Parameter	Mechanism/sector	Response
CON1	**Maximum environmental impact**	**DD**
CON2	**Maximum socio-economic impact**	**DD**
CON3a	Competition	MR
CON3b	Predation	MC
CON3c	Hybridisation	MR
CON3d	Disease transmission	DD
CON3e	Parasitism	MN
CON3f	Poisoning/toxicity	DD
CON3g	Bio-fouling or other direct physical disturbance	MO
CON3h	Grazing/herbivory/browsing	MN
CON3i	Chemical, physical, structural impact	DD
CON3k	Indirect impacts through interactions with other species	**MR**
CON3	**Maximum environmental impact (closely related taxa)**	**MR**
CON4a	Safety	DD
CON4b	Material and immaterial assets	MO
CON4c	Health	MN
CON4d	Social, spiritual and cultural relations	MO
CON4	**Maximum socio-economic impact (closely related taxa)**	**MO**
CON5	Potential impact based on traits, experiments, or models	**MO**

Table S3: Risk score = High

		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	Low	Low	Low	Medium	Medium
	Very unlikely	Low	Low	Low	Medium	High

Unlikely	Low	Low	Medium	High	High
Fairly probable	Medium	Medium	High	High	High
Probable	Medium	High	High	High	High

Table S4: Ease of management= Easy

Parameter	**Question**	**Response**
MAN3a	How accessible are populations?	0
MAN3b	Is detectability critically time-dependent?	0
MAN3c	Time to reproduction	1
MAN3d	Propagule persistence	NA
MAN3	**SUM**	1

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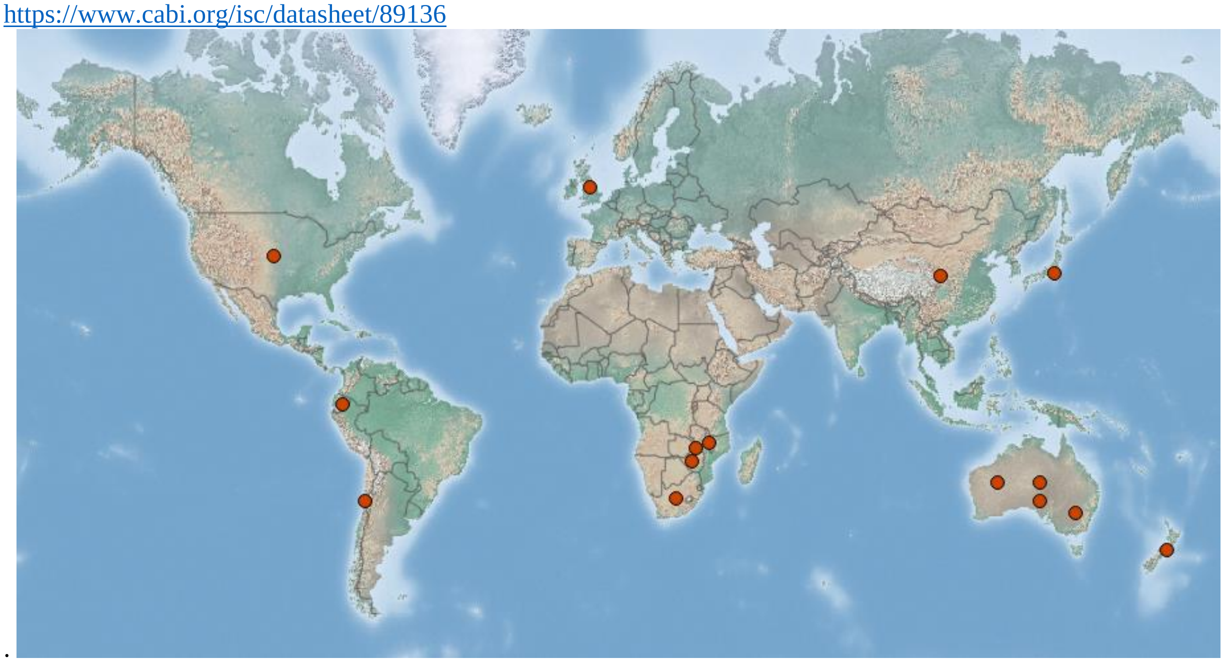
Appendix BAC8(a): Global alien range of *Cherax cainii. Sourced from CABI (2019)* https://www.cabi.org/isc/datasheet/89136



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Appendix 3.2 Risk analysis report for Yabby (*Cherax destructor*).

Risk Analysis Report

Taxon: *Cherax destructor*	***Area:*** South Africa
Compiled by: Lee-Anne Botha	**Approved by:**
Picture of *Taxon*  **Soutced from CABI:** https://www.cabi.org/isc/datasheet/89134	**Alien distribution map**  Sourced from CABI (2019): https://www.cabi.org/isc/datasheet/89134
Risk Assessment summary: *Cherax destructor* was introduced into South Africa to test its potential for aquaculture although this was not pursued further. Globally, it is a very important aquaculture species and popular in the aquarium pet trade industry. *Cherax destructor* has a high tolerance to environmental conditions and can occupy a variety of habitats. Large parts of the country are climatically suitable for this species which will increase its potential to establish populations if individuals are released into the wild. Like other crayfish species, *C. destructor* is mobile and dispersal is not limited to connected waterways. There is a lack of documented evidence of environmental and socio-economic impacts caused by *C. destructor* in its alien range. *Procambaus clarkii* (red swamp crayfish) a closely related species that has documented evidence of impacts in areas of introduction was used to infer the potential impacts of *C.destructor*. Both species are functional omnivores and have the potential to cause multiple impacts at different trophic levels of the food web. *Procambarus clarkii* has been implicated in causing major impacts on native communities through competition and predation leading to decreased abundance and local extirpation of native species. It is also known to cause habitat loss and modification through intensive grazing and stalk cutting of aquatic macrophytes that provide food, refuge and spawning sites (i.e., reproductive interference) for fish and other aquatic fauna. It is therefore, likely that *C. destructor* will cause similar impacts in areas of introduction.**.**	**Risk score:** High
Management options summary: *Cherax destructor* was introduced into the country as a possible candidate species for aquaculture but there are no records that it is currently utilized in the sector. In addition, there are anecdotal records of *C. destructor* been introduced by fishermen into several South African dams. However, these records, still need to be confirmed. Research efforts should be directed at confirming presence and then appropriate management interventions can be implemented depending on the invasion status of the species..	**Ease of management:** NA

Recommendations: *Cherax destructor* is currently listed as Category 1a under the NEMBA A&IS Regulations. However, there are no records of extant populations in the country. The results from the Risk Analysis propose that *C. destructor* should be removed from the list. Measures should be employed to prevent species from entering the area especially though pet trade and recreational fishers that may use this species as live bait.	**Listing under NEM:BA A&IS lists of 2014 as amended 2020:** Category 1a **Recommended listing category:** Remove from list

1. Background

BAC1 Name of assessor(s)		
Name of lead assessor	**Lee-Anne Botha**	
Additional assessor (1)		
Additional assessor (2)		
BAC2 Contact details of assessor (s)		
Lead assessor	Organisational affiliation: University of Pretoria, Department of Zoology and Entomology/ SANBI	
	email: u18389164@tuks.co.za	
	Phone: 072 833 7952	
Additional assessor (1)	Organisational affiliation:	
	email:	
	Phone:	
Additional assessor (2)	Organisational affiliation:	
	email:	
	Phone:	
BAC3 Name(s) and contact details of expert(s) consulted		
Expert (1)	Name: Dr Tsungai Zengeya	
	email: T.Zengeya@sanbi.org.za	
	Phone: 021 799 8408	
Expert (2)	Name:	
	email:	
	Phone:	
Comments: Dr Tsungai Zengeya works for the South African National Biodiversity Institute (SANBI). His research interests are in freshwater ecology and biological invasions. He provided comments and inputs throughout the compilation of this risk analysis that improved its quality.		
BAC4 Scientific name of *Taxon* under assessment		
Taxon name: *Cherax destructor*		Authority: Clarke, 1939

Comments:

The taxonomic status of *C. destructor* Clark 1936 has been subject to a number of revisions (Riek 1951, 1956, 1969; Austin 1986, 1996; Sokol 1988; Campbell et al. 1994; Austin et al. 2003; Munasinghe et al. 2004). These have largely tried to resolve the status of four species that are commonly referred to as the '*C. destructor'* species complex. Originally described four distinct species: *C. destructor, C. albidus, C. davisi* and *C. rotundus,* after which Riek (1969) grouped *C. destructor*, *C. albidus*, *C. davisi* and another separate species *C. esculus* (Reik 1956) together as a '*C. destructor'* species complex. A subsequent taxonomic revision of the '*C. destructor'* complex found no evidence for the recognition of *C. esculus* and *C. davisi* but confirmed *C. albidus* and *C. destructor* as distinct species (Sokol 1988). Further taxonomic revisions by Austin (1986, 1996) and Campbell et al. (1994) agreed in part with Sokol (1988) and did not recognise *C. esculus* and *C. davisi* but they classified C. *albidus* and *C. destructor* as sub-species instead of distinct species because of minimal morphological and allozyme variation.

However, in another taxonomic revision Austin et al. (2003) proposed that *C. albudus* and C. *destructor* are synonyms and should be regarded as one species, namely *C. destructor*. In addition, Austin 1996 suggested that the taxon *C. r. setosus* originally described as a subspecies of *C. rotundus* Clark (1941) by Riek (1951) but later synonymised with *C. rotundus* (Riek 1969) should be considered a subspecies of *C. destructor*, thereby expanding the '*C. destructor'* complex to four sub species. However, Austin et al. (2003) found that *C. setosus* was a valid species that was genetically different from both *C. destructor* and *C. rotundus*. Therefore the current consensus is that there is one species of *C. destructor*, that can be further divided into two subspecies *C. d. albidus* and *C. d. destructor* based on morphological and allozyme variation, while *C. rotundus* and *C. setosus* are separate and distinct species (Austin et al. 2003; Munasinghe et al. 2004).

References:

Austin CM, Nguyen TTT, Meewan MM, Jerry DR. 2003. The taxonomy and phylogeny of the '*Cherax destructor*' complex (Decapoda: Parastacidae) examined using mitochondrial 16S sequences. *Australian Journal of Zoology* 51: 99–110.

Campbell NJH, Geddes MC, Adams M. 1994. Genetic variation in yabbies', *Cherax destructor* and *C. albidus* (Crustacea: Decapoda: Parastacidae), indicates the presence of a single, highly sub-structured species. *Australian Journal of Zoology* 42: 1–16.

Clark E. 1936. The freshwater crayfishes of Australia. *Memoirs of the National Museum of Victoria* 10: 5–58.

Munasinghe DHN, Burridge CP, Austin CM. 2004. Molecular phylogeny and zoogeography of the freshwater crayfish genus *Cherax* Erichson (Decapoda: Parastacidae) in Australia. *Biological Journal of the Linnean Society* 81: 553–563.

Riek EF. 1951. The freshwater crayfish (Family: Parastacidae) of Queensland. With an appendix describing other Australian species. *Records of the Australian Museum* 22: 368–388.

Riek EF. 1956. Addition to the Australian freshwater crayfish. *Records of the Australian Museum* 24: 1–6.

Riek EF. 1967. The freshwater crayfish of Western Australia (Decapoda: Parastacidae). *Australian Journal of Zoology* 14: 103–121.

Riek EF. 1969. The Australian freshwater crayfish (Crustacea: Decapoda: Parastacidae), with the description of new species. *Australian Journal of Zoology* 17: 855-918.

Sokol A. 1988. Morphological variation in relation to the taxonomy of the destructor group of the genus *Cherax*. *Invertebrate Taxonomy* 2: 55–79.

BAC5 Synonym(s) considered

Synonyms:

Comments:

References:

BAC6 Common name(s) considered

Common names: Yabby

Comments:

References:

Beatty S, Morgan D, Gill H. 2005. Role of life history strategy in the colonisation of Western Australian aquatic systems by the introduced crayfish *Cherax destructor* Clark, 1936. *Hydrobiologia* 549: 219–237

BAC7 What is the native range of the *Taxon*? (add map in Appendix BAC7)

Response: Southeast and central Australia	Confidence: High

Comments:
In Australia, *Cherax destructor* has been translocated into New South Wales, Western Australia and Tasmania where it has established wild populations (Beatty et al 2005; Lynas et al 2007).

References:

Beatty S, Morgan D, Gill H. 2005. Role of life history strategy in the colonisation of Western Australian aquatic systems by the introduced crayfish Cherax destructor Clark, 1936. *Hydrobiologia* 549: 219–237.

Lynas J, Storey AW, Knott B. 2007. Aggressive interactions between three species of freshwater crayfish of the genus Cherax (Decapoda: Parastacidae). *Marine and Freshwater Behaviour and Physiology* 40: 105–116.

BAC8 What is the global alien range of the *Taxon*? (add map in Appendix BAC8)

Response: China, Italy, South Africa, Spain and Zambia.	Confidence: Medium

Comments:
Naturalised populations are only known from Spain and Italy (Scalici et al. 2009).

References:

Scalici M, Chiesa S, Gherardi F, Ruffini M, Gibertini G, Marzano FN. 2009. The new threat to Italian inland waters from the alien crayfish "gang": the Australian *Cherax destructor* Clark, 1936. *Hydrobiologia* 632:341–345.

http://www.iucnredlist.org/details/153877/0

BAC9 Geographic scope = the *Area* under consideration

Area of assessment: South Africa

Comments:

BAC10 Is the *Taxon* present in the *Area*?

Response: No	Confidence: Low

Comments:
Cherax destructor has been imported into the country before and there is the possibility that escapees and undocumented introductions into the wild might have established populations (de Moor 2002; Nunes et al. 2017).

References:

De Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

BAC11 Availability of physical specimen

Response: NA	Confidence in ID:

Herbarium or museum accession number:

References:

BAC12 Is the *Taxon* native to the *Area* or part of the *Area*?

The *Taxon* is native to (part of) the *Area*.	No	Confidence: High
The *Taxon* is alien in (part of) the *Area*.	Yes	Confidence: High

Comments:
There are only records for the introduction of four freshwater crayfish into South Africa that include: *Cherax destructor*, *C. cainii/tenuimanus*, *C. quadricarinatus* and *Procrambarus clarkia* (de Moor 2002; Nunes et al. 2017).

References: De Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

BAC13 What is the *Taxon*'s introduction status in the *Area*?		
The *Taxon* is in cultivation/containment.	Unknown	Confidence: Low
The *Taxon* is present outside of cultivation/containment.	Unknown	Confidence: Low
The *Taxon* has established/naturalised.	No	Confidence: Low
The *Taxon* is invasive.	No	Confidence: Low
Comments: "There are anecdotal records of *Cherax destructor* introductions by fishermen into several South African dams. However, these records, gathered by fishing and aquarium enthusiasts, should be interpreted with caution, as there are no confirmed past or present records of *C. destructor* in the wild in South Africa. *Cherax destructor* was introduced, but there are no evidence that indicates that the species succeeded to establish populations" (Nunes et al. 2017).		
References: De Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African Journal of Aquatic Science 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.		

BAC14 Primary (introduction) pathways		
Release		Confidence:
Escape	Aquarium /Pet trade Aquaculture Live food and bait	Confidence: High
Contaminant		Confidence:
Stowaway		Confidence:
Corridor		Confidence:
Unaided		Confidence:
Comments:		
References: Chucholl C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141. Nguyen TTT. 2005. A genetic investigation on translocation of Australian commercial freshwater crayfish, *Cherax destructor*. *Aquatic Living Resources*18: 319–323. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.		

2. Likelihood

LIK1 Likelihood of entry via unaided primary pathways	
Response: Very unlikely	Confidence: Low
Rationale: There are no known populations in neighbouring countries that could act as source of introduction (Madzivanzira et al. 2020). *Cherax destructor* was introduced in Zambia, although wild populations are only known from Spain and Italy (Scalici et al 2009).	
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish	

introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1-21.
Scalici M, Chiesa S, Gherardi F, Ruffini M, Gibertini G, Marzano FN. 2009. The new threat to Italian inland waters from the alien crayfish "gang": the Australian *Cherax destructor* Clark, 1936. *Hydrobiologia* 632:341–345.

LIK2 Likelihood of entry via human aided primary pathways	
Response: Fairly probable	Confidence: Low
Rationale: Primary pathways of introduction are escapees from aquaculture facilities, pet trade and sometimes crayfish that are used as bait for fish (Nguyen 2005; Chucholl 2013; Faulkes 2015).	
References: Chucholl C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141. Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Nguyen TTT. 2005. A genetic investigation on translocation of Australian commercial freshwater crayfish, *Cherax destructor*. *Aquatic Living Resources* 18: 319–323	

LIK3 Habitat suitability	
Response: Probable	Confidence: High
Rationale: *Cherax destructor* occurs in a wide variety of habitats, they have a high tolerance to salinity (15000ppm). Tolerant to conditions of low oxygen (1ppm) and low water quality in residual pools during the dry season (Beatty 2005). They occur in a wide range of habitats that include desert mound springs, alpine streams, subtropical creaks, rivers, ephemeral lakes, swamps, farms dams and irrigation canals In extreme cases they are able to migrate over land among ponds (de Moor 2002). *Cherax destructor* is a burrowing species that can excavate shafts that are 0.2-5 m deep, which are often, used as 'refugia' from desiccation in the dry season (Withnall 2000; Beaty et al. 2005).	
References: Beatty S. 2005. Translocations of freshwater crayfish: contributions from life histories, trophic relations and diseases of three species in Western Australia (Doctoral dissertation, Murdoch University). de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Withnall F. 2000. Biology of yabbies (*Cherax destructor*). Aquaculture notes of the department of Natural Resources and Environment. State of Victoria, Australia.	

LIK4 Climate suitability	
Response: Probable	Confidence: High
Rationale: *Cherax destructor* has a wide thermal tolerance range (1-35°C), with an optimal range of 22-28°C and growth ceases at <15 °C and >34°C (Zengeya unpublished data). Ecoregions that were projected to be climatically suitable for *Cherax destructor* in South Africa include the Soutpansberg, North Eastern Highlands, Eastern Bankenveld, Northern Escarpment Mountains, the northern half of the North Eastern Uplands, South Eastern Uplands and sections of the Southern Fold Mountains and Southern Coastal Belt (Nunes et al. 2017).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. Zengeya TA. Risk assessment of Cherax sp in South Africa (Unpublished data).	

LIK5 Unaided secondary (dispersal) pathways	
Response: Very unlikely	Confidence: High
Rationale:	

Currently this is very unlikely because there are no wild populations present in neighbouring countries that could disperse naturally through connected waterways (Madzivanzira et al. 2020). However, like other crayfish species, *Cherax destructor* is highly mobile and can migrate overland.
References: Beatty S. 2005. Translocations of freshwater crayfish: contributions from life histories, trophic relations and diseases of three species in Western Australia (Doctoral dissertation, Murdoch University). Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Withnall F. 2000. Biology of yabbies (*Cherax destructor*). Aquaculture notes of the department of Natural Resources and Environment. State of Victoria, Australia

LIK6 Human aided secondary (dispersal) pathways	
Response: Fairly probable	Confidence: Low
Rationale: Humans that have *Cherax destructor* as pets can intentionally release them into the wild (Chucholl 2013; Nunes et al 2017). It might already be in pet trade industry Chucholl 2013; Faulkes 2015).	
References: Chucholl C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141. Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92 Nguyen TTT. 2005. A genetic investigation on translocation of Australian commercial freshwater crayfish, *Cherax destructor. Aquatic Living Resources* 18: 319–323. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

3. Consequences

CON1 Environmental impact	
CON1a: Competition	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON1b: Predation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1c: Hybridisation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1d: Transmission of disease	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1e: Parasitism	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1f: Poisoning/toxicity	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1g: Bio-fouling or other direct physical disturbance	

Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1h: Grazing/herbivory/browsing	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1i: Chemical, physical or structural impact on ecosystem	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1 Maximum environmental impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact	
References: L. Botha (Unpublished data).	
CON2 Socio-economic impact	
CON2a: Safety	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data	
CON2b: Material and immaterial assets	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2c: Health	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2d: Social, spiritual and cultural relations	
Response: DD	Confidence: Low
Rationale:	
References: L. Botha (Unpublished data)	
CON2 Maximum socio-economic impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON3 Closely related species' Environmental impact	
CON3a: Competition	
Response: MR	Confidence: High
Rationale: *Procambarus clarkii* is very aggressive and usually out-competes native species for shelter and spawning sites, and these often lead to reproductive interference. In areas of introduction, some amphibian species (e.g., *Bufo bufo*, *B. calamita*, *Rana* sp., *Taricha torosa* and *Triturus vulgaris*) have been excluded or displaced from their natural habitats, resulting in local extinctions through either larval predation or amphibians spawning in areas that do not offer sufficient protection to avoid interaction with *P.clarkii*, resulting in low recruitment (Cruz et al. 2006, Lodge et al. 2012). In addition, as a result of direct competition, there has been	

a decrease in the distributional ranges and abundance of native crayfish populations (*Astacus astacus*, *Austropotamobius pallipes* and *A. torrentium*) in some areas in Europe and Japan (Cruz et al. 2006, Lodge et al. 2012). Furthermore, direct competition for food has caused dietary niche constriction and declines in populations of native crabs in some areas invaded by *P. clarkia* (Jackson et al. 2016).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338. Jackson MC, Grey J, Miller K, Britton, JR, Donohue, I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology* 85:1098–1107. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449-72. https://www.cabi.org/isc/datasheet/67878	
CON3b: Predation	
Response: MR	Confidence: High
Rationale: In its invasive range, there is evidence that predation by *P. clarkii* can result in the local or population extinctions of at least one native species (Lodge et al. 2012, Souty-grosset et al. 2016). For example, *P. clarkii* has been implicated in causing population declines of several species of fish and amphibians by reducing their breeding success through predation on eggs and larval amphibians (Cruz et al. 2006, Francesco et al. 2011). Indirect effects of predation can also cause trophic cascades that can lead to changes in ecosystem structure and function. For example, predation on invertebrates can release algae from grazing pressure and lead to changes in the abundance and dominance of species in algal communities (Gherardi and Barbaresi 2008).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338. Ficetola GF, Siesa ME, Manenti R, Bottoni L, De Bernardi F, Padoa-Schioppa E. 2011. Early assessment of the impact of alien species: Differential consequences of an invasive crayfish on adult and larval amphibians. *Diversity and Distributions* 17:1141–1151. Gherardi F, Barbaresi S. 2008. Feeding opportunism of the red swamp crayfish Procambarus clarkia, an invasive species. *Freshwater crayfish* 16: 77–85. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON3c: Hybridisation	
Response: MC	Confidence: Medium
Rationale: This is unlikely in South Africa because there are no native crayfish species (de Moor 2002, Nunes et al. 2017b).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	
CON3d: Transmission of disease	
Response: MR	Confidence: Medium
Rationale:	

Procambarus clarkii can harbour many pathogens, parasites, and diseases that can be transmitted to other congeneric species (Longshaw 2011, Lodge et al. 2012). There is evidence that transmission of diseases and parasites by *P. clarkii* to native species has caused local or population extinctions of at least one native species, leading to changes in community composition (Lodge et al. 2012). For example, *P. clarkii* is a vector of crayfish plague, a disease caused by the parasitic oomycete, *Aphanomyces astaci* (Longshaw 2011, Souty-grosset et al. 2016). In Europe, transmission of crayfish plague by *P. clarkii* to native crayfish species has been linked to a decline in populations of several native species of crayfish such as *Astacus astacus*, *Austropotamobius pallipes* and *A. torrentium* (Holdich et al. 2009, Longshaw 2011). *Procambarus clarkii* can also harbour white spot syndrome disease – a viral infections of crustaceans, and fungal pathogens such as *Batrachochytrium dendrobatids* that causes chytridiomycosis – a lethal skin infection in amphibians (Longshaw 2011, McMahon et al. 2013).

References:

Aquiloni L, Martín MP, Gherardi F, Diéguez-Uribeondo J. 2011. The North American crayfish *Procambarus clarkii* is the carrier of the oomycete *Aphanomyces astaci* in Italy. *Biological Invasions* 13: 359-367.

Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.

Longshaw M. 2011. Diseases of crayfish: A review. *Journal of Invertebrate Pathology* 106: 54–70.

McMahon TA, Brannelly LA, Chatfield MW, Johnson PT, Joseph MB, McKenzie VJ, Richards-Zawacki CL, Venesky MD, Rohr JR. 2013. Chytrid fungus *Batrachochytrium dendrobatidis* has non-amphibian hosts and releases chemicals that cause pathology in the absence of infection. *Proceedings of the National Academy of Sciences of the United States of America* 110: 210–215.

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON3e: Parasitism

Response: DD	Confidence: Low

Rationale:

No information is available to assess the level of impact.

References:

L. Botha (unpublished data).

CON3f: Poisoning/toxicity

Response: MN	Confidence: Low

Rationale:

See **CON4c**

References:

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

Gherardi F, Britton JR, Mavuti KM, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological* Conservation 144: 2585–2596.

Putra MD, Bláha M, Wardiatno Y, Krisanti M, Bystřický PK, Kouba A, Kalous L, Petrusek A, Patoka J. 2017. *Procambarus clarkii* (Girard, 1852) and crayfish plague as new threats for biodiversity in Indonesia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 28: 1434–1440.

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78-93.

CON3g: Bio-fouling or other direct physical disturbance

Response: DD	Confidence: Low

Rationale:

No information is available to assess the level of impact.

References:

L. Botha (Unpublished data).

CON3h: Grazing/herbivory/browsing

Response: MO	Confidence: Medium

Rationale:

Grazing by *P. clarkii* can lead to habitat loss and modification through the removal of macrophytes. Habitat loss can lead to a decline in populations of species that utilise the macrophyte stands as a food source, nesting sites, and as refugia from predation (Rosenthal et al 2005). *Procambarus clarkii* can also cause changes to community composition through trophic cascades (Gherardi and Aquistapace 2007, Souty-grosset et al. 2016). For example, in Lake Chozas (northwest Spain), grazing by *P. clarkii* caused a reduction in macrophyte communities and this impact cascaded up the food chain with declines in invertebrates, amphibians, and waterfowl (Rodriguez et al 2003). Grazing can also cause changes to community composition and structure, such as changing ecosystems from macrophyte-dominated areas with clear water, to turbid phytoplankton-dominated areas (Matsizaki et al. 2009). Excessive grazing can also lead to accelerated rates of important processes such as litter breakdown and decomposition.

References:

Gherardi F, Acquistapace P. 2007. Invasive crayfish in Europe: The impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. *Freshwater Biology* 52: 1249–59.

Matsuzaki SS, Usio N, Takamura N, Washitani I. 2009. Contrasting impacts of invasive engineers on freshwater ecosystems: An experiment and meta-analysis. *Oecologia* 158: 673–686.

Rodríguez CF, Bécares E, Fernández-Aláez M. 2003. Shift from clear to turbid phase in Lake Chozas (NW Spain) due to the introduction of American red swamp crayfish (*Procambarus clarkii*). *Hydrobiologia* 506: 421–26.

Rosenthal SK, Lodge DM, Mavuti KM, Muohi W, Ochieng P, Mungai BN, Mkoji GM. 2005. Comparing macrophyte herbivory by introduced Louisiana crayfish (*Procambarus clarkii*) (Crustacea: Cambaridea) and native Dytiscid beetles (*Cybister tripunctatus*) (Coleoptera: Dytiscidae), in Kenya. *African Journal of Aquatic Science* 30: 157–62.

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON3i: Chemical, physical or structural impact on ecosystem

Response: MN	Confidence: Medium

Rationale:

Water quality: *Procambarus clarkii* is often considered an ecosystem engineer due to its ability to change ecosystems through its burrowing activities (Souty-grosset et al. 2016). For example, its burrowing activities can cause a decrease in the water quality through bioturbation leading to increased turbidity and influx release of nutrients from sediments, often leading to algal blooms (Angeler et al. 2001, Yamamoto 2010). The impaired water quality also affects the quality of the habitats for other aquatic fauna (Angeler et al. 2001, Rodriguez et al. 2003). For example, increased turbidity can impede foraging and respiratory processes of fish (Rodriguez et al. 2003).

Erosion: Burrowing activities can cause structural damage to river banks and increase bank erosion, and also cause damage to water retention infrastructure such as dam walls and dykes (Souty-grosset et al. 2016).

References:

Angeler DG, Sánchez-Carrillo S, García G, Alvarez-Cobelas M. 2001. The influence of *Procambarus clarkii* (Cambaridae, Decapoda) on water quality and sediment characteristics in a Spanish floodplain wetland. *Hydrobiologia* 464: 89–98.

Rodríguez CF, Bécares E, Fernández-Aláez M. 2003. Shift from clear to turbid phase in Lake Chozas (NW Spain) due to the introduction of American red swamp crayfish (*Procambarus clarkii*). *Hydrobiologia* 506: 421–26.

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

Yamamoto Y. 2010. Contribution of bioturbation by the red swamp crayfish *Procambarus clarkii* to the recruitment of bloom-forming cyanobacteria from sediment. *Journal of Limnology* 69: 102– 111.

CON3k: Indirect impacts through interactions with other species

Response: DD	Confidence: Low
Rationale: The information available is not sufficient to assess the level of impact.	
References: L. Botha (unpublished data).	
CON3 Closely related species' Maximum environmental impact (Figure S3)	
Response: MR	Confidence: Medium
Rationale: Direct predation and competition for food, shelter, and spawning sites have led to local extinctions and a decrease in the abundance of native amphibians and crayfish species(Cruz et al. 2006, Gherardi & Acquistapace 2007). Impacts have been recorded in the Iberian Peninsula, Sweden, Italy (Gherardi and Acquistapace 2007), Japan, and U.S.A. (California) (Holdich et al. 2009, Lodge et al. 2012).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329-338. Gherardi F, Acquistapace P. 2007. Invasive crayfish in Europe: The impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. *Freshwater Biology* 52: 1249-59 Jackson MC, Grey J, Miller K, Britton, JR, Donohue, I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology* 85:1098–1107. Longshaw M. 2011. Diseases of crayfish: A review. *Journal of Invertebrate Pathology* 106: 54-70. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78-93.	

CON4 Closely related species' Socio-economic impact	
CON4a: Safety	
Response: DD	Confidence: Low
Rationale: The information available is not sufficient to assess the level of impact.	
References: L. Botha (unpublished data).	
CON4b: Material and immaterial assets	
Response: MO	Confidence: Low
Rationale: *Procambarus clarkii* often inhabits agricultural fields and their burrowing activities can cause damage to infrastructure such as irrigation canals and dam walls (Lodge et al. 2012, Arce and Diéguez-Uribeondo 2015). Burrowing activities can also alter soil hydrology leading to water loss. Grazing causes crop damage and reduces yield (Anastácio et al. 2005). In Europe for example, *P. clarkii* affects rice production through field water loss, damage to rice field banks and ditches, direct consumption of rice seed and plants, and clogging of pipes (Souty-grosset et al. 2016).	
References: Anastácio PM. Correia AM, Menino JP. 2005. Processes and patterns of plant destruction by crayfish: effects of crayfish size and developmental stages of rice. *Archiv für Hydrobiologie* 162: 37–51. Arce JA, Diéguez-Uribeondo J. 2015. Structural damage caused by the invasive crayfish *Procambarus clarkii* (Girard, 1852) in rice fields of the Iberian Peninsula: A study case. *Fundamental and Applied Limnology* 186: 259–269. Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red	

swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON4c: Health	
Response: MN	Confidence: Low
Rationale: *Procambarus clarkii* can bio-accumulate toxins and metals from the environment (Gherardi et al. 2011, Souty-grosset et al. 2016). These pollutants are often harmful and can be transferred to higher food web levels through the consumption of affected crayfish by humans and predators such as otters, birds, and fish (Gherardi et al. 2011, Lodge et al. 2012). *Procambarus clarkii* serves as vector for several parasites and diseases some of which are zoonotic, for example the parasitic fluke flatworms (*Paragonimus* spp.) that causes lung fluke disease in humans, tularemia-causing bacterium *Francisella tularensis*, rat lungworm *Angiostrongylus cantonensis* that causes meningitis, and the nematode *Gnathostoma spinigerum* that causes human gnathostomiasis (de Moor 2002, Souty-grosset et al. 2016, Putra et al. 2017).	
References: Alcorlo P, Otero M, Crehuet M, Baltanás A, Montes C. 2006. The use of the red swamp crayfish (*Procambarus clarkii* Girard) as indicator of the bioavailability of heavy metals in environmental monitoring in the River Guadiamar (SW Spain). *Science of the Total Environment* 366:380–390. Alcorlo P. Baltanás A. 2013. The trophic ecology of the red swamp crayfish (*Procambarus clarkii*) in Mediterranean aquatic ecosystems: A stable isotope study. *Limnetica* 32:121–138. Anda P, Segura del Pozo J, Díaz García JM, Escudero R, et al. 2001. Waterborne outbreak of tularemia associated with crayfish fishing. *Emerging Infectious Diseases* 7:575–82. Edgerton BF, Evans LH, Stephens FJ, Overstreet RM. 2002. Synopsis of freshwater crayfish diseases and commensal organisms. *Aquaculture* 206: 57–135. Gherardi F, Barbaresi S, Vaselli O, Bencini A. 2002. A comparison of trace metal accumulation in indigenous and alien freshwater macro-decapods. *Marine and Freshwater Behaviour and Physiology* 35:179–88. Lane MA, Barsanti MC, Santos CA, Yeung M, Lubner SJ, Weil GJ. 2009. Human paragonimiasis in North America following ingestion of raw crayfish. *Clinical and Infectious Diseases* 49: 55–61.	
CON4d: Social, spiritual and cultural relations	
Response: MN	Confidence: Medium
Rationale: *Procambarus clarkii* affects the fishing industry by damaging gill nets and spoiling the fish caught in the nets (Gherardi et al. 2011).	
References: Gherardi F, Robert FJ, Kenneth BB, Mavuti M, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological Conservation* 144: 2585–2596.	
CON4 Closely related species' Maximum socio-economic impact (Figure S3)	
Response: MO	Confidence: Medium
Rationale: In its invaded range *P. clarkii* had caused harmful impacts in agricultural fields (Anastácio et al. 2005) and has disrupted some recreational activities leading to economic loss Gherardi et al. 2011).	
References: Alcorlo P, Otero M, Crehuet M, Baltanás A, Montes C. 2006. The use of the red swamp crayfish (*Procambarus clarkii* Girard) as indicator of the bioavailability of heavy metals in environmental monitoring in the River Guadiamar (SW Spain). *Science of the Total Environment* 366:380–390. Gherardi F, Barbaresi S, Vaselli O, Bencini A. 2002. A comparison of trace metal accumulation in indigenous and alien freshwater macro-decapods. *Marine and Freshwater Behaviour and Physiology* 35:179–88. Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red	

swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON5 Potential impact	
Response: MR	Confidence: Medium
Rationale: *Cherax destructor* can withstand variety of environmental conditions that helps to facilitate the establishment. *Cherax destructor* has the ability to switch from a diet of fish in summer to a predominantly herbaceous/detrital diet in winter (Beaty et al.2005). Therefore, it may compete for food resources with the other native closely related decapods (de Moor 2002; Nunes et al. 2017). *Cherax destructor* is a known host of the microsporidian *Thelohania parastaci* and may transmit the disease to native fauna occurring in sympatric freshwater ecosystems (Du Preez and Smith 2013) Furthermore, burrowing behaviour of *C. destructor* is a cause for concern (Withnall 2005). They are capable of digging very deep burrows which can be 50 cm to two meters deep depending on the species (Withnall 2005). Burrows are connected by access shafts to the water. In the event of the water drying up, they are able to survive over summer in the burrows. Unfortunately, this behaviour may also destroy the integrity of dam walls by increasing soil erosion (de Moor 2005).	
References: Beatty S. 2005. Translocations of freshwater crayfish: contributions from life histories, trophic relations and diseases of three species in Western Australia (Doctoral dissertation, Murdoch University). de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African *Journal of Aquatic Science* 27: 125–139. Du Preez L, Smit N. 2013. Double blow: Alien crayfish infected with invasive temnocephalan in South African waters. *South African Journal of Science* 109**:** 01–04. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF.2017. Freshwater crayfish invasions in South Africa: Past, present and potential future, African Journal of Aquatic Science 42: 309–323 Withnall F. 2000. Biology of yabbies (*Cherax destructor*). Aquaculture notes of the department of Natural Resources and Environment. State of Victoria, Australia.	

4. Management

MAN1 What is the feasibility to stop future immigration?	
Response: High	Confidence: Low
Rationale: There are no known wild populations in neighbouring countries, thus probability of species entering via unaided primary pathways is very low (de Moor 2002; Nunes et al. 2017). However, the aquarium trade is still a relevant pathway of introductions due to species still being available to buy online via pet shops (Faulkes 2015; Nunes et al. 2017). *Cherax destructor* is common in the pet trade and is available to buy as pets in Czech Republic, Germany, Greece, Netherlands, Slovakia and the USA and the UK (Faulkes 2015). Studies need to done to assess the trade of the species in South Africa.	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African *Journal of Aquatic Science* 27: 125–139 Faulkes Z. 2015. The global trade in crayfish as pets.*Crustacean Research* 44: 75–92. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF.2017. Freshwater crayfish invasions in South Africa: Past, present and potential future, African Journal of Aquatic Science 42: 309–323.	

MAN2 Benefits of the Taxon	
MAN2a Socio-economic benefits of the *Taxon*	
Response: None	Confidence: Low

Rationale: Species was imported to test the potential for aquaculture, however there is no evidence that the species is currently utilise din the sector (de Moor 2002; Nunes et al. 2017).
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African *Journal of Aquatic Science* 27: 125–139 Nunes AL, Zengeya TA, Measey GJ, Weyl OLF.2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

MAN2b Environmental benefits of the *Taxon*	
Response: None	Confidence:
Rationale:	
References:	

MAN3 Ease of management	
MAN3a How accessible are populations?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3b Is detectability critically time-dependent?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3c Time to reproduction	
Response: NA	Confidence:
Rationale:	
References:	
MAN3d Propagule persistence	
Response: NA	Confidence:
Rationale:	
References:	
MAN3 Ease of management (SUM from Table S4)	
Response: NA	Confidence:
Rationale:	
References:	

MAN4 Has the feasibility of eradication been evaluated?	
Response: No	Confidence: Low
Rationale:	
References:	

MAN5 Control options and monitoring approaches available for the *Taxon*
Response: *Cherax destructor* seems to be susceptible to the crayfish plague caused by a parasitic oomycete, *Aphanomyces astaci* (CABI 2019). In Spain, two populations were eradicated after the disease was transferred to individuals by infected *Pacifastacus leniusculus* (CABI 2019). Generally, once crayfish species have established and is becoming widespread, it is impossible to eradicate (Gherardi et al. 2011). They are very hardy and if chemical control is considered large quantities are needed to kill crayfish and biocides have been used to eradicate crayfish populations elsewhere. Although, the chemicals used are not specific to crayfish and can also harm other freshwater species within the same freshwater

ecosystem (Gherardi et al. 2011; Nunes et al. 2017). However, when species are restricted to dams, mechanical control via traps, electrofishing could still be feasible Nunes et al. 2017).
References: Gherardi F, Aquiloni L, Diéguez-Uribeondo, J, Tricarico, E. 2011. Managing invasive crayfish: is there a hope? *Aquatic Sciences* 73:185–200. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF.2017. Freshwater crayfish invasions in South Africa: Past, present and potential future, African Journal of Aquatic Science 42: 309–323. https://www.cabi.org/ISC/datasheet/89134

MAN6 Any other management considerations to highlight? (if yes, fill in Appendix MAN6)	
Response	Yes / No

5. Calculations

Likelihood = Fairly probable

Parameter	Likelihood	Stages	Final assessment
LIK1	0.0027	P(entry) = 0.5	P (invasion) = 0.25
LIK2	0.5		
LIK3	1	P(establishment) = 1	
LIK4	1		
LIK5	0.0027	P (spread) = 0.5	
LIK6	0.5		

Consequence = MR

Parameter	Mechanism/sector	Response
CON1	**Maximum environmental impact**	**DD**
CON2	**Maximum socio-economic impact**	**DD**
CON3a	Competition	MR
CON3b	Predation	MR
CON3c	Hybridisation	MC
CON3d	Disease transmission	MR
CON3e	Parasitism	DD
CON3f	Poisoning/toxicity	MN
CON3g	Bio-fouling or other direct physical disturbance	DD
CON3h	Grazing/herbivory/browsing	MO
CON3i	Chemical, physical, structural impact	MN
CON3k	Indirect impacts through interactions with other species	DD
CON3	**Maximum environmental impact (closely related taxa)**	**MR**
CON4a	Safety	DD
CON4b	Material and immaterial assets	MO
CON4c	Health	MN
CON4d	Social, spiritual and cultural relations	MO
CON4	**Maximum socio-economic impact (closely related taxa)**	**MO**
CON5	Potential impact based on traits, experiments, or models	**MR**

Table S3: Risk score

		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	Low	Low	Low	Medium	Medium
	Very unlikely	Low	Low	Low	Medium	High

	Unlikely	Low	Low	Medium	High	High
	Fairly probable	Medium	Medium	High	High	High
	Probable	Medium	High	High	High	High

Table S4: Ease of management

Parameter	Question	Response
MAN3a	How accessible are populations?	NA
MAN3b	Is detectability critically time-dependent?	NA
MAN3c	Time to reproduction	NA
MAN3d	Propagule persistence	NA
MAN3	**SUM**	

Appendix BAC8(a): Global alien range of *Cherax destructor*. Map from CABI: https://www.cabi.org/ISC/datasheet/89134

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Appendix 3.3 Risk analysis report for Redclaw crayfish (*Cherax quadricarinatus*).

Risk Analysis Report

<table>
<tr><td>Taxon:
Cherax quadricarinatus (von Martens, 1868)</td><td colspan="2">Area: South Africa</td></tr>
<tr><td>Compiled by: Lee-Anne Botha</td><td colspan="2">Approved by:</td></tr>
<tr><td>Picture of Taxon

Sourced from CABI:
https://www.cabi.org/isc/datasheet/89135</td><td colspan="2">Alien distribution map

Map sourced from CABI 2019:
https://www.cabi.org/isc/datasheet/89135</td></tr>
<tr><td colspan="2">Risk Assessment summary:
Redclaw crayfish (Cherax quadricarinatus) has been introduced for aquaculture worldwide and is very popular in the aquarium pet trade. Cherax quadricarinatus is already established in South Africa and neighbouring countries and can inhabit a wide variety of habitats and has a high tolerance to a range of environmental conditions. Current locations can act as a source for secondary dispersal into new areas by humans. There is a lack of documented evidence of environmental and socio-economic impacts caused by C. quadricarinatus in its alien range. Based on the results from red swamp (Procambarus clarkii), the closely related species, C. quadricarinatus has the potential to cause harmful impacts through various mechanisms. It can out-compete native decapods for resources leading to a decline in population numbers or possible extinction. Direct predation and intensive grazing by C. quadricarinatus is also a threat to native macroinvertebrate and aquatic macrophyte communities especially when occurring in high densities. The genus Cherax is also known for harbouring parasites such as commensal worms (Temnocephela) that could be harmful to shrimps and freshwater crabs if transferred. Cherax quadricarinatus in already invasive in South Africa and has the potential to displace native species.</td><td>Risk score:
High</td></tr>
<tr><td colspan="2">Management options summary:
Cherax quadricarinatus is already widespread in Inkomati River and adjacent river systems and is still spreading. Eradication is no longer feasible and most practical. The practical control method is to contain populations to invaded areas and prevent further spread.</td><td>Ease of management:
Medium</td></tr>
<tr><td colspan="2" rowspan="2">Recommendations:
The species is currently listed as a Category 1b species on the NEM:BA A&IS regulations. The results from this Risk Analysis support this listing because the species is widespread across several catchments and is likely to continue to spread naturally through these connected waterways. Relevant stakeholders should be engaged when management protocols are developed to prevent future intentional introductions and to minimise natural spread. The illegal pet trade industry still poses a significant risk for intentional and accidental release of species into the wild. There is therefore a need to assess the trade of, and movement of the species through this pathway.</td><td>Listing under NEM:BA A&IS lists of 2014 as amended 2020:
Category 1b</td></tr>
<tr><td>Recommended listing category:
No change</td></tr>
</table>

1. Background

BAC1 Name of assessor(s)	
Name of lead assessor	**Lee-Anne Botha**
Additional assessor (1)	
Additional assessor (2)	
BAC2 Contact details of assessor (s)	
Lead assessor	Organisational affiliation: University of Pretoria, Department of Zoology and Entomology/ South African National Biodiversity Institute (SANBI)
	email: u18389164@tuks.co.za
	Phone: 072 833 7952
Additional assessor (1)	Organisational affiliation:
	email:
	Phone:
Additional assessor (2)	Organisational affiliation:
	email:
	Phone:
BAC3 Name(s) and contact details of expert(s) consulted	
Expert (1)	Name: Dr Tsungai Zengeya
	email:T.Zengeya@sanbi.org.za
	Phone: 021 799 8408
Expert (2)	Name:
	email:
	Phone:
Comments: Dr Tsungai Zengeya works for the South African National Biodiversity Institute (SANBI). His research interests are in freshwater ecology and biological invasions. He provided comments and inputs throughout the compilation of this risk analysis that improved its quality.	
BAC4 Scientific name of *Taxon* under assessment	
Taxon name: *Cherax quadricarinatus*	Authority: (von Martens,1868)
Comments:	
References: Crandall KA, De Grave S, 2017. An updated classification of the freshwater crayfishes (Decapoda: Astacidea) of the world, with a complete species list. *Journal of Crustacean Biology* 27: 615–653.	
BAC5 Synonym(s) considered	
Synonyms:	
Comments:	
References:	
BAC6 Common name(s) considered	
Common names: Redclaw crayfish	
Comments:	
References:	
BAC7 What is the native range of the *Taxon*? (add map in Appendix BAC7)	
Response: northern Australia and Papua New Guinea	Confidence: High

Comments:			
References: Zengeya TA. Risk assessment of Cherax sp in South Africa (Unpublished data).			
BAC8 What is the global alien range of the *Taxon*? (add map in Appendix BAC8)			
Response: Feral populations have established in South Africa, Mexico, Jamaica and Puerto Rico.			Confidence: Medium
Comments: Species have been introduced ± 26 countries, but feral populations are only known from the countries mentioned above (Zengeya unpublished data).			
References: Zengeya TA. Risk assessment of Cherax sp in South Africa (Unpublished data). https://www.cabi.org/isc/datasheet/89135			
BAC9 Geographic scope = the *Area* under consideration			
Area of assessment: South Africa			
Comments:			
BAC10 Is the *Taxon* present in the *Area*?			
Response: Yes			Confidence: High
Comments: Species is widespread in the Inkomati River and adjacent river systems in South Africa and neighbouring countries such as Mozambique, Swaziland, Zambia and Zimbabwe (de Moor 2002, Nunes et al. 2017b, 2017a).			
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African *Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Hoffman AC, Measey GJ, Weyl, OL. 2017a. Distribution and establishment of the alien Australian redclaw crayfish, *Cherax quadricarinatus*, in South Africa and Swaziland. *PeerJ* 5: 1-21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF.2017b. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309-323.			
BAC11 Availability of physical specimen			
Response: Albany Museum, Grahamstown			Confidence in ID: Medium
Herbarium or museum accession number: GEN 1565A			
References: Albany Museum, Grahamstown			
BAC12 Is the *Taxon* native to the *Area* or part of the *Area*?			
The *Taxon* is native to (part of) the *Area*.	No		Confidence: High
The *Taxon* is alien in (part of) the *Area*.	Yes		Confidence: High
Comments: Species native to northern Australia and Papua New Guinea, South Africa has no indigenous freshwater crayfish (de Moor 2002, Nunes et al. 2017)			
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African *Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Hoffman AC, Measey GJ, Weyl, OL. 2017a. Distribution and establishment of the alien Australian redclaw crayfish, Cherax quadricarinatus, in South Africa and Swaziland. *PeerJ* 5: 1-21			
BAC13 What is the *Taxon*'s introduction status in the *Area*?			
The *Taxon* is in cultivation/containment.	Don't know		Confidence: Low

The *Taxon* is present outside of cultivation/containment.	Yes	Confidence: High
The *Taxon* has established/naturalised.	Yes	Confidence: High
The *Taxon* is invasive.	Yes	Confidence: High

Comments:
Species is invasive and is widespread in the Inkomati River Catchment and adjacent rivers in South Africa and neighbouring countries such as Mozambique, Swaziland and Zimbabwe (Douthwaite et al. 2018, Marufu et al. 2018). It is also known to occur in other countries in the region such as Zambia (Nunes et al. 2017a).

References:

Douthwaite RJ, Jones EW, Tyser AB, Vrdoljak SM. 2018. The introduction, spread and ecology of redclaw crayfish *Cherax quadricarinatus* in the Zambezi catchment. *African Journal of Aquatic Science* 43: 353–366.

Marufu L, Barson M, Chifamba P, Tiki M, Nhiwatiwa.2018.The population dynamics of a recently introduced crayfish, *Cherax quadricarinatus* (von Martens, 1868), in the Sanyati Basin of Lake Kariba, Zimbabwe. *African Zoology* 53:17–22.

Nunes AL, Zengeya TA, Hoffman AC, Measey GJ, Weyl OL. 2017. Distribution and establishment of the alien Australian redclaw crayfish, *Cherax quadricarinatus*, in South Africa and Swaziland. *PeerJ* 5: 1–21.

BAC14 Primary (introduction) pathways

Release		Confidence:
Escape	Aquarium /Pet trade Aquaculture	Confidence: Medium
Contaminant		Confidence:
Stowaway		Confidence:
Corridor		Confidence:
Unaided		Confidence:

Comments:
Cherax qudricarintus are well suited and highly sought after aquaculture species due to their tolerance to wide variations in water quality, a wide range of trophic and ecological adaptations, adaptive life history traits such as high reproductive potential and high growth rates and conspicuous colour that makes them desirable and popular in the aquarium trade (Patoka et al. 2014, Nunes et al. 2017b).

References:

Patoka J, Petrtýl M, Kalous L. 2014. Garden ponds as potential introduction pathway of ornamental crayfish. *Knowledge and Management of Aquatic Ecosystems* 414: 13–21.

Patoka J, Wardiatno Y, Kuříková P, Petrtýl, M, Kalous L. 2016. *Cherax quadricarinatus* (von Martens) has invaded Indonesian territory west of the Wallace Line: evidences from Java. *Knowledge and Management of Aquatic Ecosystems* 417: 39-45.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

https://www.gbif.org/species/2227300

https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=217

2. Likelihood

LIK1 Likelihood of entry via unaided primary pathways	
Response: Probable	Confidence: High

Rationale:
Redclaw crayfish is already present in the country and it has established populations in the wild (Nunes et al. 2017a, Petersen et al. 2017). Furthermore, there are feral population in several countries in southern Africa (Douthwaite et al. 2018, Marufu et al. 2018). Species likely to spread natural along connected waterways in the country and across borders (Nunes et al. 2017a).

References: Douthwaite RJ, Jones EW, Tyser AB, Vrdoljak SM. 2018. The introduction, spread and ecology of redclaw crayfish *Cherax quadricarinatus*in the Zambezi catchment. *African Journal of Aquatic Science* 43: 353–366. Marufu L, Barson M, Chifamba P, Tiki M, Nhiwatiwa.2018.The population dynamics of a recently introduced crayfish, *Cherax quadricarinatus* (von Martens, 1868), in the Sanyati Basin of Lake Kariba, Zimbabwe. *African Zoology* 53:17–22. Nunes AL, Zengeya TA, Hoffman AC, Measey GJ, Weyl OL. 2017. Distribution and establishment of the alien Australian redclaw crayfish, *Cherax quadricarinatus*, in South Africa and Swaziland.*PeerJ* 5: 1–21. Petersen RM, Hoffman AC, Kotze P, Marr SM. 2017. First record of the invasive Australian redclaw crayfish *Cherax quadricarinatus* (von Martens, 1868) in the Crocodile River, Kruger National Park, South Africa.Koedoe 59: 1–3.

LIK2 Likelihood of entry via human aided primary pathways	
Response: Probable	Confidence: High
Rationale: Primary pathway of introduction includes escapees from aquaculture facilities and pet trade and sometimes crayfish that are used as bait for fish (Patoka et al. 2014, Douthwaite et al. 2018).	
References: Douthwaite RJ, Jones EW, Tyser AB, Vrdoljak SM. 2018. The introduction, spread and ecology of redclaw crayfish *Cherax quadricarinatus* in the Zambezi catchment. *African Journal of Aquatic Science* 43: 353–366. Patoka J, Petrtýl M, Kalous L. 2014. Garden ponds as potential introduction pathway of ornamental crayfish. *Knowledge and Management of Aquatic Ecosystems* 414: 13–21.	

LIK3 Habitat suitability	
Response: Probable	Confidence: High
Rationale: *Cherax quadricarinatus* can occupy a wide range of habitats from ponds, rivers which are found throughout the country(de Moor 2002). Preferred habitats include rocky reaches with plenty of crevices for shelter and foraging, especially during the moulting phase (Zengeya Unpublished data).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African *Journal of Aquatic Science* 27: 125–139. Zengeya TA. Risk assessment of *Cherax* sp in South Africa (Unpublished data).	

LIK4 Climate suitability	
Response: Probable	Confidence: High
Rationale: Thermal tolerance range 10-34°C, optimal range 22-32°C, lethal limits 9-10°C and 34-35°C (Zengeya unpublished data). Based on niche models, Ecoregions that were projected to be climatically suitable for *Cherax qudricarintus* were largely restricted to the north and eastern parts of the country and include the Soutpansberg, North Eastern Highlands, Eastern Bankenveld, Highveld, Northern Coastal Belt and South Eastern Uplands(Nunes et al. 2017b). There is some evidence that redclaw crayfish can adapt to new temperature regimes if moved e.g. in Tasmania feral populations of *Cherax qudricarintus* have been reported to survive in water temperatures as low as 2-4 °C (de Moor 2002).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF.2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309-323. Zengeya TA. Risk assessment of *Cherax* sp in South Africa (Unpublished data).	

LIK5 Unaided secondary (dispersal) pathways

Response: Probable	Confidence: High
Rationale: Like all other crayfish species, dispersal is not limited to connected waterways (Lodge et al. 2012). *Cherax quadricarinatis* is mobile and can migrate overland to favourable areas (Lodge et al. 2012).	
References: Lodge DM, Deines A, Gherardi F, Yeo, DC, Arcella T, Baldridge, AK, Barnes MA, Chadderton WL, Feder JL, Gantz CA, Howard GW, 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution, and Systematics* 43**:** 449–472.	

LIK6 Human aided secondary (dispersal) pathways	
Response: Probable	Confidence: Low
Rationale: There are many human pathways available; The current populations can act as a source for secondary dispersal by humans for example, bucket release by anglers (Nunes et al. 2017a). *Cherax quadricarinatus* is present in the pet trade industry in several countries leading to the accidental release in the wild as unwanted pets (Faulkes 2015).	
References: Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Nunes AL, Zengeya TA, Hoffman AC, Measey GJ, Weyl OL. 2017a. Distribution and establishment of the alien Australian redclaw crayfish, *Cherax quadricarinatus*, in South Africa and Swaziland. *PeerJ* 5: 1–21.	

3. Consequences

CON1 Environmental impact	
CON1a: Competition	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON1b: Predation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1c: Hybridisation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1d: Transmission of disease	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1e: Parasitism	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1f: Poisoning/toxicity	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1g: Bio-fouling or other direct physical disturbance	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON1h: Grazing/herbivory/browsing	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1i: Chemical, physical or structural impact on ecosystem	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1 Maximum environmental impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact	
References: L. Botha (Unpublished data).	

CON2 Socio-economic impact	
CON2a: Safety	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data	
CON2b: Material and immaterial assets	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2c: Health	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2d: Social, spiritual and cultural relations	
Response: DD	Confidence: Low
Rationale:	
References: L. Botha (Unpublished data)	
CON2 Maximum socio-economic impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON3 Closely related species' Environmental impact	
CON3a: Competition	
Response: MR	Confidence: Medium
Rationale: *Procambarus clarkii* is very aggressive and usually out-competes native species for shelter and spawning sites, and these often lead to reproductive interference. In areas of introduction, some amphibian species (e.g., *Bufo bufo*, *B. calamita*, *Rana* sp., *Taricha torosa* and *Triturus vulgaris*) have been excluded or displaced from their natural habitats, resulting in local extinctions through either larval predation or amphibians spawning in areas that do not offer sufficient protection to avoid interaction with *P.clarkii*, resulting in low recruitment (Cruz et al. 2006; Lodge et al. 2012). In addition, as a result of direct competition, there has been a decrease in the distributional ranges and abundance of native crayfish populations (*Astacus astacus*,	

Austropotamobius pallipes and *A. torrentium*) in some areas in Europe and Japan (Cruz et al. 2006; Lodge et al. 2012). Furthermore, direct competition for food has caused dietary niche constriction and declines in populations of native crabs in some areas invaded by *P. clarkia* (Jackson et al. 2016).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338. Jackson MC, Grey J, Miller K, Britton,JR, Donohue, I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology*, 85:1098–1107. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.	
CON3b: Predation	
Response: MR	Confidence: Medium
Rationale: In its invasive range, there is evidence that predation by *P. clarkii* can result in the local or population extinctions of at least one native species (Lodge et al. 2012; Souty-grosset et al. 2016). For example, *P. clarkii* has been implicated in causing population declines of several species of fish and amphibians by reducing their breeding success through predation on eggs and larval amphibians (Cruz et al. 2006; Francesco et al. 2011). Indirect effects of predation can also cause trophic cascades that can lead to changes in ecosystem structure and function. For example, predation on invertebrates can release algae from grazing pressure and lead to changes in the abundance and dominance of species in algal communities (Gherardi and Barbaresi 2008).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338. Ficetola GF, Siesa ME, Manenti R, Bottoni L, De Bernardi F, Padoa-Schioppa E. 2011. Early assessment of the impact of alien species: Differential consequences of an invasive crayfish on adult and larval amphibians. *Diversity and Distributions* 17:1141–1151. Gherardi F, Barbaresi S. 2008. Feeding opportunism of the red swamp crayfish Procambarus clarkia, an invasive species. *Freshwater crayfish* 16: 77–85. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON3c: Hybridisation	
Response: MC	Confidence: High
Rationale: This is unlikely in South Africa because there are no native crayfish species.	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	
CON3d: Transmission of disease	
Response: MR	Confidence: High
Rationale: *Procambarus clarkii* can harbour many pathogens, parasites, and diseases that can be transmitted to other congeneric species (Longshaw 2011, Lodge et al. 2012). There is evidence that transmission of diseases and parasites by *P. clarkii* to native species has caused local or population extinctions of at least one native species, leading to changes in community composition (Lodge et al. 2012). For example, *P. clarkii* is a vector of crayfish plague, a disease caused by the parasitic oomycete, *Aphanomyces astaci* (Longshaw 2011, Souty-	

grosset et al. 2016). In Europe, transmission of crayfish plague by *P. clarkii* to native crayfish species has been linked to a decline in populations of several native species of crayfish such as *Astacus astacus*, *Austropotamobius pallipes* and *A. torrentium* (Holdich et al. 2009, Longshaw 2011). *Procambarus clarkii* can also harbour white spot syndrome disease – a viral infections of crustaceans, and fungal pathogens such as *Batrachochytrium dendrobatids* that causes chytridiomycosis – a lethal skin infection in amphibians (Longshaw 2011, McMahon et al. 2013).	
References: Aquiloni L, Martín MP, Gherardi F, Diéguez-Uribeondo J. 2011. The North American crayfish *Procambarus clarkii* is the carrier of the oomycete *Aphanomyces astaci* in Italy. *Biological Invasions* 13: 359–367. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449 –72. Longshaw M. 2011. Diseases of crayfish: A review. *Journal of Invertebrate Pathology* 106: 54–70. McMahon TA, Brannelly LA, Chatfield MW, Johnson PT, Joseph MB, McKenzie VJ, Richards-Zawacki CL, Venesky MD, Rohr JR. 2013. Chytrid fungus *Batrachochytrium dendrobatidis* has non-amphibian hosts and releases chemicals that cause pathology in the absence of infection. *Proceedings of the National Academy of Sciences of the United States of America* 110: 210–215. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON3e: Parasitism	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References:	
CON3f: Poisoning/toxicity	
Response: MN	Confidence: Low
Rationale: See **CON4c**	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Gherardi F, Britton JR, Mavuti KM, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological* Conservation 144: 2585–2596. Putra MD, Bláha M, Wardiatno Y, Krisanti M, Bystřický PK, Kouba A, Kalous L, Petrusek A, Patoka J. 2017. *Procambarus clarkii* (Girard, 1852) and crayfish plague as new threats for biodiversity in Indonesia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 28: 1434–1440. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON3g: Bio-fouling or other direct physical disturbance	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON3h: Grazing/herbivory/browsing	
Response: MO	Confidence: Medium
Rationale: Grazing by *P. clarkii* can lead to habitat loss and modification through the removal of macrophytes. Habitat loss can lead to a decline in populations of species that utilise the macrophyte stands as a food source, nesting sites, and as refugia from predation (Rosenthal et al 2005). *Procambarus clarkii* can also cause changes to community composition through trophic cascades (Gherardi and Aquistapace 2007, Souty-grosset et al.	

2016). For example, in Lake Chozas (northwest Spain), grazing by *P. clarkii* caused a reduction in macrophyte communities and this impact cascaded up the food chain with declines in invertebrates, amphibians, and waterfowl (Rodriguez et al 2003). Grazing can also cause changes to community composition and structure, such as changing ecosystems from macrophyte-dominated areas with clear water, to turbid phytoplankton-dominated areas (Matsizaki et al. 2009). Excessive grazing can also lead to accelerated rates of important processes such as litter breakdown and decomposition.	
References: Gherardi F, Acquistapace P. 2007. Invasive crayfish in Europe: The impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. *Freshwater Biology* 52: 1249–59. Matsuzaki SS, Usio N, Takamura N, Washitani I. 2009. Contrasting impacts of invasive engineers on freshwater ecosystems: An experiment and meta-analysis. *Oecologia* 158: 673–686. Rodríguez CF, Bécares E, Fernández-Aláez M. 2003. Shift from clear to turbid phase in Lake Chozas (NW Spain) due to the introduction of American red swamp crayfish (*Procambarus clarkii*). *Hydrobiologia* 506: 421–26. Rosenthal SK, Lodge DM, Mavuti KM, Muohi W, Ochieng P, Mungai BN, Mkoji GM. 2005. Comparing macrophyte herbivory by introduced Louisiana crayfish (*Procambarus clarkii*) (Crustacea: Cambaridea) and native Dytiscid beetles (*Cybister tripunctatus*) (Coleoptera: Dytiscidae), in Kenya. *African Journal of Aquatic Science* 30: 157–62. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON3i: Chemical, physical or structural impact on ecosystem	
Response: MO	Confidence: Medium
Rationale: **Water quality**: *Procambarus clarkii* is often considered an ecosystem engineer due to its ability to change ecosystems through its burrowing activities (Souty-grosset et al. 2016). For example, its burrowing activities can cause a decrease in the water quality through bioturbation leading to increased turbidity and influx release of nutrients from sediments, often leading to algal blooms (Angeler et al. 2001, Yamamoto 2010). The impaired water quality also affects the quality of the habitats for other aquatic fauna (Angeler et al. 2001, Rodriguez et al. 2003). For example, increased turbidity can impede foraging and respiratory processes of fish (Rodriguez et al. 2003). **Erosion**: Burrowing activities can cause structural damage to river banks and increase bank erosion, and also cause damage to water retention infrastructure such as dam walls and dykes (Souty-grosset et al. 2016).	
References: Angeler DG, Sánchez-Carrillo S, García G, Alvarez-Cobelas M. 2001. The influence of *Procambarus clarkii* (Cambaridae, Decapoda) on water quality and sediment characteristics in a Spanish floodplain wetland. *Hydrobiologia* 464: 89–98. Rodríguez CF, Bécares E, Fernández-Aláez M. 2003. Shift from clear to turbid phase in Lake Chozas (NW Spain) due to the introduction of American red swamp crayfish (*Procambarus clarkii*). *Hydrobiologia* 506: 421–26. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93. Yamamoto Y. 2010. Contribution of bioturbation by the red swamp crayfish *Procambarus clarkii* to the recruitment of bloom-forming cyanobacteria from sediment. *Journal of Limnology* 69: 102– 111.	
CON3k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON3 Maximum environmental impact (Figure S3)	
Response: MR	Confidence: Medium
Rationale: Direct predation and competition for food, shelter, and spawning sites have led to local extinctions and a	

decrease in the abundance of native amphibians and crayfish species(Cruz et al. 2006, Gherardi & Acquistapace 2007). Impacts have been recorded in the Iberian Peninsula, Sweden, Italy (Gherardi and Acquistapace 2007), Japan, and U.S.A. (California) (Holdich et al. 2009, Lodge et al. 2012).
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338. Gherardi F, Acquistapace P. 2007. Invasive crayfish in Europe: The impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. *Freshwater Biology* 52: 1249–59 Jackson MC, Grey J, Miller K, Britton,JR, Donohue, I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology*, 85:1098–1107. Longshaw M. 2011. Diseases of crayfish: A review. *Journal of Invertebrate Pathology* 106: 54–70. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016.The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON4 Closely related species' Socio-economic impact	
CON4a: Safety	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (unpublished data).	
CON4b: Material and immaterial assets	
Response: MO	Confidence: Medium
Rationale: *Procambarus clarkii* often inhabits agricultural fields and their burrowing activities can cause damage to infrastructure such as irrigation canals and dam walls (Lodge et al. 2012, Arce and Diéguez-Uribeondo 2015). Burrowing activities can also alter soil hydrology leading to water loss. Grazing causes crop damage and reduces yield (Anastácio et al. 2005). In Europe for example, *P. clarkii* affects rice production through field water loss, damage to rice field banks and ditches, direct consumption of rice seed and plants, and clogging of pipes (Souty-grosset et al. 2016).	
References: Anastácio PM. Correia AM, Menino JP. 2005. Processes and patterns of plant destruction by crayfish: effects of crayfish size and developmental stages of rice. *Archiv für Hydrobiologie* 162: 37–51. Arce JA, Diéguez-Uribeondo J. 2015. Structural damage caused by the invasive crayfish *Procambarus clarkii* (Girard, 1852) in rice fields of the Iberian Peninsula: A study case. *Fundamental and Applied Limnology* 186: 259–269. Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON4c: Health	
Response: MN	Confidence: Low
Rationale: *Procambarus clarkii* can bio-accumulate toxins and metals from the environment (Gherardi et al. 2011b, Souty-grosset et al. 2016). These pollutants are often harmful and can be transferred to higher food web levels through the consumption of affected crayfish by humans and predators such as otters, birds, and fish (Gherardi et al. 2011b, Lodge et al. 2012). *Procambarus clarkii* serves as vector for several parasites and diseases some of which are zoonotic, for	

example the parasitic fluke flatworms (*Paragonimus* spp.) that causes lung fluke disease in humans, tularemia-causing bacterium *Francisella tularensis*, rat lungworm *Angiostrongylus cantonensis* that causes meningitis, and the nematode *Gnathostoma spinigerum* that causes human gnathostomiasis (de Moor 2002, Souty-grosset et al. 2016, Putra et al. 2017).

References:

Alcorlo P, Otero M, Crehuet M, Baltanás A, Montes C. 2006. The use of the red swamp crayfish (*Procambarus clarkii* Girard) as indicator of the bioavailability of heavy metals in environmental monitoring in the River Guadiamar (SW Spain). *Science of the Total Environment* 366:380– 390.

Alcorlo P. Baltanás A. 2013. The trophic ecology of the red swamp crayfish (*Procambarus clarkii*) in Mediterranean aquatic ecosystems: A stable isotope study. *Limnetica* 32:121–138.

Anda P, Segura del Pozo J, Díaz García JM, Escudero R, et al. 2001. Waterborne outbreak of tularemia associated with crayfish fishing. *Emerging Infectious Diseases* 7:575–82.

Edgerton BF, Evans LH, Stephens FJ, Overstreet RM. 2002. Synopsis of freshwater crayfish diseases and commensal organisms. *Aquaculture* 206: 57–135.

Gherardi F, Barbaresi S, Vaselli O, Bencini A. 2002. A comparison of trace metal accumulation in indigenous and alien freshwater macro-decapods. *Marine and Freshwater Behaviour and Physiology* 35:179–88.

Lane MA, Barsanti MC, Santos CA, Yeung M, Lubner SJ, Weil GJ. 2009. Human paragonimiasis in North America following ingestion of raw crayfish. *Clinical and Infectious Diseases* 49: 55–61.

Vasconcelos V, Oliveira S, Teles FO. 2001. Impact of a toxic and a non-toxic strain of *Microcystis aeruginosa* on the crayfish *Procambarus clarkii*. *Toxicon* 39:1461–1470.

CON4d: Social, spiritual and cultural relations

Response: MO	Confidence: Medium

Rationale:

Procambarus clarkii affects the fishing industry by damaging gill nets and spoiling the fish caught in the nets (Gherardi et al. 2011).

References:

Gherardi F, Robert FJ, Kenneth BB, Mavuti M, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological Conservation* 144: 2585–2596.

CON4 Maximum socio-economic impact Closely related species' (Figure S3)

Response: MO	Confidence: Medium

Rationale:

In its invaded range *P.clarkii* had caused harmful impacts in agricultural fields (Anastácio et al. 2005) and has disrupted some recreational activities leading to economic loss Gherardi et al. 2011).

References:

Arce JA, Diéguez–Uribeondo J. 2015. Structural damage caused by the invasive crayfish *Procambarus clarkii* (Girard, 1852) in rice fields of the Iberian Peninsula: A study case. *Fundamental and Applied Limnology* 186: 259–269.

Gherardi F, Robert FJ, Kenneth BB, Mavuti M, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological Conservation* 144: 2585–2596.

CON5 Potential impact

Response: MR	Confidence: Medium

Rationale:

Cherax quadricarinatus is already invasive in the country but there is a lack of direct impacts in recipient areas of introduction (Nunes et al. 2017). Based on the information gathered form the impact assessment for *P. clarkii*, *C. quadricainatus* has the potential to cause negative impacts in its invaded range. It can outcompete native species for shared resources leading to reproductive interference and decline in numbers (de Moor 2002). Furthermore, being a functionall omnivore, *C. quadricarinatus* can impact macroinvertebrates and aquatic macrophyte communities through direct predation and intensive grazing when occurring in high densities (de Moor 2002). *Cherax* genus is also known for harbouring parasites such as commensal worms (*Temnocephela* species) (Tavakol et al. 2016). These parasites can be harmful when

transferred to native decapods such as crabs and shrimp resulting in decline of populations or affect their overall performance.
References: De Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African *Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Hoffman AC, Measey GJ, Weyl OL. 2017. Distribution and establishment of the alien Australian redclaw crayfish, *Cherax quadricarinatus*, in South Africa and Swaziland. *PeerJ* 5: 1–21. Tavakol S, Luus-Powell WJ, Smit WJ, Baker C, Hoffman A, Halajian A. 2016. First Introduction of Two Australian Temnocephalan Species into Africa with an Alien Host: Double Trouble. *Journal of Parasitology* 102: 653–658.

4. Management

MAN1 What is the feasibility to stop future immigration?	
Response: Low	Confidence: Medium
Rationale: There are wild populations in neighbouring countries, Swaziland, Mozambique, and Zimbabwe which poses a risk for future introductions (Nunes et al. 2017a, Douthwaite et al. 2018, Marufu et al. 2018). Furthermore, the illegal pet trade remains to be a problem and can still be bought online (Faulkes 2015, Nunes et al. 2017b). It is present in the pet trade industry in the Czech Republic, Germany, Greece Netherlands Slovakia, Singapore and the USA (Faulkes 2015). Studies need to be done to assess the trade of the species in South Africa.	
References: Douthwaite RJ, Jones EW, Tyser AB, Vrdoljak SM. 2018. The introduction, spread and ecology of redclaw crayfish *Cherax quadricarinatus* in the Zambezi catchment. *African Journal of Aquatic Science* 43: 353–366. Faulkes Z. 2015. The global trade in crayfish as pets.*Crustacean Research* 44: 75–92. Marufu L, Barson M, Chifamba P, Tiki M, Nhiwatiwa.2018. The population dynamics of a recently introduced crayfish, *Cherax quadricarinatus* (von Martens, 1868), in the Sanyati Basin of Lake Kariba, Zimbabwe. *African Zoology* 53:17–22. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

MAN2 Benefits of the Taxon	
MAN2a Socio-economic benefits of the *Taxon*	
Response: Low	Confidence: Medium
Rationale: Several counties have invested in *Cherax qudricarinatus* aquaculture farms. Although with marginal growth in the industry, the production remains low (FAO 2012). For example, Australia only produced approximately 400 tonnes annually in the span 10 years (FAO 2012). In Mexico the production estimate is around 50 tonnes. In other regions such as Panama and the U.S.A, it is lower with less than 10 tonnes (FAO 2012). Large scale farming has been established in Morocco and Spain but production from these regions remain unknown (FAO 2012).	
References: http://www.fao.org/fishery/culturedspecies/Cherax_quadricarinatus/en	
MAN2b Environmental benefits of the *Taxon*	
Response: None	Confidence:
Rationale:	
References:	

MAN3 Ease of management	
MAN3a How accessible are populations?	
Response: 1	Confidence: High
Rationale: Moderately accessible - Species is widespread in the Inkomati and adjacent river systems but there is safety risk because of wildlife (hippos and crocodiles) and there is need for land owner permission to access sites as large sections of the river flow through private land.	
References: Nunes AL, Zengeya TA, Hoffman AC, Measey GJ, Weyl OL. 2017. Distribution and establishment of the alien Australian redclaw crayfish, *Cherax quadricarinatus*, in South Africa and Swaziland. *PeerJ*, 5**:** 1–21.	
MAN3b Is detectability critically time-dependent?	
Response: 0	Confidence: High
Rationale: Species can be detected throughout the year; however, species is primarily nocturnal (Azofeifa-solano et al. 2017).	
References: Azofeifa-solano, JC, Naranjo-elizondo B, Rojas-carranza AH. Cedeño-fonseca M. 2017. Presence of the Australian redclaw crayfish *Cherax quadricarinatus* (von Martens, 1868) (Parastacidae, Astacoidea) in a freshwater system in the Caribbean drainage of Costa Rica 6**:** 351–355.	
MAN3c Time to reproduction	
Response: 2	Confidence: High
Rationale: *Cherax quadricarinatus* reaches sexual maturity within the first year and can have multiple spawning events when environmental conditions are optimal.	
References:	
MAN3d Propagule persistence	
Response: NA	Confidence:
Rationale:	
References:	
MAN3 Ease of management (SUM from Table S4)	
Response: Medium	Confidence: Low
Rationale: *Cherax quadricarinarus* is already widespread in the Mpumalanga Province and eradication is no longer feasible for various reasons (accessibility of populations, eradication methods) (Nunes et al. 2017a, Petersen et al. 2017). Management strategies should therefore aim to prevent populations from spreading into new areas and stop new introductions from neighbouring countries (Nunes et al. 2017b).	
References: Nunes AL, Zengeya TA, Hoffman AC, Measey GJ, Weyl OL. 2017a. Distribution and establishment of the alien Australian redclaw crayfish, *Cherax quadricarinatus*, in South Africa and Swaziland.*PeerJ* 5: 1-21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017b. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. Petersen RM, Hoffman AC, Kotze P, Marr SM. 2017. First record of the invasive Australian redclaw crayfish *Cherax quadricarinatus* (von Martens, 1868) in the Crocodile River, Kruger National Park, South Africa. Koedoe 59**:** 1–3.	

MAN4 Has the feasibility of eradication been evaluated?	
Response: No	Confidence: Low
Rationale:	

Cherax quadriacrinatus have established populations in both South Africa other neighbouring countries; therefore act as a constant source for future introductions (de Moor 2002, Nunes et al. 2017a). Species is widespread in the Inkomati River and is continuing to spread(Nunes et al. 2017a). Thus, the most practical management option would be to prevent further spread into new areas as eradication is no longer feasible (Nunes et al. 2017b). Chemical control is no longer an option and the manual removal will be a costly expedition and with crocodiles and hippos present in the Inkomati River also poses a problem (Gherardi et al. 2011a, Nunes et al. 2017a).
References: de Moor I, 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Gherardi F, Aquiloni, L, Diéguez-Uribeondo J, Tricarico E. 2011. Managing invasive crayfish: is there a hope?.*Aquatic Sciences* 73: 185–200. Nunes AL, Zengeya TA, Hoffman AC, Measey GJ, Weyl OL. 2017a. Distribution and establishment of the alien Australian redclaw crayfish, *Cherax quadricarinatus*, in South Africa and Swaziland. *PeerJ* 5**:** 1-21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF.2017b. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

MAN5 Control options and monitoring approaches available for the *Taxon*
Response: NO
References:

MAN6 Any other management considerations to highlight? (if yes, fill in Appendix MAN6)	
Response	Yes / No

5. Calculations

Likelihood = Probable

Parameter	**Likelihood**	**Stages**	**Final assessment**
LIK1	1	P(entry) = 1	P (invasion) = 1
LIK2	1		
LIK3	1	P(establishment) = 1	
LIK4	1		
LIK5	1	P (spread) = 1	
LIK6	1		

Consequence = MR

Parameter	**Mechanism/sector**	**Response**
CON1	**Maximum environmental impact**	**DD**
CON2	**Maximum socio-economic impact**	**DD**
CON3a	Competition	MR
CON3b	Predation	MR
CON3c	Hybridisation	MC
CON3d	Disease transmission	MR
CON3e	Parasitism	DD
CON3f	Poisoning/toxicity	MN
CON3g	Bio-fouling or other direct physical disturbance	DD
CON3h	Grazing/herbivory/browsing	MO
CON3i	Chemical, physical, structural impact	MN

CON3k	Indirect impacts through interactions with other species	DD
CON3	**Maximum environmental impact (closely related taxa)**	**MR**
CON4a	Safety	DD
CON4b	Material and immaterial assets	MO
CON4c	Health	MN
CON4d	Social, spiritual and cultural relations	MO
CON4	**Maximum socio-economic impact (closely related taxa)**	**MO**
CON5	Potential impact based on traits, experiments, or models	**MR**

Table S3: Risk score

		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	Low	Low	Low	Medium	Medium
	Very unlikely	Low	Low	Low	Medium	High
	Unlikely	Low	Low	Medium	High	High
	Fairly probable	Medium	Medium	High	High	High
	Probable	Medium	high	High	High	High

Table S4: Ease of management

Parameter	Question	Response
MAN3a	How accessible are populations?	1
MAN3b	Is detectability critically time-dependent?	0
MAN3c	Time to reproduction	2
MAN3d	Propagule persistence	NA
MAN3	**SUM**	3

Appendix BAC8(a): Global alien range of *Cherax quadricarinatus.* Map from CABI*:* https://www.cabi.org/isc/datasheet/89135

Appendix 3.4 Risk analysis report for Hairy marron (*Cherax tenuimanus*).

Risk Analysis Report

Taxon: *Cherax tenuimanus* (Smith, 1912)	**Area:** South Africa
Compiled by: Lee-Anne Botha	**Approved by:**
Picture of *Taxon*  https://phys.org/news/2014-01-captive-hairy-marron-populace-bolstered.html	**Alien distribution map**  Sourced from GBIF (2019)
Risk Assessment summary: The marron, *Cherax tenuimanus* was originally described in 1912 but a taxonomic revision in 2002 revealed that the species was not homogenous but instead consisted of genetically-distinct forms *C. tenuimanus* and *C. cainii*. The former is restricted to Margaret River in Australia and the latter is widespread and widely utilised for aquaculture. Introduction records of marron in South Africa prior to 2002 refer to *C. tenuimanus* but recent import permit records indicate that both species are likely present in the country, but this still needs to be genetically verified. In addition, there are no known naturalised populations of *C. tenuimanus* in South Africa but the potential for intentional and accidental release from aquaculture facilities into the wild is high. Escapees are able to disperse overland into adjacent river systems to colonise new areas. There is a lack of documented evidence of environmental and socio-economic impacts caused by *C. tenuimanus* in its alien range, and red swamp crayfish (*Procambaus clarkii*), a closely related species that has documented evidence of impacts in areas of introduction was used to infer the potential impacts of *C. tenuimanus*. Both species are functional omnivores and have the potential to cause multiple impacts at different levels of the food web. *Procambarus clarkii* has been implicated in causing major impacts on native communities through competition and predation leading to decreased abundance and local extirpation of native species. It is also known to cause habitat loss and modification through intensive grazing and stalk cutting of aquatic macrophytes that provide food, refuge and spawning sites (i.e., reproductive interference) for fish and other aquatic fauna. It is therefore likely that *C. tenuimanus* will cause similar impacts in areas of introduction.	**Risk score:** Medium
Management options summary: There are management protocols for the farming of marron in the Western Cape Province that aim to minimise the risk of escape from confinement and naturalisation. Similar protocols should be adopted by other provinces in the country. In the event that the species escapes, incursion response using biocides, as observed in New Zealand may be highly effective at eradicating localised populations. Therefore, early detection and response is crucial to prevent further spread.	**Ease of management:** Easy
Recommendations: *Cherax teniumanus* is currently listed a Category 2 under NEM:BA regulations; and the results of this Risk Analysis support this listing. There is however a need to genetically verify if the species is present in the country and if it is absent it should be delisted from the regulations.	**Listing under NEM:BA A&IS lists of 2014 as amended 2020:** Category 2

	Recommended listing category: Category 2/ Remove from list

1. Background

BAC1 Name of assessor(s)		
Name of lead assessor	**Lee-Anne Botha**	
Additional assessor (1)		
BAC2 Contact details of assessor (s)		
Lead assessor	Organisational affiliation: Department of Zoology and Entomology, University of Pretoria and The South African National Biodiversity Institute (SANBI).	
	email: u18389164@tuks.co.za	
	Phone: 072 833 7952	
Additional assessor (1)		
BAC3 Name(s) and contact details of expert(s) consulted		
Expert (1)	Name: Dr Tsungai Zengeya	
	email: T.Zengeya@sanbi.org.za	
	Phone: 021 799 8408	
Expert (2)	Name:	
	email:	
	Phone:	
Comments: Dr Tsungai Zengeya works for the South African National Biodiversity Institute (SANBI). His research interests are in freshwater ecology and biological invasions. He provided comments and inputs throughout the compilation of this risk analysis that improved its quality.		
BAC4 Scientific name of *Taxon* under assessment		
Taxon name: *Cherax tenuimanus*		Authority: (Smith, 1912)
Comments: *Cherax tenuimanus* was originally described by Smith in 1932 from the Margaret River in Western Australia (Austin and Ryan 2002). Examination of marron populations from different river systems in Australia however revealed two genetically distinct marron species, *C. tenuimanus* that is restricted to the Margaret River, Western Australia, and *C. cainii* which is widespread within south-west of Western Australia and other areas in South Australia and Victoria because of extensive introductions for aquaculture (Morrissy 1976; Austin and Ryan 2002).		
References: Austin CM, Ryan SG. 2002. Allozyme evidence for a new species of freshwater crayfish of genus *Cherax* Erichson (Decapoda: Parastacidae) from the south-west of Western Australia. *Invertebrate Systematics* 16: 357–367. Morrissy NM. 1976. Aquaculture of Marron, *Cherax tenuimanus* (Smith) Part 2: Breeding and Early Rearing. *Fisheries Research Bulletin of Western Australia* 17: 1–32.		

BAC5 Synonym(s) considered

Synonyms: None

Comments:
Cherax cainii and *C. tenuimanus* were initially classified as one, thus literature records prior to 2002 could be referring to either one of the two species (Austin and Ryan 2002). For this risk analysis, information on both species was used.

References:

Austin CM, Ryan SG. 2002. Allozyme evidence for a new species of freshwater crayfish of genus *Cherax* Erichson (Decapoda: Parastacidae) from the south-west of Western Australia. *Invertebrate Systematics* 16: 357–367.

BAC6 Common name(s) considered

Common names: hairy marron/ marron

Comments:
Cherax tenuimanus has two common names: hairy marron and marron (Austin and Ryan 2002; Beatty et al. 2004).

References:

Austin CM, Ryan SG. 2002. Allozyme evidence for a new species of freshwater crayfish of genus *Cherax* Erichson (Decapoda: Parastacidae) from the south-west of Western Australia. *Invertebrate Systematics* 16: 357-367.

Beatty SJ, Morgan DL, Gill HS. 2004. Biology of a translocated population of the large freshwater crayfish, *Cherax cainii* Austin & Ryan, 2002 in a Western Australian River. *Crustaceana* 77:1329–1351.

BAC7 What is the native range of the *Taxon*? (add map in Appendix BAC7)

Response: south-west of Western Australia	Confidence: High

Comments:
Cherax tenuimanus is native to the Margaret River that is located in south-west of Western Australia (Austin and Ryan 2002; Beatty et al. 2004).

References:

Austin CM, Ryan SG. 2002. Allozyme evidence for a new species of freshwater crayfish of genus *Cherax* Erichson (Decapoda: Parastacidae) form the south-west of Western Australia. *Invertebrate Systematics* 16: 357–367.

Beatty SJ, Morgan D, Gill HS. 2004. Biology of a translocated population of the large freshwater crayfish, *Cherax cainii* Austin & Ryan, 2002 in a Western Australian River. *Crustaceana* 77: 1329–1351.

https://www.cabi.org/isc/datasheet/89136

BAC8 What is the global alien range of the *Taxon*? (add map in Appendix BAC8)

Response: Australia	Confidence: Medium

Comments:
Cherax tenuimanus is largely restricted to the upper reaches of Margaret River but it has been translocated to river systems within this region and other states in Australia (Austin and Ryan 2002; Lawrence and Jones 2002; Beatty et al. 2004). It has also been introduced to South Africa for aquaculture (Zengeya and Wilson 2019).

References:

Austin CM, Ryan SG. 2002. Allozyme evidence for a new species of freshwater crayfish of genus *Cherax* Erichson (Decapoda: Parastacidae) form the south-west of Western Australia. *Invertebrate Systematics* 16: 357–367.

Beatty SJ, Morgan DL, Gill HS. 2004. Biology of a translocated population of the large freshwater crayfish, *Cherax cainii* Austin & Ryan, 2002 in a Western Australian River. *Crustaceana* 77: 1329–1351.

Lawrence C, Jones C. 2002. *Cherax*. In: Holdich DM (ed.) Biology of freshwater crayfish. Blackwell Science, U.K.

Zengeya TA, Wilson JR. (eds.) 2020. The status of biological invasions and their management in South Africa in 2019. South African National Biodiversity Institute, Kirstenbosch and DSI-NRF Centre of Excellence for Invasion Biology, Stellenbosch

https://www.cabi.org/isc/datasheet/89136

BAC9 Geographic scope = the *Area* under consideration

Area of assessment: South Africa

Comments: Geographic scope of assessment is limited to South Africa.

BAC10 Is the *Taxon* present in the *Area*?

Response: Yes	Confidence: Low

Comments:

Cherax tenuimanus is likely to be present in South Africa because there are import permits records that indicate that it was introduced for aquaculture but there are no known naturalised populations (Zengeya and Wilson 2019). A few aquaculture farms in Eastern and Western Cape are reportedly rearing marron but it is not clear which of the two species (*C. cainii* and/or *C. tenuimanus*) is been farmed (de Moor 2002; Nunes et al. 2017). It is assumed to be *C. cainii* because it's is widely utilised for aquaculture whereas *C. tenuimanus* seems to be largely restricted to the Margaret River, Australia (Austin and Ryan 2002; Beatty et al. 2004). There is therefore is a need for follow up studies to genetically verify the identity of the species utilised.

References:

Austin CM, Ryan SG. 2002. Allozyme evidence for a new species of freshwater crayfish of genus *Cherax* Erichson (Decapoda: Parastacidae) form the south-west of Western Australia. *Invertebrate Systematics* 16: 357–367.

Beatty SJ, Morgan DL, Gill HS. 2004. Biology of a translocated population of the large freshwater crayfish, *Cherax cainii* Austin & Ryan, 2002 in a Western Austral ian River. *Crustaceana* 77: 1329–1351.

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

Zengeya TA, Wilson JR. (eds.) 2020. The status of biological invasions and their management in South Africa in 2019. South African National Biodiversity Institute, Kirstenbosch and DSI-NRF Centre of Excellence for Invasion Biology, Stellenbosch.

BAC11 Availability of physical specimen

Response: Yes (Albany Museum, Grahamstown, South Africa)	Confidence in ID: Low

Herbarium or museum accession number: GEN 833A. Species was collected in South Africa, Arigata Fish Farm near Marina Beach (-30.9300000000, 30.27000000) and recorded as *Cherax teniumanus.*

References:

Albany Museum Grahamstown, South Africa

https://www.gbif.org/occurrence/1299981578

BAC12 Is the *Taxon* native to the *Area* or part of the *Area*?

The *Taxon* is native to (part of) the *Area*.	No	Confidence: High
The *Taxon* is alien in (part of) the *Area*.	Yes	Confidence: High

Comments:

Cherax tenuimanus is native to Australia and there are no freshwater crayfish native to South Africa (Austin and Ryan 2002, de Moor 2002, Nunes et al. 2017).

References:

Austin CM, Ryan SG. 2002. Allozyme evidence for a new species of freshwater crayfish of genus *Cherax* Erichson (Decapoda: Parastacidae) form the south-west of Western Australia. *Invertebrate Systematics* 16: 357–367.

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

BAC13 What is the *Taxon*'s introduction status in the *Area*?

The *Taxon* is in cultivation/containment.	Yes	Confidence: Low
The *Taxon* is present outside of cultivation/containment.	Unknown	Confidence: Low
The *Taxon* has established/naturalised.	Unknown	Confidence: Low
The *Taxon* is invasive.	Unknown	Confidence: Low

Comments:

Cherax tenuimanus are likely present in the country because there are import permit records for its introduction for aquaculture, however there are no known naturalised populations (de Moor 2002; Nunes et al. 2017; Zengeya and Wilson 2019).

References:

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF.2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

Zengeya TA, Wilson JR. (eds.) 2020. The status of biological invasions and their management in South Africa in 2019. South African National Biodiversity Institute, Kirstenbosch and DSI-NRF Centre of Excellence for Invasion Biology, Stellenbosch.

BAC14 Primary (introduction) pathways

Release	NA	Confidence:
Escape	Aquaculture	Confidence: Low
Contaminant	NA	Confidence:
Stowaway	NA	Confidence:
Corridor	NA	Confidence:
Unaided	NA	Confidence:

Comments:

Import permit records indicate that *C. tenuimanus* has been introduced for aquaculture in South Africa (de Moor 2002; Nunes et al. 2017; Zengeya and Wilson 2019).

References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. Zengeya TA, Wilson JR. (eds.) 2020. The status of biological invasions and their management in South Africa in 2019. South African National Biodiversity Institute, Kirstenbosch and DSI-NRF Centre of Excellence for Invasion Biology, Stellenbosch.

2. Likelihood

LIK1 Likelihood of entry via unaided primary pathways	
Response: Probable	Confidence: Low
Rationale: *Cherax tenuimanus* is already present in the country. Permit records indicate that *Cherax tenuimanus* has been introduced in South Africa for aquaculture (de Moor 2002; Zengeya and Wilson 2019). However, if it were in neighbouring countries it would be difficult to stop natural dispersal (Nunes et al. 2017).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. Zengeya TA, Wilson JR. (eds.) 2020. The status of biological invasions and their management in South Africa in 2019. South African National Biodiversity Institute, Kirstenbosch and DSI-NRF Centre of Excellence for Invasion Biology, Stellenbosch. https://www.cabi.org/isc/datasheet/89136	

LIK2 Likelihood of entry via human aided primary pathways	
Response: Probable	Confidence: Medium
Rationale: Permit records indicate that *Cherax tenuimanus* has been introduced in South Africa for aquaculture (de Moor 2002; Nunes et al. 2017; Zengeya and Wilson 2019). *Cherax tenuimanus* appears to be not popular in the pet trade industry (Faulkes 2015).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Faulkes, Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44:75–92. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. Zengeya TA, Wilson JR. (eds.) 2020. The status of biological invasions and their management in South Africa in 2019. South African National Biodiversity Institute, Kirstenbosch and DSI-NRF Centre of Excellence for Invasion Biology, Stellenbosch.	

LIK3 Habitat suitability	
Response: Fairly probable	Confidence: Medium
Rationale: *Cherax tenuimanus* occurs in deep perennial rivers and prefers sandy areas in rivers particularly where organic matter accumulates (Beatty et al. 2004). *Cherax tenuimanus* requires structural diversity for shelter and refuge (de Moor 2002). Areas susceptible to *C. tenuimanus* are cool permanent streams in the Highveld and in the southern and south-western Cape (Nunes et al. 2017).	
References: Beatty SJ, Morgan DL, Gill HS. 2004. Biology of a translocated population of the large freshwater crayfish, *Cherax cainii* Austin & Ryan, 2002 in a Western Australian River. *Crustaceana* 77: 1329–1351 de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.	

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309-323.

LIK4 Climate suitability	
Response: Fairly probable	Confidence: High
Rationale: *Cherax tenuimanus* has a thermal tolerance range of 8-29°C with an optimal range of 17-25°C. Growth ceases when temperature is <12.5 °C (Byrant and Papas 2007). The projected areas that are climatically suitable for marron in South Africa are located mainly in the eastern part of the country and a few areas in the Western Cape (Nunes et al. 2017). The suitable areas were mainly restricted to upland areas of the Greater Berg, Kromme, Great Kei, Mzimvubu, uMngeni, Phongolo, Crocodile and Limpopo catchment areas (Nunes et al. 2017).	
References: Bryant D, Papas P. 2007. Marron *Cherax cainii* (Austin) in Victoria – a literature review. Arthur Rylah Institute for Environmental Research Technical Report Series No. 167. (Department of Sustainability and Environment: Heidelberg). Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

LIK5 Unaided secondary (dispersal) pathways	
Response: Unlikely	Confidence: Medium
Rationale: There are no naturalised populations in South Africa or neighbouring countries that could act as sources for secondary dispersal (de Moor 2002; Nunes et al. 2017).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

LIK6 Human aided secondary (dispersal) pathways	
Response: Probable	Confidence: Medium
Rationale: *Cherax tenuimanus* is mainly used for aquaculture and the potential for intentional release is high (de Moor 2002; Bryant and Papas 2007; Nunes et al. 2017).	
References: Bryant D, Papas P. 2007. Marron *Cherax cainii* (Austin) in Victoria – a literature review. Arthur Rylah Institute for Environmental Research Technical Report Series No. 167. (Department of Sustainability and Environment: Heidelberg). de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

3. Consequences

CON1 Environmental impact	
CON1a: Competition	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON1b: Predation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	

References: L. Botha (Unpublished data).	
CON1c: Hybridisation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1d: Transmission of disease	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1e: Parasitism	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1f: Poisoning/toxicity	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1g: Bio-fouling or other direct physical disturbance	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1h: Grazing/herbivory/browsing	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1i: Chemical, physical or structural impact on ecosystem	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1 Maximum environmental impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact	
References: L. Botha (Unpublished data).	

CON2 Socio-economic impact	
CON2a: Safety	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data	
CON2b: Material and immaterial assets	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2c: Health	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2d: Social, spiritual and cultural relations	

Response: DD	Confidence: Low
Rationale:	
References: L. Botha (Unpublished data)	
CON2 Maximum socio-economic impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON3 Closely related species' environmental impact	
CON3a: Competition	
Response: MR	Confidence: Medium
Rationale: *Procambarus clarkii* is very aggressive and usually out-competes native species for shelter and spawning sites, and these often leads to reproductive interference (Cruz et al. 2006; Lodge et al. 2012). For example, in areas were *P. clarkii* has been introduced , some amphibian species (e.g., *Bufo bufo*, *B. calamita*, *Rana* sp., *Taricha torosa* and *Triturus vulgaris*) have been excluded or displaced from their natural habitats, resulting in local extinctions through reproductive failure (Cruz et al. 2006; Lodge et al. 2012). In addition, as a result of direct competition, there has been a decrease in the distributional ranges and abundance of native crayfish populations (*Astacus astacus*, *Austropotamobius pallipes* and *A. torrentium*) in some areas in Europe and Japan (Cruz et al. 2006; Lodge et al. 2012). Furthermore, direct competition for food has caused dietary niche constriction and declines in populations of native crabs in some areas invaded by *P. clarkii* (Jackson et al. 2016).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338. Jackson MC, Grey J, Miller K, Britton JR, Donohue I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology*, 85:1098–1107. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology*, *Evolution and Systematics* 43: 449–72.	
CON3b: Predation	
Response: MR	Confidence: Medium
Rationale: In its invasive range, there is evidence that predation by *P. clarkii* can result in the local or population extinctions of at least one native species (Lodge et al. 2012; Souty-Grosset et al. 2016). For example, *P. clarkii* has been implicated in causing population declines of several species of fish and amphibians by reducing their breeding success through predation on eggs and larval amphibians (Cruz et al. 2006; Ficetola et al. 2011). Indirect effects of predation can also cause trophic cascades that can lead to changes in ecosystem structure and function. For example, predation on invertebrates can release algae from grazing pressure and lead to changes in the abundance and dominance of species in algal communities (Gherardi and Barbaresi 2008).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338. Ficetola GF, Siesa ME, Manenti R, Bottoni L, De Bernardi F, Padoa-Schioppa E. 2011. Early assessment of the impact of alien species: Differential consequences of an invasive crayfish on adult and larval amphibians. *Diversity and Distributions* 17:1141–1151. Gherardi F, Barbaresi S. 2008. Feeding opportunism of the red swamp crayfish *Procambarus clarkia*, an invasive species. *Freshwater crayfish* 16: 77–85. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem	

services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON3c: Hybridisation

Response: MC	Confidence: Low

Rationale:

This is unlikely in South Africa because there are no native crayfish species (de Moor 2002; Nunes et al. 2017).

References:

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017b. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

CON3d: Transmission of disease

Response: MR	Confidence: High

Rationale:

Procambarus clarkii can harbour many pathogens, parasites, and diseases that can be transmitted to other congeneric species (Longshaw 2011; Lodge et al. 2012). There is evidence that transmission of diseases and parasites by *P. clarkii* to native species has caused local or population extinctions of at least one native species, leading to changes in community composition (Lodge et al. 2012). For example, *P. clarkii* is a vector of crayfish plague, a disease caused by the parasitic oomycete, *Aphanomyces astaci* (Aquiloni et al, 2011; Longshaw 2011; Souty-Grosset et al. 2016). In Europe, transmission of crayfish plague by *P. clarkii* to native crayfish species has been linked to a decline in populations of several native crayfish species of as *Astacus astacus*, *Austropotamobius pallipes* and *A. torrentium* (Holdich et al. 2009; Longshaw 2011). *Procambarus clarkii* can also harbour white spot syndrome disease – a viral infections of crustaceans, and fungal pathogens such as *Batrachochytrium dendrobatids* that causes chytridiomycosis – a lethal skin infection in amphibians (Longshaw 2011; McMahon et al. 2013).

References:

Aquiloni L, Martín MP, Gherardi F, Diéguez-Uribeondo J. 2011. The North American crayfish *Procambarus clarkii* is the carrier of the oomycete *Aphanomyces astaci* in Italy. *Biological Invasions* 13: 35–367.

Holdich, DM, Reynolds JD, Sibley P J. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems* 11:394–395.

Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449 –472.

Longshaw M. 2011. Diseases of crayfish: A review. *Journal of Invertebrate Pathology* 106: 54–70.

McMahon TA, Brannelly LA, Chatfield MW, Johnson PT, Joseph MB, McKenzie VJ, Richards-Zawacki CL, Venesky MD, Rohr JR. 2013. Chytrid fungus *Batrachochytrium dendrobatidis* has non-amphibian hosts and releases chemicals that cause pathology in the absence of infection. *Proceedings of the National Academy of Sciences of the United States of America* 110: 210–215.

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON3e: Parasitism

Response: DD	Confidence: Low

Rationale: No information is available to assess the level of impact.

References: L. Botha (Unpublished data).

CON3f: Poisoning/toxicity

Response: MN	Confidence: Medium

Rationale: See CON4c

References: See CON4c

CON3g: Bio-fouling or other direct physical disturbance

Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON3h: Grazing/herbivory/browsing	
Response: MO	Confidence: Medium
Rationale: Grazing by *P. clarkii* can lead to habitat loss and modification through the removal of macrophytes. Habitat loss can lead to a decline in populations of species that utilise the macrophyte stands as a food source, nesting sites, and as refugia from predation (Rosenthal et al. 2005). *Procambarus clarkii* can also cause changes to community composition through trophic cascades (Gherardi and Aquistapace 2007; Souty-Grosset et al. 2016). For example, in Lake Chozas (northwest Spain), grazing by *P. clarkii* caused a reduction in macrophyte communities and this impact cascaded up the food chain with declines in invertebrates, amphibians, and waterfowl (Rodriguez et al 2003). Grazing can also cause changes to community composition and structure, such as changing ecosystems from macrophyte-dominated areas with clear water, to turbid phytoplankton-dominated areas (Matsizaki et al. 2009). Excessive grazing can also lead to accelerated rates of important processes such as litter breakdown and decomposition (Gherardi and Aquistapace 2007; Souty-Grosset et al. 2016).	
References: Gherardi F, Acquistapace P. 2007. Invasive crayfish in Europe: The impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. *Freshwater Biology* 52: 1249–59. Matsuzaki SS, Usio N, Takamura N, Washitani I. 2009. Contrasting impacts of invasive engineers on freshwater ecosystems: An experiment and meta-analysis. *Oecologia* 158: 673–686. Rodríguez CF, Bécares E, Fernández-Aláez M. 2003. Shift from clear to turbid phase in Lake Chozas (NW Spain) due to the introduction of American red swamp crayfish (*Procambarus clarkii*). *Hydrobiologia* 506: 421–26. Rosenthal SK, Lodge DM, Mavuti KM, Muohi W, Ochieng P, Mungai BN, Mkoji GM. 2005. Comparing macrophyte herbivory by introduced Louisiana crayfish (*Procambarus clarkii*) (Crustacea: Cambaridea) and native Dytiscid beetles (*Cybister tripunctatus*) (Coleoptera: Dytiscidae), in Kenya. *African Journal of Aquatic Science* 30: 157–62. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON3i: Chemical, physical or structural impact on ecosystem	
Response: MN	Confidence: Medium
Rationale: **Water quality**: *Procambarus clarkii* is often considered an ecosystem engineer due to its ability to change ecosystems through its burrowing activities (Souty-Grosset et al. 2016). For example, its burrowing activities can cause a decrease in the water quality through bioturbation leading to increased turbidity and influx release of nutrients from sediments, often leading to algal blooms (Angeler et al. 2001; Yamamoto 2010). The impaired water quality also affects the quality of the habitats for other aquatic fauna (Angeler et al. 2001; Rodriguez et al. 2003). For example, increased turbidity can impede foraging and respiratory processes of fish (Rodriguez et al. 2003). **Erosion**: Burrowing activities can cause structural damage to river banks and increase bank erosion, and also cause damage to water retention infrastructure such as dam walls and dykes (Souty-Grosset et al. 2016).	
References: Angeler DG, Sánchez-Carrillo S, García G, Alvarez-Cobelas M. 2001. The influence of *Procambarus clarkii* (Cambaridae, Decapoda) on water quality and sediment characteristics in a Spanish floodplain wetland. *Hydrobiologia* 464: 89–98. Rodríguez CF, Bécares E, Fernández-Aláez M. 2003. Shift from clear to turbid phase in Lake Chozas (NW Spain) due to the introduction of American red swamp crayfish (*Procambarus clarkii*). *Hydrobiologia* 506: 421–26. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93. Yamamoto Y. 2010. Contribution of bioturbation by the red swamp crayfish *Procambarus clarkii* to the	

recruitment of bloom-forming cyanobacteria from sediment. *Journal of Limnology* 69: 102– 111.	
CON3k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: The information available is not sufficient to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON3 Maximum environmental impact (Figure S3)	
Response: MR	Confidence: Medium
Rationale: Direct predation and competition for food, shelter, and spawning sites have led to local extinctions and a decrease in the abundance of native amphibians and crayfish species (Cruz et al. 2006; Gherardi & Acquistapace 2007; Jackson et al. 2016). Impacts have been recorded in the Iberian Peninsula, Sweden, Italy (Gherardi and Acquistapace 2007), Japan, and U.S.A. (California) (Holdich et al. 2009; Lodge et al. 2012).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338. Gherardi F, Acquistapace P. 2007. Invasive crayfish in Europe: The impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. *Freshwater Biology* 52: 1249–59. Holdich, DM, Reynolds JD, Sibley P J. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems* 11:394–395 Jackson MC, Grey J, Miller K, Britton JR, Donohue I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology*, 85:1098–1107. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449 –472.	

CON4 Closely related species' socio-economic impact	
CON4a: Safety	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact	
References: L. Botha (Unpublished data).	
CON4b: Material and immaterial assets	
Response: MO	Confidence: Low
Rationale: *Procambarus clarkii* often inhabits agricultural fields and their burrowing activities can cause damage to infrastructure such as irrigation canals and dam walls (Lodge et al. 2012; Arce and Diéguez-Uribeondo 2015). Burrowing activities can also alter soil hydrology leading to water loss. Grazing causes crop damage and reduces yield (Anastácio et al. 2005; Arce and Diéguez-Uribeondo 2015). In Europe for example, *P. clarkii* affects rice production through field water loss, damage to rice field banks and ditches, direct consumption of rice seed and plants, and clogging of pipes (Anastácio et al. 2005; Souty-Grosset et al. 2016).	
References: Anastácio PM. Correia AM, Menino JP. 2005. Processes and patterns of plant destruction by crayfish: effects of crayfish size and developmental stages of rice. *Archiv für Hydrobiologie* 162: 37–51. Arce JA, Diéguez-Uribeondo J. 2015. Structural damage caused by the invasive crayfish *Procambarus clarkii* (Girard, 1852) in rice fields of the Iberian Peninsula: A study case. *Fundamental and Applied Limnology* 186: 259–269. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449-472. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red	

swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON4c: Health

Response: MN | Confidence: Medium

Rationale:

Procambarus clarkii can bio-accumulate toxins and metals from the environment (Gherardi et al. 2011; Alcorlo et al. 2016; Souty-Grosset et al. 2016). These pollutants are often harmful and can be transferred to higher food web levels through the consumption of affected crayfish by humans and predators such as otters, birds, and fish (Anda et al. 2001; Gherardi et al. 2011; Lodge et al. 2012).

Procambarus clarkii serves as vector for several parasites and diseases some of which are zoonotic, for example the parasitic fluke flatworms (*Paragonimus* spp.) that causes lung fluke disease in humans, tularemia-causing bacterium *Francisella tularensis*, rat lungworm *Angiostrongylus cantonensis* that causes meningitis, and the nematode *Gnathostoma spinigerum* that causes human gnathostomiasis (Edgerton et al. 2002; Lane et al 2009; Souty-Grosset et al. 2016).

References:

Alcorlo P, Otero M, Crehuet M, Baltanás A, Montes C. 2006. The use of the red swamp crayfish (*Procambarus clarkii* Girard) as indicator of the bioavailability of heavy metals in environmental monitoring in the River Guadiamar (SW Spain). *Science of the Total Environment* 366:380-–390.

Anda P, Segura del Pozo J, Díaz García JM, Escudero R, et al. 2001. Waterborne outbreak of tularemia associated with crayfish fishing. *Emerging Infectious Diseases* 7:575–82.

Edgerton BF, Evans LH, Stephens FJ, Overstreet RM. 2002. Synopsis of freshwater crayfish diseases and commensal organisms. *Aquaculture* 206: 57–135.

Gherardi F, Barbaresi S, Vaselli O, Bencini A. 2002. A comparison of trace metal accumulation in indigenous and alien freshwater macro-decapods. *Marine and Freshwater Behaviour and Physiology* 35:179–88.

Lane MA, Barsanti MC, Santos CA, Yeung M, Lubner SJ, Weil GJ. 2009. Human paragonimiasis in North America following ingestion of raw crayfish. *Clinical and Infectious Diseases* 49: 55–61.

Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–472.

CON4d: Social, spiritual and cultural relations

Response: MO | Confidence: Medium

Rationale:

Procambarus clarkii affects the fishing industry by damaging gill nets and spoiling the fish caught in the nets (Gherardi et al. 2011).

References:

Gherardi F, Robert FJ, Kenneth BB, Mavuti M, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological Conservation* 144: 2585–2596

CON4 Maximum socio-economic impact (Figure S3)

Response: MO | Confidence: Low

Rationale:

In its invaded range *P. clarkii* had caused harmful impacts in agricultural fields (Anastácio et al. 2005) and has disrupted some recreational activities leading to economic loss Gherardi et al. 2011).

References:

Alcorlo P, Otero M, Crehuet M, Baltanás A, Montes C. 2006. The use of the red swamp crayfish (*Procambarus clarkii* Girard) as indicator of the bioavailability of heavy metals in environmental monitoring in the River Guadiamar (SW Spain). *Science of the Total Environment* 366:380—390.

Gherardi F, Barbaresi S, Vaselli O, Bencini A. 2002. A comparison of trace metal accumulation in indigenous and alien freshwater macro-decapods. *Marine and Freshwater Behaviour and Physiology* 35:179–88.

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON5 Potential impact	
Response: MO	Confidence: Low
Rationale: In South Africa, there are no freshwater crayfish species but other closely related decapods such as crabs are likely to have broad habitat and trophic overlaps (Jackson et al. 2016). The outcome of such resource overlap between *C. tenuimanus* and indigenous fauna is unknown, but given that *P. clarkii* has caused adverse impact in other areas of introduction there is a cause of concern for possible impacts of *C. tenuimanus* in South African river systems (Lodge et al. 2012). Another major concern is the transmission of diseases to native decapods and other freshwater fauna (Tavakol et al. 2016). The potential for hybridisation in South Africa is very unlikely as there are no native freshwater crayfish (de Moor 2002). There are no known naturalised populations in the wild, although, should *C. tenuimanus* be present in South Africa, it is most likely confined to aquaculture facilities (Zengeya and Wilson 2019). In the event that it manages to escape from such facilities, it's very unlikely that it will spread rapidly due to its low tolerance to a wide range of environmental conditions (Byrant and Pappas 2007).	
References: Bryant D, Papas P. 2007. Marron *Cherax cainii* (Austin) in Victoria – a literature review. Arthur Rylah Institute for Environmental Research Technical Report Series No. 167. (Department of Sustainability and Environment: Heidelberg). de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African Journal of Aquatic Science 27: 125–139. Jackson MC, Grey J, Miller K, Britton, JR, Donohue, I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology*, 85:1098–1107. Lodge DM, Deines A, Gherardi, F, Yeo, DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology Evolution Systematics* 43: 449–72. Tavakol S, Luus-Powell WJ, Smit WJ, Baker C, Hoffman A, AlHalajian A. 2016. First introduction of two Australian Temnocephalan species into Africa with an alien host: Double Trouble. *Journal of Parasitology* 102: 653–658. Zengeya, T.A. & Wilson, J.R. (eds.) 2020. The status of biological invasions and their management in South Africa in 2019. South African National Biodiversity Institute, Kirstenbosch and DSI-NRF Centre of Excellence for Invasion Biology, Stellenbosch.	

4. Management

MAN1 What is the feasibility to stop future immigration?	
Response: High	Confidence: Low
Rationale: *Cherax tenuimanus* is mainly used for aquaculture and there are no known wild populations in neighbouring countries (Burgess 2007; de Moor 2002; Nunes et al. 2017). However, if it were in neighbouring countries it would be difficult to stop natural dispersal (Nunes et al. 2017).	
References: Burgess M. 2007. Pioneers of SA marron production. Farmer's Weekly Magazine. Mon 30 April 2007. http://www.farmersweekly.co.za/article.aspx?id=520&h=Pioneers-of-SA-marron-production de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

MAN2 Benefits of the Taxon	
MAN2a Socio-economic benefits of the *Taxon*	
Response: Medium	Confidence: Low

Rationale: Production of crayfish in South Africa has had mixed success because of several challenges that have been encountered in trying to farm the species (Nunes et al. 2017). As a result, marron aquaculture has been mainly restricted to a few small scale aquaculture farms in Eastern Cape and Western Cape (Madzivanzira et al. 2020).
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey, GJ, Weyl, OLF. 2017. Freshwater crayfish invasions In South Africa: past, present and potential future *African Journal of Aquatic Science* 42: 309–323.

MAN2b Environmental benefits of the *Taxon*	
Response: None	Confidence: Low
Rationale: No documented information available.	
References: L. Botha (Unpublished data).	

MAN3 Ease of management	
MAN3a How accessible are populations?	
Response: 0	Confidence: Low
Rationale: There are records of permit applications at CapeNature to import marron for aquaculture. A follow up study needs to be undertaken to check if farms are still in production and to ascertain the identity of the species utilised (de Moor 2002; Burgess 2007; Nunes et al. 2017). There is uncertainty on the species utilised (see taxonomy notes)	
References: Burgess M. 2007. Pioneers of SA marron production. Farmer's Weekly Magazine. Mon 30 April 2007. http://www.farmersweekly.co.za/article.aspx?id=520&h=Pioneers-of-SA-marron-production de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	
MAN3b Is detectability critically time-dependent?	
Response: 0	Confidence: Low
Rationale: *Cherax tenuimanus* can be detected throughout the year, although species seem to be more active at night (Bryrant and Papas 2007).	
References: Bryant D, Papas P. 2007. Marron *Cherax cainii* (Austin) in Victoria – a literature review. Arthur Rylah Institute for Environmental Research Technical Report Series No. 167. (Department of Sustainability and Environment: Heidelberg).	
MAN3c Time to reproduction	
Response: 1	Confidence: Low
Rationale: *Cherax tenuimanus* reaches sexual maturity when two to three years (Beatty et al.2004).	
References: Beatty SJ, Morgan DL, Gill HS. 2004. Biology of a translocated population of the large freshwater crayfish, *Cherax cainii* Austin & Ryan, 2002 in a Western Australian River. *Crustaceana*, 77: 1329–1351.	
MAN3d Propagule persistence	
Response: NA	Confidence: NA
Rationale: *Cherax tenuimanus* is an invertebrate	
References:	

MAN3 Ease of management (SUM from Table S4)	
Response: Easy	Confidence: Low
Rationale: There are no known wild populations in the country. It is assumed that *C. tenuimanus* individuals are confined to aquaculture facilities in Eastern and Western Cape (de Moor 2002, Nunes et al. 2017, Madzivanzira et al. 2020). In addition, some provinces e.g. Western Cape has management plans in place to prevent escape and introduction into the wild.	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

MAN4 Has the feasibility of eradication been evaluated?	
Response: No	Confidence: Low
Rationale:' Currently there are no known wild populations in the country (de Moor 2002; Nunes et al. 2017). It is assumed that species are confined to aquaculture facilities, thus eradication feasibility could be evaluated if necessary (Nunes et al. 2017; Madzivanzira et al. 2020).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. Gould B. 2005. Marron. Interagency collaboration follows surprise catch. Biosecurity 60: 10–11.	

MAN5 Control options and monitoring approaches available for the *Taxon*
Response: Yes
References: *Cherax tenuimnanus* is susceptible to use of biocides e.g. in New Zealand biocides have been used to control and eradicate marron crayfish (Gould 2005).

MAN6 Any other management considerations to highlight? (if yes, fill in Appendix MAN6)	
Response	No

5. Calculations

Likelihood = Fairly probable

Parameter	Likelihood	Stages	Final assessment
LIK1	1	P(entry) = 1	P (invasion) = 0.5
LIK2	1		
LIK3	0.5	P(establishment) = 0.5	
LIK4	0.5		
LIK5	0.027	P (spread) = 1	
LIK6	1		

Consequence = MR

Parameter	Mechanism/sector	Response
CON1	**Maximum environmental impact**	**DD**
CON2	**Maximum socio-economic impact**	**DD**
CON3a	Competition	MR
CON3b	Predation	MR
CON3c	Hybridisation	MC
CON3d	Disease transmission	MR
CON3e	Parasitism	DD
CON3f	Poisoning/toxicity	MN
CON3g	Bio-fouling or other direct physical disturbance	DD
CON3h	Grazing/herbivory/browsing	MO
CON3i	Chemical, physical, structural impact	MN
CON3k	Indirect impacts through interactions with other species	DD
CON3	**Maximum environmental impact (closely related taxa)**	**MR**
CON4a	Safety	DD
CON4b	Material and immaterial assets	MO
CON4c	Health	MN
CON4d	Social, spiritual and cultural relations	MO
CON4	**Maximum socio-economic impact (closely related taxa)**	**MO**
CON5	Potential impact based on traits, experiments, or models	**MO**

Table S3: Risk score = High

		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	Low	Low	Low	Medium	Medium
	Very unlikely	Low	Low	Low	Medium	High
	Unlikely	Low	Low	Medium	High	High
	Fairly probable	Medium	Medium	High	High	High
	Probable	Medium	high	high	high	high

Table S4: Ease of management = Easy

Parameter	Question	Response
MAN3a	How accessible are populations?	0
MAN3b	Is detectability critically time-dependent?	0
MAN3c	Time to reproduction	1
MAN3d	Propagule persistence	0
MAN3	**SUM**	1

BAC8(a): Global alien range of *Cherax tenuimanus.* Sourced from GBIF (2019).
https://www.gbif.org/species/4648604

Appendix 3.5 Risk analysis report for Calico crayfish (*Faxonius immunis*).

Risk Analysis Report

***Taxon*:** *Faxonius immunis* (Hagen, 1870)	***Area*:** South Africa
Compiled by: Lee-Anne Botha	**Approved by:**
Picture of *Taxon*  https://alchetron.com/Orconectes-immunis	**Alien distribution map**  https://www.gbif.org/species/2227004

Risk Assessment summary: The current distribution for Calico crayfish (*Faxonius immunis*) is restricted to North America and Europe. The likelihood of entry into South Africa via unaided pathways is very unlikely because there are no known neighbouring countries where connected waterways may act as a source of entry. *Faxonius immunis* is present but considered rare in the pet trade industry. This pathway of introduction however, still remains a cause for concern. There are no documented impacts of *F. immunis* but thare are for *F. rusticus*, a closely related species, that has been implicated in causing detrimental impacts in its invaded range. Native fish and crayfish species have been displaced by *F. rusticus* as a result of competition. The opportunistic feeding behavior of *F. rusticus* has contributed to the decline in freshwater macrophytes (grazing) and invertebrate communities (direct predation). *Faxonius immunis* is likely to have similar impacts in areas of introduction and is a vector for the crayfish plague which may be transferred to native decapod species. *Faxoniuss immunis* also digs burrows, which allow it to occupy shallow and temporary water bodies that can cause structural damage to ecosystems.	**Risk score:** High
Management options summary: *Faxonius immunis* is not present in South Africa. Manegemnt efforts should thererofe be directed at preventing introductions. Eslewhere, where it has managed to establish populations, there has been no successful eradication attempt. However, there has been successful control interventions for some closely related species, such as *F. rusticus*, using a combination of techniques, for example, intensive trapping and fish predation that has manged to reduce population densities in invasived areas..	**Ease of management:** NA
Recommendations: *Faxoius immunis* is currently not listed under the NEM:BA Alien and Invasive Species (A&IS) regulations. There are no records of its occurrence in either South Africa or neighbouring countries. The results from this Risk Analysis supports the current listing of the specis. Illegal pet trade industry still poses a significant risk of intentional release of species into the wild. There is therefore, a need to assess the trade of, and movement of the species through the pet trade and it use as bait in recreational angling	**Listing under NEM:BA A&IS lists of 2014 as amended 2020:** Not listed **Recommended listing category:** No change

1. Background

BAC1 Name of assessor(s)	
Name of lead assessor	**Lee-Anne Botha**
Additional assessor (1)	
Additional assessor (2)	
BAC2 Contact details of assessor (s)	
Lead assessor	Organisational affiliation: University of Pretoria, Department of Zoology and Entomology/ SANBI
	email: u18389164@tuks.co.za
	Phone: 072 833 7952
Additional assessor (1)	Organisational affiliation:
	email:
	Phone:
Additional assessor (2)	Organisational affiliation:
	email:
	Phone:
BAC3 Name(s) and contact details of expert(s) consulted	
Expert (1)	Name: Dr Tsungai Zengeya
	email: T.Zengeya@sanbi.org.za
	Phone: 021 799 8408
Expert (2)	Name:
	email:
	Phone:
Comments: Dr Tsungai Zengeya works for the South African National Biodiversity Institute (SANBI). His research interests are in freshwater ecology and biological invasions. He provided comments and inputs throughout the compilation of this risk analysis that improved its quality.	
BAC4 Scientific name of *Taxon* under assessment	
Taxon name: *Faxonius immunis*	Authority: (Hagen, 1870)
Comments: *Faxonius immunis* has been reclassified in 2019 (Crandall and De Grave 2017). The group of surface-dwelling crayfish in the *Orconectes* genus was moved to *Faxonius* (Crandall and De Grave 2017, CABI 2019).	
References: Crandall KA, De Grave S, 2017. An updated classification of the freshwater crayfishes (Decapoda: Astacidea) of the world, with a complete species list. *Journal of Crustacean Biology* 27: 615–653.	
BAC5 Synonym(s) considered	
Synonyms:	

Comments: The crayfish inhibiting caves and the surface dwelling crayfish was split into two groups (Crandall and De Grave 2017). The non-cave dwelling crayfish in the *Orconectes* genus was moved to *Faxonius* (Crandall and De Grave 2017).	
References: Crandall KA, De Grave S, 2017. An updated classification of the freshwater crayfishes (Decapoda: Astacidea) of the world, with a complete species list. *Journal of Crustacean Biology* 27: 615–653.	
BAC6 Common name(s) considered	
Common names: Calico crayfish	
Comments: Adams S, Schuster GA, Taylor CA. 2010. *Orconectes immunis. The IUCN Red List of ThreatenedSpecies2010*:e.T153925A4564415.http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T153925A4564415.en	
References:	
BAC7 What is the native range of the *Taxon*? (add map in Appendix BAC7)	
Response: Canada and United States	Confidence: Low
Comments:	
References: Soes M, Koese B. 2010. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis.	
BAC8 What is the global alien range of the *Taxon*? (add map in Appendix BAC8)	
Response: Germany and France	Confidence: Medium
Comments:	
References: Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems* 11*:*1–46. Soes M, Koese B. 2010. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis.Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis.	
BAC9 Geographic scope = the *Area* under consideration	
Area of assessment: South Africa	
Comments:	
BAC10 Is the *Taxon* present in the *Area*?	
Response: No	Confidence: low
Comments: There are no records of species being in the country (Nunes et al. 2017). *Faxonius immunis* might be present through the pet trade, although this needs to be assessed (Chucholl 2012; Faulkes 2015).	
References: Chucholl, C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141. Faulkes, Z, 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

BAC11 Availability of physical specimen	
Response:	Confidence in ID:
Herbarium or museum accession number:	
References:	

BAC12 Is the *Taxon* native to the *Area* or part of the *Area*?		
The *Taxon* is native to (part of) the *Area*.	No	Confidence: High
The *Taxon* is alien in (part of) the *Area*.	Yes	Confidence: High
Comments: South Africa has no indigenous freshwater crayfish (de Moor 2002, Nunes et al. 2017).		
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.		

BAC13 What is the *Taxon*'s introduction status in the *Area*?		
The *Taxon* is in cultivation/containment.	Don't know	Confidence: Low
The *Taxon* is present in the wild.	No	Confidence: Low
The *Taxon* has established/naturalised.	No	Confidence: Low
The *Taxon* is invasive.	No	Confidence: Low
Comments: There are only records for the introduction of four freshwater crayfish into South Africa that include: *Cherax destructor*, *C. cainii/tenuimanus*, *C. quadricarinatus* and *Procrambarus clarkii* (de Moor 2002, Nunes et al. 2017).		
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.		

BAC14 Primary (introduction) pathways		
Release	NA	Confidence:
Escape	Aquarium trade	Confidence: High
Contaminant	NA	Confidence:
Stowaway	NA	Confidence:
Corridor	NA	Confidence:
Unaided	NA	Confidence:
Comments:		

References: Chucholl, C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141. Faulkes, Z, 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems* 11*:*1–46

2. Likelihood

LIK1 Likelihood of entry via unaided primary pathways	
Response: Very unlikely	Confidence: low
Rationale: There is no wild populations in neighbouring countries that could act as source for unaided introductions Nunes et al. 2017; Madzivanzira et al. 2020).	
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020. A Review of Freshwater Crayfish Introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

LIK2 Likelihood of entry via human aided primary pathways	
Response: Unlikely	Confidence: Low
Rationale: *Faxonius immunis* is present in the pet trade, however it is considered rare and has only been found in the Germany and the United States of America (Chucholl 2013; Faulkes 2015).	
References: Chucholl C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141. Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44**:** 75–92.	

LIK3 Habitat suitability	
Response: Fairly probable	Confidence: low
Rationale: This is a generalist species can occupy a variety of freshwater habitats (Adams et al 2010). Examples include ponds, floodplains, drainage ditches and small sluggish streams. It can also occur in higher gradient gravel-bedded streams (Chucholl 2009; Soes and Koese 2010). The substrate in the habitats of this species is generally soft mud or clay with abundant aquatic vegetation. *Faxonius immunis* can travel across dry ground, especially in wet weather enabling the species to colonise new areas (Chucholl 2009; Soes and Koese 2010). Despite the broad ecological niche of *Faxonius immunis*, it is unable to colonise fast flowing streams, restricting its distribution (Chucholl 2009; Soes and Koese 2010). *Faxonius immunis* are known to dig deep burrows, which allow it to occupy shallow and temporary water bodies (Chucholl 2009; Soes and Koese 2010).	
References: Adams S, Schuster GA, Taylor CA. 2010. *Orconectes immunis. The IUCN Red List of Threatened Species 2010*: e.T153925A4564415. Chucholl C., 2009. The 'new comer' *Orconectes immunis* keeps spreading in the upper Rhine plain. *Crayfish News: IAA Newsletter* 31: 4–5. Soes M, Koese B, 2010. Invasive freshwater crayfish in the Netherlands: a preliminary riskanalysis. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis	

LIK4 Climate suitability	
Response: Fairly probable	Confidence: Low
Rationale: *No climate data available for Faxonius immunis,* however, closely related species, *F. rusticus* prefers well	

oxygenated water and a temperature range of 20-25°C but can withstand seasonal water temperatures of 0-39°C within its native range (GISD 2015). In temperatures over 30°C, adults have been observed digging burrows to escape the heat (GISD 2015).
References: Global Invasive Species Database (GISD) 2015. Species profile *Orconectes rusticus*.Available from: http://www.iucngisd.org/gisd/species.php?sc=217 [Accessed 03 July2018]

LIK5 Unaided secondary (dispersal) pathways	
Response: Very unlikely	Confidence: low
Rationale: There are no wild populations in South Africa or neighbouring countries, thus unaided secondary dispersal through connected waterways is very unlikely (Madzivanzira et al. 2020).	
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020. A Review of Freshwater Crayfish Introductions in Africa. *Reviews in fisheries science & aquaculture* 1–21.	

LIK6 Human aided secondary (dispersal) pathways	
Response: Fairly probable	Confidence: low
Rationale: *Orconectes immunis* has been released into the wild by humans as unwanted pets in areas of introduction (Holdich et al 2009; Soes and Koese 2010; Faulkes 2015).	
References: Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44**:** 75–92. Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems* 11*:*1–46 Soes M, Koese B. 2010. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis	

3. Consequences

CON1 Environmental impact	
CON1a: Competition	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON1b: Predation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1c: Hybridisation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1d: Transmission of disease	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1e: Parasitism	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1f: Poisoning/toxicity	
Response: DD	Confidence: Low

Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1g: Bio-fouling or other direct physical disturbance	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1h: Grazing/herbivory/browsing	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1i: Chemical, physical or structural impact on ecosystem	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1 Maximum environmental impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact	
References: L. Botha (Unpublished data).	

CON2 Socio-economic impact	
CON2a: Safety	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data	
CON2b: Material and immaterial assets	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2c: Health	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2d: Social, spiritual and cultural relations	
Response: DD	Confidence: Low
Rationale:	
References: L. Botha (Unpublished data)	
CON2 Maximum socio-economic impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON3 Closely related species' Environmental impact	
CON3a: Competition	
Response: MO	Confidence: Medium
Rationale: *Faxonius rusticus* is a fierce competitor and is known to displace native crayfish in areas of introduction through the exclusion of resources (Klocker and Strayer 2004, Lodge et al. 2012). *Faxonius rusticus* is	

relatively bigger in body size (and has a larger chela) than its native congenerics (Garvey and Stein 1993). A feature which predisposes it to physically out-compete its congenerics for resources. For example, *F. rusticus* has displaced native crayfish (*F. propinquus F. sanborni* and *F. virilis*) in its invasive range through direct competition for food and shelter. In addition, the displaced native species become more susceptible to predation because of a lack of shelter (Garvey and Stein 19993, Byron and Wilson 200, Lodge et al. 2012).

References:

Byron CJ, Wilson KA. 2001. Rusty crayfish (*Orconectes rusticus*) movement within and between habitats in Trout Lake, Vilas County, Wisconsin. *Journal of the North American Benthological Society* 20: 606–614.

Garvey JE, Stein RA. 1993. Evaluating how chela size influences the invasion potential of an introduced crayfish (*Orconectes rusticus*). *American Midland Naturalist 129:* 172–181.

Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178.

Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.

https://www.cabi.org/isc/datasheet/72037

CON3b: Predation

Response: MO	Confidence: Medium

Rationale:

Direct predation by *Faxonius rusticus* on native fauna has caused a decline in population size of at least one native species in areas of introduction (Johnson et al. 2009). For example, predation on fish eggs by *F. rusticus* has led to declines in population size and community composition in Vilas County, Winsconsin, U.S.A (Jonas et al. 2005).

Faxonius rusticus is also known to feed on invertebrates, and in Trout Lake, Wisconsin, U.S.A, direct predation on invertebrate communities has led to a decrease in the mean abundance of several invertebrates orders such as Odonata, Amphipoda and Trichoptera (Lodge et al. 2005, Klocker and Strayer 2004, Wilson et al. 2004, Kreps et al. 2012).

References:

Johnson PT, Olden JD, Solomon CT, Vander Zanden MJ. 2009. Interactions among Invaders: Community and ecosystem effects of multiple invasive species in an experimental aquatic system. *Oecologia* 159: 161–170.

Jonas JL, Claramunt RM, Fitzsimons JD, Marsden JE, Ellrott BJ. 2005. Estimates of egg deposition and effects of lake trout (*Salvelinus namaycush*) egg predators in three regions of the Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 62: 2254–2264.

Kreps TA, Baldridge AK, Lodge DM. 2012. The impact of an invasive predator (*Orconectes rusticus*) on freshwater snail communities: Insights on habitat-specific effects from a multilake long-term study.*Canadian Journal of Fisheries and Aquatic Sciences* 69:1164–1173.

Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178

Lodge DM, Kershner MW, Aloi JE.1995. Effects of an omnivorous crayfish (*Orconectes rusticus*) on a freshwater littoral food web. *Ecology* 75: 1265–1281.

Wilson KA., Magnuson JJ, Lodge DM, Hill AM, Kratz, TK, Perry WL, Willis TV. 2004. A long-term rusty crayfish (*Orconectes rusticus*) invasion: Dispersal patterns and community change in a north temperate lake. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 2255–2266.

CON3c: Hybridisation

Response: MO	Confidence: Low

Rationale:

Hybridisation is known to occur among congenerics of *F. rusticus* (Perry et al. 2001). However, this is unlikely to occur in South Africa because there are no native crayfish species (Lodge et al. 2012).

References:

Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.

Perry WL, Feder JL, Dwyer G, Lodge DM. 2001. Hybrid zone dynamics and species replacement between *Orconectes* crayfishes in a northern Wisconsin lake. *Evolution* 55: 1153–1166.

Perry WL, Feder JL, Lodge DM. 2001. Implications of hybridization between introduced and resident *Orconectes* crayfishes. *Conservation Biology* 15: 1656–1666.

CON3d: Transmission of disease

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (unpublished data).

CON3e: Parasitism

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data).

CON3f: Poisoning/toxicity

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data).

CON3g: Bio-fouling or other direct physical disturbance

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data).

CON3h: Grazing/herbivory/browsing

Response: MO	Confidence: Medium

Rationale:
Faxonius rusticus is a functional omnivore and feed readily on freshwater macrophytes in its invaded range, altering community structure (Roth et al. 2006). For example, in Lake Michigan, U.S.A *F. rusticus* reduced the macrophyte abundance and species richness by 80% (Wilson et al. 2004).

References:
Roth BM, Hein, CL, Vander Zanden MJ, 2006. Using bioenergetics and stable isotopes to assess the trophic role of rusty crayfish (*Orconectes rusticus*) in lake littoral zones.*Canadian Journal of Fisheries and Aquatic Sciences* 63**:** 335–344.

Wilson KA., Magnuson JJ, Lodge DM, Hill AM, Kratz, TK, Perry WL, Willis TV. 2004. A long-term rusty crayfish (*Orconectes rusticus*) invasion: Dispersal patterns and community change in a north temperate lake. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 2255–2266.

CON3i: Chemical, physical or structural impact on ecosystem

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data).

CON3k: Indirect impacts through interactions with other species

Response: MO	Confidence: Medium

Rationale:
In its invasive range, *Faxonius rusticus* may occur with other alien species, and interactions with other these

species could facilitate impacts that ultimately lead to a decline in population size of native fauna.
In the United States of America, *F. rusticus* occurs with another invasive snail, *Bellamya chinesis* that has a thick shell that prevents predation from rusty crayfish (Johnson et al. 2009). However, competition and predation pressure from both invasive species have reduced native snail biomass immensely (Johnson et al. 2009).

References:

Johnson PT, Olden JD, Solomon CT, Vander Zanden MJ. 2009. Interactions among Invaders: Community and ecosystem effects of multiple invasive species in an experimental aquatic system.*Oecologia* 159: 161–170.

CON3 Maximum environmental impact (Figure S3)

Response: MO	Confidence: Medium

Rationale:
In areas of introduction, direct predation, competition for food, shelter and spawning sites have led to local extinctions and a decrease in the abundance of native crayfish and fish species (Garvey and Stein 1993, Klocker and Strayer 2004).

References:

Garvey JE, Stein RA. 1993. Evaluating how chela size influences the invasion potential of an introduced crayfish (*Orconectes rusticus*). *American Midland Naturalist* 129: 172–181.

Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178.

Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.

CON4 Closely related species Socio-economic impact

CON4a: Safety

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data).

CON4b: Material and immaterial assets

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data).

CON4c: Health

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data).

CON4d: Social, spiritual and cultural relations

Response: MO	Confidence: Low

Rationale:
Faxonius rusticus invasions can disrupt recreational activities in the invaded range. This can ultimately affect the well-being of humans because they can no longer participate in these activities (Keller et al. 2008). In Vilas County, *F. rusticus* has reduced sport fish populations though egg predation and/or competition with juveniles. Consequently, this leads to an estimated annual loss of 1.5 million US dollars (Keller et al. 2008).

References:
Keller RP, Frang K, Lodge DM. 2008. Preventing the spread of invasive species: Economic benefits of

intervention guided by ecological predictions. *Conservation Biology* 22: 80–88.

CON4 Maximum socio-economic impact (Figure S3)	
Response: MO	Confidence: Low

Rationale:
Faxonius rusticus invasions have caused disruption in recreational activities by reducing sport fish populations though egg predation and/or competition with juveniles (Keller et al. 2008).

References:
Keller RP, Frang K, Lodge DM. 2008. Preventing the spread of invasive species: Economic benefits of intervention guided by ecological predictions. *Conservation Biology* 22: 80–88.

CON5 Potential impact	
Response: MV	Confidence: High

Rationale:
Based on the risk assessment done for *Faxonius rusticus* which is the closely related species, *F. immunis* may impact multiple trophic levels within the invaded freshwater ecosystem (Lodge et al. 2012; Holdich et al 2009). *Faxonius immunis* is a functional omnivore and may also have detrimental impacts on macroinvertebrates and macrophyte communities in areas where invaded (Klocker and Strayer 2004; Roth et al 2006 Kreps et al 2012). They can also influence the occurrence and species composition of fish communities (Keller et al. 2008). In addition, being a vector for the crayfish plague is another cause of concern because this disease may be transferable and could be detrimental for native freshwater crustaceans in South Africa (Lodge et al. 2012).
Orconectes immunis also digs deep burrows, which allow it to occupy shallow and temporary water bodies. Burrowing activities by invasive crayfish species may destabilise riverbanks, causing erosion (Chucholl 2009; Soes and Koese 2010).

References:
Chucholl C. 2009. The ‘new comer’ *Orconectes immunis* keeps spreading in the upper Rhine plain. *Crayfish News: IAA Newsletter* 31:.4–5.
Keller RP, Frang K, Lodge DM. 2008. Preventing the spread of invasive species: Economic benefits of intervention guided by ecological predictions. *Conservation Biology* 22: 80–88
Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178.
Kreps TA, Baldridge AK, Lodge DM. 2012. The impact of an invasive predator (*Orconectes rusticus*) on freshwater snail communities: Insights on habitat-specific effects from a multilake long-term study. *Canadian Journal of Fisheries and Aquatic Sciences* 69:1164–1173.
Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.
Roth BM, Hein, CL, Vander Zanden MJ, 2006. Using bioenergetics and stable isotopes to assess the trophic role of rusty crayfish (*Orconectes rusticus*) in lake littoral zones. *Canadian Journal of Fisheries and Aquatic Sciences* 63: 335–344.
Soes M, Koese B. 2010. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis.

4. Management

MAN1 What is the feasibility to stop future immigration?	
Response: High	Confidence: low

Rationale:
There are no known populations in neighbouring countries, thus species entering via unaided primary pathways is very low. *Faxonius immunis* is however present the pet trade industry in the Germany and the

U.S.A (Chucholl 2013, Faulkes 2015). Should the species be traded illegally as pets, it would be challenging to prevent future introductions, and *Faxonius immunis* might already be in South Africa. Thus, the trading of this species still needs to be assessed thoroughly.
References: Chucholl C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125-141. Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92.

MAN2 Benefits of the Taxon	
MAN2a Socio-economic benefits of the *Taxon*	
Response: None	Confidence: low
Rationale:	
References:	
MAN2b Environmental benefits of the *Taxon*	
Response: None	Confidence: low
Rationale:	
References:	

MAN3 Ease of management (Table 4)	
Response: NA	Confidence:
Rationale:	
References:	
MAN3a How accessible are populations?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3b Is detectability critically time-dependent?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3c Time to reproduction	
Response: NA	Confidence:
Rationale:	
References:	
MAN3d Propagule persistence	
Response: NA	Confidence:
Rationale:	
References:	
MAN3 Ease of management (Table 4)	
Response: NA	Confidence:
Rationale:	
References:	

MAN4 Has the feasibility of eradication been evaluated?	
Response: No	Confidence: Low
Rationale: In areas of introduction, where it has managed to establish populations, there has been no successful eradication attempt. Generally, once crayfish species have established and have become widespread, it is impossible to eradicate (Gherardi et al 2011). They are very hardy and if chemical control is considered large quantities are needed to kill crayfish and biocides have been used to eradicate crayfish populations elsewhere (Gherardi et al. 2011). Furthermore, the chemicals used are not specific to crayfish and can also extirpate other freshwater species within the same freshwater ecosystem (Ghrardi et al. 2011). However, when species are restricted to dams, mechanical control via traps, electrofishing could still be feasible (Gherardi et al 2011).	
References: Gherardi F, Aquiloni L, Diéguez-Uribeondo J, Tricarico E. 2011. Managing invasive crayfish: is there a hope?.*Aquatic Sciences* 73: 185–200.	

MAN5 Control options and monitoring approaches available for the *Taxon*
Response: Not assessed
References:

MAN6 Any other management considerations to highlight? (if yes, fill in Appendix MAN6)	
Response	Yes / No

5. Calculations

Likelihood = Unlikely

Parameter	Likelihood	Stages	Final assessment
LIK1	Very unlikely	P(entry) = 0.027	P (invasion) = 0.006
LIK2	Unlikely		
LIK3	Fairly Probable	P(establishment) = 0.5	
LIK4	Fairly Probable		
LIK5	Very unlikely	P (spread) = 0.5	
LIK6	Fairly probable		

Consequence = MR (Major)

Parameter	Mechanism/sector	Response
CON1	**Maximum environmental impact**	**DD**
CON2	**Maximum socio-economic impact**	**DD**
CON3a	Competition	MO
CON3b	Predation	MO
CON3c	Hybridisation	MO
CON3d	Disease transmission	DD
CON3e	Parasitism	DD
CON3f	Poisoning/toxicity	DD
CON3g	Bio-fouling or other direct physical disturbance	DD
CON3h	Grazing/herbivory/browsing	MO
CON3i	Chemical, physical, structural impact	DD
CON3k	Indirect impacts through interactions with other species	MO
CON3	**Maximum environmental impact (closely related taxa)**	**MO**
CON4a	Safety	DD
CON4b	Material and immaterial assets	DD

CON4c	Health	DD
CON4d	Social, spiritual and cultural relations	MN
CON4	**Maximum socio-economic impact (closely related taxa)**	**MN**
CON5	Potential impact based on traits, experiments, or models	**MR**

Table S3: Risk score

		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	low	low	low	medium	medium
	Very unlikely	low	low	low	medium	high
	Unlikely	low	low	medium	high	high
	Fairly probable	medium	medium	high	high	high
	Probable	medium	high	high	high	high

Table S4: Ease of management

Parameter	Question	Response
MAN3a	How accessible are populations?	0
MAN3b	Is detectability critically time-dependent?	0
MAN3c	Time to reproduction	0
MAN3d	Propagule persistence	0
MAN3	**SUM**	0

Appendix BAC7: Global alien range for *Orconectes immunis*
Map from GBIF: https://www.gbif.org/species/2227004

Appendix 3.6 Risk analysis report for Kentucky River crayfish (*Faxonius juvenilis*).

Risk Analysis Report

Taxon: *Faxonius juvenilis* (Hagen, 1870)	***Area***: South Africa
Compiled by: Lee-Anne Botha	**Approved by:**
Picture of *Taxon*  Chucholl & Daudey,. 2008.	**Alien distribution map**  **https://www.gbif.org/species/5789975**

Risk Assessment summary: Kentucky River crayfish (*Faxonius juvenilis*) is not widely distributed and is only known from one location in France. The likelihood of entry into South Africa via unaided pathways is very unlikely because there are no known populations in neighbouring countries where connected waterways may act as a source of entry. *Faxonius juvenilis* has not been found in the pet trade yet and is considered rare. This pathway of introduction however, still remains a cause for concern. There is no information on impacts caused by F. juvenilis and therefore impacts were inferred from *F. rusticus*, a closely related species, has been implicated in causing detrimental impacts in its invaded range. Native fish and crayfish species have been displaced by *F. rusticus* as a result of competition. The opportunistic feeding behavior of *F. rusticus* has contributed to the decline in freshwater macrophytes (grazing) and invertebrate communities (direct predation). *Faxonius juvenilis* is likely to have similar impacts in areas of introduction.	**Risk score:** Medium
Management options summary: The species not in present in South Africa. Maagement effort should therefore be directed at preventing introduction. It may be possible to control established as demonstrated by the reduction of population densities of *F. rusticus* through a combination of techniques, for example, intensive trapping and fish predation its invasive range	**Ease of management:** NA
Recommendations: The species is currently not listed under the NEM:BA Alien and Invasive species (A&IS) regulations. The results from this Risk Analysis support the current listing of this species because there are no records of the species being present in the country or neighbouring countries. Illegal pet trade industry still poses a significant risk of intentional release of species into the wild. There is therefore, a need to assess the trade of, and movement of the species through the pet trade and bait industry.	**Listing under NEM:BA A&IS lists of 2014 as amended 2020:** Not listed **Recommended listing category:** No change

1. Background

BAC1 Name of assessor(s)	
Name of lead assessor	**Lee-Anne Botha**
Additional assessor (1)	
Additional assessor (2)	
BAC2 Contact details of assessor (s)	
Lead assessor	Organisational affiliation: University of Pretoria, Department of Zoology and Entomology/ SANBI
	email: u18389164@tuks.co.za
	Phone: 072 833 7952
Additional assessor (1)	Organisational affiliation:
	email:
	Phone:
Additional assessor (2)	Organisational affiliation:
	email:
	Phone:
BAC3 Name(s) and contact details of expert(s) consulted	
Expert (1)	Name: Dr Tsungai Zengeya
	email: T.Zengeya@sanbi.org.za
	Phone: 021 799 8408
Expert (2)	Name:
	email:
	Phone:
Comments: Dr Tsungai Zengeya works for the South African National Biodiversity Institute (SANBI). His research interests are in freshwater ecology and biological invasions. He provided comments and inputs throughout the compilation of this risk analysis that improved its quality.	
BAC4 Scientific name of *Taxon* under assessment	
Taxon name: *Faxonius juvenilis*	Authority: (Hagen,1870)
Comments: *Faxonius juvenilis* has been reclassified in 2019 (Crandall and De Grave 2017). The group of surface-dwelling crayfish in the *Orconectes* genus was moved to *Faxonius* (Crandall and De Grave 2017, CABI 2019).	
References: Crandall KA, De Grave S, 2017. An updated classification of the freshwater crayfishes (Decapoda: Astacidea) of the world, with a complete species list. *Journal of Crustacean Biology* 27: 615–653.	
BAC5 Synonym(s) considered	

Synonyms:

Comments:
The crayfish inhibiting caves and the surface dwelling crayfish was split into two groups (Crandall and De Grave 2017). The non-cave dwelling crayfish in the *Orconectes* genus was moved to *Faxonius* (Crandall and De Grave 2017).

References:
Crandall KA, De Grave S, 2017. An updated classification of the freshwater crayfishes (Decapoda: Astacidea) of the world, with a complete species list. *Journal of Crustacean Biology* 27: 615–653.

BAC6 Common name(s) considered

Common names: Kentucky River crayfish

Comments:

References:
Adams S, Schuster GA, Taylor CA. 2010. *Orconectes juvenilis*. *The IUCN Red List of Threatened Species* 2010:e.T153954A4568495.

BAC7 What is the native range of the *Taxon*? (add map in Appendix BAC7)

Response: United States (Indiana, Kentucky)	Confidence: low

Comments:

References:
Adams S, Schuster GA, Taylor CA. 2010. *Orconectes juvenilis*. *The IUCN Red List of Threatened Species* 2010:e.T153954A4568495.

BAC8 What is the global alien range of the *Taxon*? (add map in Appendix BAC8)

Response: France	Confidence: Medium

Comments:

References:
Chucholl C, Daude, T. 2008. First record of *Orconectes juvenilis* (Hagen, 1870) in eastern France: update to the species identity of a recently introduced orconectid crayfish (Crustacea: Astacida). *Aquatic Invasions* 3:105–107.

BAC9 Geographic scope = the *Area* under consideration

Area of assessment: South Africa

Comments:

BAC10 Is the *Taxon* present in the *Area*?

Response: No	Confidence: Low

Comments:
There are no records of species being in the country (Nunes et al. 2017). *Faxonius juvenilis* might be present through the pet trade, although this needs to be assessed (Chucholl 2012; Faulkes 2015).

References:
Chucholl C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141.
Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92.
Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323

BAC11 Availability of physical specimen

Response:	Confidence in ID:

Herbarium or museum accession number:		
References:		
BAC12 Is the *Taxon* native to the *Area* or part of the *Area*?		
The *Taxon* is native to (part of) the *Area*.	No	Confidence: High
The *Taxon* is alien in (part of) the *Area*.	Yes	Confidence: High
Comments: South Africa has no indigenous freshwater crayfish (de Moor 2002, Nunes et al. 2017).		
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139 Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.		
BAC13 What is the *Taxon*'s introduction status in the *Area*?		
The *Taxon* is in cultivation/containment.	Unknown	Confidence: Low
The *Taxon* is present in the wild.	No	Confidence: Low
The *Taxon* has established/naturalised.	No	Confidence: Low
The *Taxon* is invasive.	No	Confidence: Low
Comments: There are only records for the introduction of four freshwater crayfish into South Africa that include: *Cherax destructor*, *C. cainii/tenuimanus*, *C. quadricarinatus* and *Procrambarus clarkii* (de Moor 2002, Nunes et al. 2017).		
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139 Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.		
BAC14 Primary (introduction) pathways		
Release	NA	Confidence:
Escape	Consumption trade	Confidence: High
Contaminant	NA	Confidence:
Stowaway	NA	Confidence:
Corridor	NA	Confidence:
Unaided	NA	Confidence:
Comments: It is suspected that individuals escaped from a breeding population in ponds at a restaurant advertising crayfish as a delicacy into the Dessoubre river in eastern France where it was discovered in 2005 and has since become established. In 2006 it was found to have colonized at least a 700 m stretch of the river.		
References: Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems* 11:1–46.		

2. Likelihood

LIK1 Likelihood of entry via unaided primary pathways

Response: Very unlikely	Confidence: Low
Rationale: There are no records of wild populations in South Africa or in neighbouring countries that could act as source for unaided introductions (Holdich et al. 2009; Nunes et al. 2019; Madzivanzira et al. 2020).	
References: Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems* 11:1–46. Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

LIK2 Likelihood of entry via human aided primary pathways	
Response: Unlikely	Confidence: Low
Rationale: Species are considered rare in the pet trade and there are currently no records of it present in the trade industry (Holdich et al. 2009; Chucholl 2013)	
References: Chucholl C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish.*Biological Invasions* 15: 125–141. Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems* 11:1–46.	

LIK3 Habitat suitability	
Response: Fairly probable	Confidence: Low
Rationale: This species inhabits streams and creeks with gravel, cobble and mud substrates Chucholl and Daude 2008).	
References: Chucholl C, Daude T. 2008. First record of *Orconectes juvenilis* (Hagen, 1870) in eastern France: update to the species identity of a recently introduced orconectid crayfish (Crustacea: Astacida).*Aquatic Invasions* 3:105–107.	

LIK4 Climate suitability	
Response: Fairly probable	Confidence: Low
Rationale: *No climate data available for O.juvenilis*, however, closely related species, *F. rusticus* prefers well oxygenated water and a temperature range of 20-25°C but can withstand seasonal water temperatures of 0-39°C within its native range (GISD 2015). In temperatures over 30°C, adults have been observed digging burrows to escape the heat (GISD 2015).	
References: **Global Invasive Species Database** (GISD) 2015. Species profile *Orconectes rusticus*. Available from: http://www.iucngisd.org/gisd/species.php?sc=217 [Accessed 03 July2018].	

LIK5 Unaided secondary (dispersal) pathways	
Response: Very unlikely	Confidence: Low
Rationale: Currently this is very unlikely due to no feral populations present in neighbouring countries that could disperse naturally through connected waterways (Nunes et al. 2019; Madzivanzira et al. 2020). However, should species enter the country, it is important to note that all crayfish species are mobile and therefore not restricted to waterways and can migrate overland to colonise new areas (Holdich et al. 2009; Soes and Koese 2010).	
References: Holdich DM, Reynolds, JD, Souty-Grosset C, Sibley PJ, 2009. A review of the ever increasing threat to	

European crayfish from non-indigenous crayfish species. *Knowledge and management of aquatic ecosystems* 11: 394–395.
Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21.
Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.
Soes M, Koese B. 2010. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis.

LIK6 Human aided secondary (dispersal) pathways	
Response: Unlikely	Confidence: Low
Rationale: Crayfish can be released into the wild by humans that have them as pets. *Faxonius juvenilis* is however not present in the trade (Chucholl 2013; Faulkes 2015).	
References: Chucholl C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish.*Biological Invasions* 15: 125–141. Faulkes Z. 2015. The global trade in crayfish as pets.*Crustacean Research* 44: 75–92.	

3. Consequences

CON1 Environmental impact	
CON1a: Competition	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON1b: Predation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1c: Hybridisation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1d: Transmission of disease	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1e: Parasitism	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1f: Poisoning/toxicity	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1g: Bio-fouling or other direct physical disturbance	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1h: Grazing/herbivory/browsing	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON1i: Chemical, physical or structural impact on ecosystem	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1 Maximum environmental impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact	
References: L. Botha (Unpublished data).	

CON2 Socio-economic impact	
CON2a: Safety	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data	
CON2b: Material and immaterial assets	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2c: Health	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2d: Social, spiritual and cultural relations	
Response: DD	Confidence: Low
Rationale:	
References: L. Botha (Unpublished data)	
CON2 Maximum socio-economic impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON3 Closely related species' Environmental impact	
CON3a: Competition	
Response: MO	Confidence: Medium
Rationale: *Faxonius rusticus* is a fierce competitor and is known to displace native crayfish in areas of introduction through the exclusion of resources (Klocker and Strayer 2004, Lodge et al. 2012). *Faxonius rusticus* is relatively bigger in body size (and has a larger chela) than its native congenerics (Garvey and Stein 1993). A feature which predisposes it to physically out-compete its congenerics for resources. For example, *F. rusticus* has displaced native crayfish (*F. propinquus F. sanborni* and *F. virilis*) in its invasive range through direct competition for food and shelter. In addition, the displaced native species become more susceptible to predation because of a lack of shelter (Garvey and Stein 19993, Byron and Wilson 200, Lodge et al. 2012).	
References: Byron CJ, Wilson KA. 2001. Rusty crayfish (*Orconectes rusticus*) movement within and between habitats in Trout Lake, Vilas County, Wisconsin. *Journal of the North American Benthological Society* 20: 606–614. Garvey JE, Stein RA. 1993. Evaluating how chela size influences the invasion potential of an introduced	

crayfish (*Orconectes rusticus*). *American Midland Naturalist 129:* 172–181.
Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178.
Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.
https://www.cabi.org/isc/datasheet/72037

CON3b: Predation

Response: MR	Confidence: Medium

Rationale:

Direct predation by *Faxonius rusticus* on native fauna has caused a decline in population size of at least one native species in areas of introduction (Johnson et al. 2009). For example, predation on fish eggs by *F. rusticus* has led to declines in population size and community composition in Vilas County, Winsconsin, U.S.A (Jonas et al. 2005).

Faxonius rusticus is also known to feed on invertebrates, and in Trout Lake, Wisconsin, U.S.A, direct predation on invertebrate communities has led to a decrease in the mean abundance of several invertebrates orders such as Odonata, Amphipoda and Trichoptera (Lodge et al. 2005, Klocker and Strayer 2004, Wilson et al. 2004, Kreps et al. 2012).

References:

Johnson PT, Olden JD, Solomon CT, Vander Zanden MJ. 2009. Interactions among Invaders: Community and ecosystem effects of multiple invasive species in an experimental aquatic system. *Oecologia* 159: 161–170.
Jonas JL, Claramunt RM, Fitzsimons JD, Marsden JE, Ellrott BJ. 2005. Estimates of egg deposition and effects of lake trout (*Salvelinus namaycush*) egg predators in three regions of the Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 62: 2254–2264.
Kreps TA, Baldridge AK, Lodge DM. 2012. The impact of an invasive predator (*Orconectes rusticus*) on freshwater snail communities: Insights on habitat-specific effects from a multilake long-term study. *Canadian Journal of Fisheries and Aquatic Sciences* 69:1164–1173.
Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178
Lodge DM, Kershner MW, Aloi JE.1995. Effects of an omnivorous crayfish (*Orconectes rusticus*) on a freshwater littoral food web. *Ecology* 75: 1265–1281.
Wilson KA., Magnuson JJ, Lodge DM, Hill AM, Kratz, TK, Perry WL, Willis TV. 2004. A long-term rusty crayfish (*Orconectes rusticus*) invasion: Dispersal patterns and community change in a north temperate lake. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 2255–2266.

CON3c: Hybridisation

Response: MO	Confidence: Low

Rationale:

Hybridisation is known to occur among congenerics of *F. rusticus* (Perry et al. 2001). However, this is unlikely to occur in South Africa because there are no native crayfish species (Lodge et al. 2012).

References:

Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.
Perry WL, Feder JL, Dwyer G, Lodge DM. 2001. Hybrid zone dynamics and species replacement between *Orconectes* crayfishes in a northern Wisconsin lake.*Evolution* 55**:** 1153–1166.
Perry WL, Feder JL, Lodge DM. 2001. Implications of hybridization between introduced and resident *Orconectes* crayfishes. *Conservation Biology* 15: 1656–1666.

CON3d: Transmission of disease

Response: DD	Confidence: Low

Rationale: No information is available to assess the level of impact.	
References: L. Botha (unpublished data).	
CON3e: Parasitism	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON3f: Poisoning/toxicity	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON3g: Bio-fouling or other direct physical disturbance	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON3h: Grazing/herbivory/browsing	
Response: MR	Confidence: Medium
Rationale: *Faxonius rusticus* is a functional omnivore and feed readily on freshwater macrophytes in its invaded range, altering community structure (Roth et al. 2006). For example, in Lake Michigan, U.S.A *F. rusticus* reduced the macrophyte abundance and species richness by 80% (Wilson et al. 2004).	
References: Roth BM, Hein, CL, Vander Zanden MJ, 2006. Using bioenergetics and stable isotopes to assess the trophic role of rusty crayfish (*Orconectes rusticus*) in lake littoral zones. *Canadian Journal of Fisheries and Aquatic Sciences* 63: 335–344. Wilson KA., Magnuson JJ, Lodge DM, Hill AM, Kratz, TK, Perry WL, Willis TV. 2004. A long-term rusty crayfish (*Orconectes rusticus*) invasion: Dispersal patterns and community change in a north temperate lake. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 2255–2266.	
CON3i: Chemical, physical or structural impact on ecosystem	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON3k: Indirect impacts through interactions with other species	
Response: MO	Confidence: Medium
Rationale: In its invasive range, *Faxonius rusticus* may occur with other alien species, and interactions with other these species could facilitate impacts that ultimately lead to a decline in population size of native fauna. In the United States of America, *F. rusticus* occurs with another invasive snail, *Bellamya chinesis* that has a thick shell that prevents predation from rusty crayfish (Johnson et al. 2009). However, competition and predation pressure from both invasive species have reduced native snail biomass immensely (Johnson et al. 2009).	
References: Johnson PT, Olden JD, Solomon CT, Vander Zanden MJ. 2009. Interactions among Invaders: Community and ecosystem effects of multiple invasive species in an experimental aquatic system. *Oecologia* 159: 161–170.	

CON3 Maximum environmental impact (Figure S3)	
Response: MO	Confidence: Medium
Rationale: In areas of introduction, direct predation, competition for food, shelter and spawning sites have led to local extinctions and a decrease in the abundance of native crayfish and fish species (Garvey and Stein 1993, Klocker and Strayer 2004).	
References: Garvey JE, Stein RA. 1993. Evaluating how chela size influences the invasion potential of an introduced crayfish (*Orconectes rusticus*). *American Midland Naturalist* 129: 172–181. Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11**:**167–178. Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.	

CON4 Closely related species' Socio-economic impact	
CON4a: Safety	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON4b: Material and immaterial assets	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON4c: Health	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON4d: Social, spiritual and cultural relations	
Response: MO	Confidence: Low
Rationale: *Faxonius rusticus* invasions can disrupt recreational activities in the invaded range. This can ultimately affect the well-being of humans because they can no longer participate in these activities (Keller et al. 2008). In Vilas County, *F. rusticus* has reduced sport fish populations though egg predation and/or competition with juveniles. Consequently, this leads to an estimated annual loss of 1.5 million US dollars (Keller et al. 2008).	
References: Keller RP, Frang K, Lodge DM. 2008. Preventing the spread of invasive species: Economic benefits of intervention guided by ecological predictions. *Conservation Biology* 22: 80–88.	
CON4 Maximum socio-economic impact (Figure S3)	
Response: MO	Confidence: Low
Rationale: *Faxonius rusticus* invasions have caused disruption in recreational activities by reducing sport fish populations though egg predation and/or competition with juveniles (Keller et al. 2008).	
References:	

Keller RP, Frang K, Lodge DM. 2008. Preventing the spread of invasive species: Economic benefits of intervention guided by ecological predictions. *Conservation Biology* 22: 80–88.

CON5 Potential impact	
Response: MR	Confidence: High
Rationale: Similar to the closely related species (*Faxonius rusticus*) used for the impact assessment. *Faxonius juvenilis* may outcompete native freshwater crab species in South Africa, displacing it in freshwater ecosystems (Jackson et al. 2016). Being a functional omnivore, this species may also have detrimental impacts on macroinvertebrates and macrophyte communities in areas where invaded (Klocker and Strayer 2004; Roth et al. 2006; Kreps et al 2012). They can also influence occurrence and species composition of fish communities (Keller et al. 2008). In addition, being a vector for the crayfish plague is another cause of concern (Lodge et al. 2012). This disease may be transferable and could be detrimental to native freshwater crustaceans in South Africa.	
References: Keller RP, Frang K, Lodge DM. 2008. Preventing the spread of invasive species: Economic benefits of intervention guided by ecological predictions. *Conservation Biology* 22: 80–88 Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178. Kreps TA, Baldridge AK, Lodge DM. 2012. The impact of an invasive predator (*Orconectes rusticus*) on freshwater snail communities: Insights on habitat-specific effects from a multilake long-term study. *Canadian Journal of Fisheries and Aquatic Sciences* 69:1164–1173. Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. Roth BM, Hein, CL, Vander Zanden MJ, 2006. Using bioenergetics and stable isotopes to assess the trophic role of rusty crayfish (*Orconectes rusticus*) in lake littoral zones. *Canadian Journal of Fisheries and Aquatic Sciences* 63: 335–344.	

4. Management

MAN1 What is the feasibility to stop future immigration?	
Response: High	Confidence: low
Rationale: There are no known wild populations in neighbouring countries, thus the probability *F. juvenilis* entering via unaided primary pathways is very low. *Faxonius juvenilis has* also not been found present the pet trade industry (Chucholl 2013, Faulkes 2015). Should the species be traded illegally as pets, it would be challenging to prevent future introductions, and *Faxonius juvenilis* might already be in South Africa. Thus, the trading of this species still needs to be assessed thoroughly.	
References: Chucholl, C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish.*Biological Invasions* 15: 125–141. Faulkes Z, 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

MAN2 Benefits of the Taxon
MAN2a Socio-economic benefits of the *Taxon*

Response: None	Confidence: low
Rationale:	
References:	
MAN2b Environmental benefits of the *Taxon*	
Response: None	Confidence: low
Rationale:	
References:	

MAN3 Ease of management (Table 4)	
Response: NA	Confidence:
Rationale:	
References:	
MAN3a How accessible are populations?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3b Is detectability critically time-dependent?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3c Time to reproduction	
Response: NA	Confidence:
Rationale:	
References:	
MAN3d Propagule persistence	
Response: NA	Confidence:
Rationale:	
References:	
MAN3 Ease of management (Table 4)	
Response: NA	Confidence:
Rationale:	
References:	

MAN4 Has the feasibility of eradication been evaluated?	
Response: No	Confidence: Low
Rationale: In areas of introduction, where it has managed to establish populations, there has been no successful eradication attempt. Generally, once crayfish species have established and become widespread, it is impossible to eradicate them (Gherardi et al 2011). They are very hardy and if chemical control is considered large quantities are needed to kill crayfish and biocides have been used to eradicate crayfish populations elsewhere (Gherardi et al. 2011).	

Furthermore, the chemicals used are not specific to crayfish and can also extirpate other freshwater species within the same freshwater ecosystem (Ghrardi et al. 2011). However, when species are restricted to dams, mechanical control via traps, electrofishing could still be feasible (Gherardi et al 2011).
References: Gherardi F, Aquiloni L, Diéguez-Uribeondo J, Tricarico E. 2011. Managing invasive crayfish: is there a hope?. *Aquatic Sciences* 73**:** 185–200.

MAN5 Control options and monitoring approaches available for the *Taxon*
Response:
References:

MAN6 Any other management considerations to highlight? (if yes, fill in Appendix MAN6)	
Response	Yes / No

5. Calculations

Likelihood = Very unlikely

Parameter	**Likelihood**	**Stages**	**Final assessment**
LIK1	0.0027	P(entry) = Unlikely	P (invasion) = 0.003
LIK2	0.027		
LIK3	0.5	P(establishment) = Fairly probable	
LIK4	0.5		
LIK5	0.0027	P (spread) = Unlikely	
LIK6	0.027		

Consequence = MR (Major)

Parameter	**Mechanism/sector**	**Response**
CON1	**Maximum environmental impact**	**DD**
CON2	**Maximum socio-economic impact**	**DD**
CON3a	Competition	MO
CON3b	Predation	MR
CON3c	Hybridisation	MO
CON3d	Disease transmission	DD
CON3e	Parasitism	DD
CON3f	Poisoning/toxicity	DD
CON3g	Bio-fouling or other direct physical disturbance	DD
CON3h	Grazing/herbivory/browsing	MR
CON3i	Chemical, physical, structural impact	DD
CON3k	Indirect impacts through interactions with other species	MO
CON3	**Maximum environmental impact (closely related taxa)**	**MO**
CON4a	Safety	DD
CON4b	Material and immaterial assets	DD
CON4c	Health	DD
CON4d	Social, spiritual and cultural relations	MN
CON4	**Maximum socio-economic impact (closely related taxa)**	**MN**
CON5	Potential impact based on traits, experiments, or models	**MR**

Risk = Medium

		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	low	low	low	medium	medium
	Very unlikely	low	low	low	medium	high
	Unlikely	low	low	medium	high	high
	Fairly probable	medium	medium	high	high	high
	Probable	medium	high	high	high	high

Table S4: Ease of management

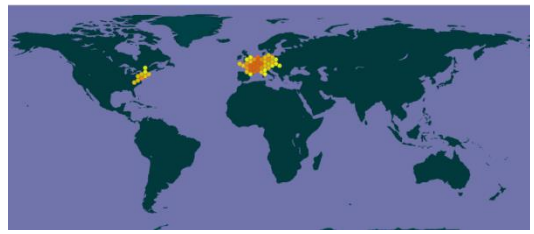
Parameter	Question	Response
MAN3a	How accessible are populations?	0
MAN3b	Is detectability critically time-dependent?	0
MAN3c	Time to reproduction	0
MAN3d	Propagule persistence	0
MAN3	**SUM**	0

Appendix BAC7: Global alien range of *Orconectes juvenilis*
Map from GBIF: https://www.gbif.org/species/5789975

Appendix 3.7 Risk analysis report for Spiny-cheek crayfish (*Faxonius limosus*).

Risk Analysis Report

<table>
<tr><td>Taxon:
Faxonius limosus (Rafinesque, 1817)</td><td>Area:
South Africa</td></tr>
<tr><td>Compiled by:
Lee-Anne Botha</td><td>Approved by:</td></tr>
<tr><td>Picture of Taxon

NOBANIS_Orconectes limosus</td><td>Alien distribution map

https://www.gbif.org/species/2227000</td></tr>
</table>

<table>
<tr><td>Risk Assessment summary:
The Spiny-cheek crayfish (Faxonius limosus), native to North Ameriaca has been widely distributed in Europe. However, the likelihood of entry into South Africa via unaided pathways is very unlikely because there are no known populations in neighbouring countries where connected waterways may act as a source of entry. Faxonius limosus is present in the pet trade in a few countries, thus the illegal pet trade still remain a cause for concern. There are no doumnetd impacts from F. limosus, therefore impacts were inferred from Faxonius rusticus, a closely related species, has been implicated in causing detrimental impacts in its invaded range. Native fish and crayfish species have been displaced by F. rusticus as a result of competition. The opportunistic feeding behavior of F. rusticus has contributed to the decline in freshwater macrophytes (grazing) and invertebrate communities (direct predation). Faxonius limosus is likely to have similar impacts in areas of introduction. Faxonius limosus is also a vector for crayfish plague that decimated native freshwater crayfish in Europe, and this disease may be transmitted to native freshwater crustaceans in South Africa.</td><td>Risk score:

High</td></tr>
<tr><td>Management options summary:
The species not in present in South Africa. Management effort should therefore be directed at preventing introduction. It may be possible to control established as demonstrated by the reduction of population densities of F. rusticus through a combination of techniques, for example, intensive trapping and fish predation its invasive range.</td><td>Ease of management:

NA</td></tr>
<tr><td rowspan="2">Recommendations:
Faxonius limosus is currently listed as Category 1a under the NEM:BA Alien and Invasive Species (A&IS) Regulations. The results from this Risk Analysis recommend removing it from the list because there are no records of its occurrence in either South Africa or neighbouring countries. Illegal pet trade industry still poses a significant risk of intentional release of species into the wild. There is therefore, a need to assess the trade of, and movement of the species through the pet trade and bait industry.</td><td>Listing under NEM:BA A&IS lists of 2014 as amended 2020:
Category 1a</td></tr>
<tr><td>Recommended listing category:
Remove from list</td></tr>
</table>

1. Background

BAC1 Name of assessor(s)	
Name of lead assessor	**Lee-Anne Botha**
Additional assessor (1)	
Additional assessor (2)	

BAC2 Contact details of assessor (s)	
Lead assessor	Organisational affiliation: University of Pretoria, Department of Zoology and Entomology/ SANBI
	email: u18389164@tuks.co.za
	Phone: 072 833 7952
Additional assessor (1)	Organisational affiliation:
	email:
	Phone:
Additional assessor (2)	Organisational affiliation:
	email:
	Phone:

BAC3 Name(s) and contact details of expert(s) consulted	
Expert (1)	Name: Dr Tsungai Zengeya
	email: T.Zengeya@sanbi.org.za
	Phone: 021 799 8408
Expert (2)	Name:
	email:
	Phone:

Comments:
Dr Tsungai Zengeya works for the South African National Biodiversity Institute (SANBI). His research interests are in freshwater ecology and biological invasions. He provided comments and inputs throughout the compilation of this risk analysis that improved its quality.

BAC4 Scientific name of *Taxon* under assessment	
Taxon name: *Faxonius limosus*	Authority:(Rafinesque,1817)

Comments:
Faxonius limosus has been reclassified in 2019 (Crandall and De Grave 2017). The group of surface-dwelling crayfish in the *Orconectes* genus was moved to *Faxonius* (Crandall and De Grave 2017, CABI 2019).

References:
Crandall KA, De Grave S, 2017. An updated classification of the freshwater crayfishes (Decapoda: Astacidea) of the world, with a complete species list. *Journal of Crustacean Biology* 27: 615–653.

BAC5 Synonym(s) considered

Synonyms: *Cambarus affinis* *Cambarus limosus* *Orconectes limosus*	
Comments: The crayfish inhibiting caves and the surface dwelling crayfish was split into two groups (Crandall and De Grave 2017). The non-cave dwelling crayfish in the *Orconectes* genus was moved to *Faxonius* (Crandall and De Grave 2017).	
References: Crandall KA, De Grave S, 2017. An updated classification of the freshwater crayfishes (Decapoda: Astacidea) of the world, with a complete species list. *Journal of Crustacean Biology* 27: 615–653. Alekhnovich A, Buřič M. 2017: NOBANIS – Invasive Alien Species Fact Sheet – *Orconectes limosus*. – From : Online Database of the European Network on Invasive Alien Species – NOBANIS www.nobanis.org, Date of access 22/01/2019	
BAC6 Common name(s) considered	
Common names: Spinycheek crayfish	
Comments: Adams S, Schuster GA, Taylo, CA. 2010. *Orconectes limosus. The IUCN Red List of Threatened Species 2010*: e.T153764A4541724.http://dx.doi.org/10.2305/IUCN.UK.2010 3.RLTS.T153764A4541724.en	
References:	
BAC7 What is the native range of the *Taxon*? (add map in Appendix BAC7)	
Response: Canada (New Brunswick, Quebec); United States (Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia, West Virginia)	Confidence: Low
Comments:	
References: Adams S, Schuster GA, Taylo, CA. 2010. *Orconectes limosus. The IUCN Red List of Threatened Species 2010*: e.T153764A4541724.http://dx.doi.org/10.2305/IUCN.UK.2010 3.RLTS.T153764A4541724.en Pilotto F, Free G, Crosa G, Sena F, Ghiani M, Cardoso AC. 2008. The invasive crayfish *Orconectes limosus* in Lake Varese: estimating abundance and population size structure in the context of habitat and methodological constraints. *Journal of Crustacean Biology* 28:633–640.	
BAC8 What is the global alien range of the *Taxon*? (add map in Appendix BAC8)	
Response: Austria; Belgium; Czech Republic; France (France (mainland)); Germany; Hungary; Italy (Italy (mainland)); Lithuania; Luxembourg; Montenegro; Morocco; Netherlands; Poland; Russian Federation (Kaliningrad); Switzerland; United Kingdom (Great Britain)	Confidence: Medium
Comments:	
References: Adams S, Schuster GA, Taylo, CA. 2010. *Orconectes limosus. The IUCN Red List of Threatened Species 2010*: e.T153764A4541724.http://dx.doi.org/10.2305/IUCN.UK.2010 3.RLTS.T153764A4541724.en	
BAC9 Geographic scope = the *Area* under consideration	
Area of assessment: South Africa	
Comments:	

BAC10 Is the *Taxon* present in the *Area*?	
Response: No	Confidence: low
Comments: There are no records of species being in the country (Nunes et al. 2017). *Faxonius limosus* might be present through the pet trade, although this needs to be assessed (Chucholl 2012; Faulkes 2015).	
References: Chucholl, C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141. Faulkes, Z, 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

BAC11 Availability of physical specimen	
Response: NA	Confidence in ID:
Herbarium or museum accession number:	
References:	

BAC12 Is the *Taxon* native to the *Area* or part of the *Area*?		
The *Taxon* is native to (part of) the *Area*.	No	Confidence: High
The *Taxon* is alien in (part of) the *Area*.	Yes	Confidence: High
Comments: South Africa has no indigenous freshwater crayfish (de Moor 2002, Nunes et al. 2017).		
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African Journal of Aquatic Science 27: 125–139 Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.		

BAC13 What is the *Taxon*'s introduction status in the *Area*?		
The *Taxon* is in cultivation/containment.	Unknown	Confidence: Low
The *Taxon* is present in the wild.	No	Confidence: Low
The *Taxon* has established/naturalised.	No	Confidence: Low
The *Taxon* is invasive.	No	Confidence: Low
Comments: There are only records for the introduction of four freshwater crayfish into South Africa that include: *Cherax destructor*, *C. cainii/tenuimanus*, *C. quadricarinatus* and *Procrambarus clarkii* (de Moor 2002, Nunes et al. 2017).		
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African Journal of Aquatic Science 27: 125–139 Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323		

BAC14 Primary (introduction) pathways		
Release	NA	Confidence:

Escape	Aquaculture Ornamental Bait	Confidence: High
Contaminant	NA	Confidence:
Stowaway	NA	Confidence:
Corridor	NA	Confidence:
Unaided	NA	Confidence:
Comments:		
References: Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Lodge DM, Deines A, Gherardi, F, Yeo, DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology Evolution Systematics* 43: 449–72.		

2. Likelihood

LIK1 Likelihood of entry via unaided primary pathways	
Response: Very unlikely	Confidence: Low
Rationale: Entry via unaided pathways is very unlikely because there are no wild population are present in neighbouring countries that could act as source for unaided introductions through connected waterways (Nunes et al. 2019; Madzivanzira et al. 2020).	
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

LIK2 Likelihood of entry via human aided primary pathways	
Response: Fairly probable	Confidence: Low
Rationale: Species could be bought via pet trade and used as live bait which could lead to intentional and unintentional release into the wild (Faulkes 2015; Alekhnovich and Buric 2017).	
References: Alekhnovich A, Buřič M. 2017: NOBANIS – Invasive Alien Species Fact Sheet – *Orconectes limosus*. – From : Online Database of the European Network on Invasive Alien Species – NOBANIS www.nobanis.org, Date of access 22/01/2019 Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92.	

LIK3 Habitat suitability	
Response: Fairly probable	Confidence: Low
Rationale: This species inhabits clear streams with silt, cobble, gravel and sand substrates (Adams et al 2010). Individuals are often found in lakes, shallow depressions in pools and have rarely been captured where silt is absent from the substrate (Holdich et al. 2009; Adams et al. 2010). Generally it is very tolerant to a wide range of environmental conditions and is able to cope with polluted canals and organically enriched lakes and ponds (Holdich et al 2009).	
References: Adams S, Schuster GA, Taylo, CA. 2010. *Orconectes limosus. The IUCN Red List of Threatened Species 2010*: e.T153764A4541724.http://dx.doi.org/10.2305/IUCN.UK.2010 3.RLTS.T153764A4541724.en Holdich DM, Reynolds, JD, Souty-Grosset C, Sibley PJ, 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and management of aquatic ecosystems* 11: 394–395.	

LIK4 Climate suitability	
Response: Fairly probable	Confidence: Low
Rationale: There are no environmental data available for *F. limosus* Adults are known to be tolerant to wide temperatures. Closely related species, *F. rusticus* prefers well oxygenated water and a temperature range of 20-25°C but can withstand seasonal water temperatures of 0-39°C within its native range (GISD 2015). In temperatures over 30°C, adults have been observed digging burrows to escape the heat (GISD 2015).	
References: Alekhnovich A, Buřič M. 2017: NOBANIS – Invasive Alien Species Fact Sheet – *Orconectes limosus*. – From : Online Database of the European Network on Invasive Alien Species – NOBANIS www.nobanis.org, Date of access 22/01/2019 Global Invasive Species Database (GISD) 2015. Species profile *Orconectes rusticus*. Available from: http://www.iucngisd.org/gisd/species.php?sc=217 [Accessed 03 July2018].	

LIK5 Unaided secondary (dispersal) pathways	
Response: Very unlikely	Confidence: Low
Rationale: Currently this is very unlikely due to no feral populations present in neighbouring countries that would enable crayfish to disperse naturally through connected waterways (Nunes et al. 2019; Madzivanzira et al. 2020). However, should species enter the country, it is important to note that all crayfish species are mobile and therefore not restricted to waterways and can migrate overland and colonise new areas (Soes and Koese 2010). In Germany, researchers estimated a natural dispersal of 5 km/year in one direction for populations of the spiny-cheek crayfish (Holdich et al 2009; Soes and Koese 2010).	
References: Holdich DM, Reynolds, JD, Souty-Grosset C, Sibley PJ, 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and management of aquatic ecosystems* 11: 394–395. Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. Soes M, Koese B. 2010. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis.	

LIK6 Human aided secondary (dispersal) pathways	
Response: Unlikely	Confidence: Low
Rationale: Crayfish can be released into the wild by humans that have them as pets (Faulkes 2015). *Faxonius limosus* is present in the trade; however it is not as common as other crayfish (Faulkes 2015).	
References: Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92.	

3. Consequences

CON1 Environmental impact	
CON1a: Competition	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON1b: Predation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	

References: L. Botha (Unpublished data).	
CON1c: Hybridisation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1d: Transmission of disease	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1e: Parasitism	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1f: Poisoning/toxicity	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1g: Bio-fouling or other direct physical disturbance	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1h: Grazing/herbivory/browsing	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1i: Chemical, physical or structural impact on ecosystem	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1 Maximum environmental impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact	
References: L. Botha (Unpublished data).	

CON2 Socio-economic impact	
CON2a: Safety	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data	
CON2b: Material and immaterial assets	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2c: Health	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2d: Social, spiritual and cultural relations	
Response: DD	Confidence: Low

Rationale:	
References: L. Botha (Unpublished data)	
CON2 Maximum socio-economic impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON3 Closely related species' Environmental impact	
CON3a: Competition	
Response: MO	Confidence: Medium
Rationale: *Faxonius rusticus* is a fierce competitor and is known to displace native crayfish in areas of introduction through the exclusion of resources (Klocker and Strayer 2004, Lodge et al. 2012). *Faxonius rusticus* is relatively bigger in body size (and has a larger chela) than its native congenerics (Garvey and Stein 1993). A feature which predisposes it to physically out-compete its congenerics for resources. For example, *F. rusticus* has displaced native crayfish (*F. propinquus F. sanborni* and *F. virilis*) in its invasive range through direct competition for food and shelter. In addition, the displaced native species become more susceptible to predation because of a lack of shelter (Garvey and Stein 19993, Byron and Wilson 200, Lodge et al. 2012).	
References: Byron CJ, Wilson KA. 2001. Rusty crayfish (*Orconectes rusticus*) movement within and between habitats in Trout Lake, Vilas County, Wisconsin. *Journal of the North American Benthological Society* 20: 606–614. Garvey JE, Stein RA. 1993. Evaluating how chela size influences the invasion potential of an introduced crayfish (*Orconectes rusticus*). *American Midland Naturalist 129:* 172–181. Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178. Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. https://www.cabi.org/isc/datasheet/72037	
CON3b: Predation	
Response: MR	Confidence: Medium
Rationale: Direct predation by *Faxonius rusticus* on native fauna has caused a decline in population size of at least one native species in areas of introduction (Johnson et al. 2009). For example, predation on fish eggs by *F. rusticus* has led to declines in population size and community composition in Vilas County, Winsconsin, U.S.A (Jonas et al. 2005). *Faxonius rusticus* is also known to feed on invertebrates, and in Trout Lake, Wisconsin, U.S.A, direct predation on invertebrate communities has led to a decrease in the mean abundance of several invertebrates orders such as Odonata, Amphipoda and Trichoptera (Lodge et al. 2005, Klocker and Strayer 2004, Wilson et al. 2004, Kreps et al. 2012).	
References: Johnson PT, Olden JD, Solomon CT, Vander Zanden MJ. 2009. Interactions among Invaders: Community and ecosystem effects of multiple invasive species in an experimental aquatic system. *Oecologia* 159: 161–170. Jonas JL, Claramunt RM, Fitzsimons JD, Marsden JE, Ellrott BJ. 2005. Estimates of egg deposition and effects of lake trout (*Salvelinus namaycush*) egg predators in three regions of the Great Lakes.*Canadian Journal of Fisheries and Aquatic Sciences* 62: 2254–2264. Kreps TA, Baldridge AK, Lodge DM. 2012. The impact of an invasive predator (*Orconectes rusticus*) on freshwater snail communities: Insights on habitat-specific effects from a multilake long-term study. *Canadian Journal of Fisheries and Aquatic Sciences* 69:1164–1173.	

Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178

Lodge DM, Kershner MW, Aloi JE.1995. Effects of an omnivorous crayfish (*Orconectes rusticus*) on a freshwater littoral food web. *Ecology* 75: 1265–1281.

Wilson KA., Magnuson JJ, Lodge DM, Hill AM, Kratz, TK, Perry WL, Willis TV. 2004. A long-term rusty crayfish (*Orconectes rusticus*) invasion: Dispersal patterns and community change in a north temperate lake. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 2255–2266.

CON3c: Hybridisation

Response: MO	Confidence: Low

Rationale:

Hybridisation is known to occur among congenerics of *F. rusticus* (Perry et al. 2001). However, this is unlikely to occur in South Africa because there are no native crayfish species (Lodge et al. 2012).

References:

Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.

Perry WL, Feder JL, Dwyer G, Lodge DM. 2001. Hybrid zone dynamics and species replacement between *Orconectes* crayfishes in a northern Wisconsin lake. *Evolution* 55: 1153–1166.

Perry WL, Feder JL, Lodge DM. 2001. Implications of hybridization between introduced and resident *Orconectes* crayfishes. *Conservation Biology* 15: 1656–1666.

CON3d: Transmission of disease

Response: DD	Confidence: Low

Rationale:

No information is available to assess the level of impact.

References:

L. Botha (unpublished data).

CON3e: Parasitism

Response: DD	Confidence: Low

Rationale:

No information is available to assess the level of impact.

References:

L. Botha (Unpublished data).

CON3f: Poisoning/toxicity

Response: DD	Confidence: Low

Rationale:

No information is available to assess the level of impact.

References:

L. Botha (Unpublished data).

CON3g: Bio-fouling or other direct physical disturbance

Response: DD	Confidence: Low

Rationale:

No information is available to assess the level of impact.

References:

L. Botha (Unpublished data).

CON3h: Grazing/herbivory/browsing

Response: MR	Confidence: Medium

Rationale:

Faxonius rusticus is a functional omnivore and feed readily on freshwater macrophytes in its invaded range, altering community structure (Roth et al. 2006). For example, in Lake Michigan, U.S.A *F. rusticus* reduced the macrophyte abundance and species richness by 80% (Wilson et al. 2004).

References:

Roth BM, Hein, CL, Vander Zanden MJ, 2006. Using bioenergetics and stable isotopes to assess the trophic role of rusty crayfish (*Orconectes rusticus*) in lake littoral zones. *Canadian Journal of Fisheries and*

Aquatic Sciences 63**:** 335–344. Wilson KA., Magnuson JJ, Lodge DM, Hill AM, Kratz, TK, Perry WL, Willis TV. 2004. A long-term rusty crayfish (*Orconectes rusticus*) invasion: Dispersal patterns and community change in a north temperate lake. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 2255–2266.	
CON3i: Chemical, physical or structural impact on ecosystem	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON3k: Indirect impacts through interactions with other species	
Response: MO	Confidence: Medium
Rationale: In its invasive range, *Faxonius rusticus* may occur with other alien species, and interactions with other these species could facilitate impacts that ultimately lead to a decline in population size of native fauna. In the United States of America, *F. rusticus* occurs with another invasive snail, *Bellamya chinesis* that has a thick shell that prevents predation from rusty crayfish (Johnson et al. 2009). However, competition and predation pressure from both invasive species have reduced native snail biomass immensely (Johnson et al. 2009).	
References: Johnson PT, Olden JD, Solomon CT, Vander Zanden MJ. 2009. Interactions among Invaders: Community and ecosystem effects of multiple invasive species in an experimental aquatic system. *Oecologia* 159: 161–170.	
CON3 Maximum environmental impact (Figure S3)	
Response: MO	Confidence: Medium
Rationale: In areas of introduction, direct predation, competition for food, shelter and spawning sites have led to local extinctions and a decrease in the abundance of native crayfish and fish species (Garvey and Stein 1993, Klocker and Strayer 2004).	
References: Garvey JE, Stein RA. 1993. Evaluating how chela size influences the invasion potential of an introduced crayfish (*Orconectes rusticus*). *American Midland Naturalist* 129: 172–181. Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178. Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.	

CON4 Closely related species' Socio-economic impact	
CON4a: Safety	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON4b: Material and immaterial assets	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON4c: Health	

Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON4d: Social, spiritual and cultural relations	
Response: MO	Confidence: Low
Rationale: *Faxonius rusticus* invasions can disrupt recreational activities in the invaded range. This can ultimately affect the well-being of humans because they can no longer participate in these activities (Keller et al. 2008). In Vilas County, *F. rusticus* has reduced sport fish populations though egg predation and/or competition with juveniles. Consequently, this leads to an estimated annual loss of 1.5 million US dollars (Keller et al. 2008).	
References: Keller RP, Frang K, Lodge DM. 2008. Preventing the spread of invasive species: Economic benefits of intervention guided by ecological predictions. *Conservation Biology* 22: 80–88.	
CON4 Maximum socio-economic impact (Figure S3)	
Response: MO	Confidence: Low
Rationale: *Faxonius rusticus* invasions have caused disruption in recreational activities by reducing sport fish populations though egg predation and/or competition with juveniles (Keller et al. 2008).	
References: Keller RP, Frang K, Lodge DM. 2008. Preventing the spread of invasive species: Economic benefits of intervention guided by ecological predictions. *Conservation Biology* 22: 80–88.	

CON5 Potential impact	
Response: MR	Confidence: High
Rationale: Similar to the closely related species (*Faxonius rusticus*) used for the impact assessment. *Orconectes limosus* may outcompete native freshwater crab species in South Africa, displacing it in freshwater ecosystems (Jackson et al. 2016). Being a functional omnivore, this species may also have detrimental impacts on macroinvertebrates and macrophyte communities in areas where invaded (Klocker and Strayer 2004; Roth et al. 2006; Kreps et al 2012). They can also influence occurrence and species composition of fish communities (Keller et al. 2008). In addition, being a vector for the crayfish plague is another cause of concern. This disease may be transferable and could be detrimental to native freshwater crustaceans in South Africa. This species also burrows when environmental conditions become unfavourable and this may destabilise river banks causing erosion (Holdiche et al. 2009; Soes and Koese 2010; Alekhnovich and Buric 2017).	
References: Alekhnovich A, Buřič M. 2017: NOBANIS – Invasive Alien Species Fact Sheet – *Orconectes limosus*. – From : Online Database of the European Network on Invasive Alien Species – NOBANIS www.nobanis.org, Date of access 22/01/2019. Keller RP, Frang K, Lodge DM. 2008. Preventing the spread of invasive species: Economic benefits of intervention guided by ecological predictions. *Conservation Biology* 22: 80–88 Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178. Kreps TA, Baldridge AK, Lodge DM. 2012. The impact of an invasive predator (*Orconectes rusticus*) on freshwater snail communities: Insights on habitat-specific effects from a multilake long-term study. *Canadian Journal of Fisheries and Aquatic Sciences* 69:1164–1173. Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. Roth BM, Hein, CL, Vander Zanden MJ, 2006. Using bioenergetics and stable isotopes to assess the trophic	

role of rusty crayfish (*Orconectes rusticus*) in lake littoral zones. *Canadian Journal of Fisheries and Aquatic Sciences* 63: 335–344.
Soes M, Koese B. 2010. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis.

4. Management

MAN1 What is the feasibility to stop future immigration?	
Response: Low	Confidence: Low
Rationale: There are no known wild populations in neighbouring countries, thus the probability *F. limosus* entering via unaided primary pathways is very low (Nunes et al. 2019; Madzivanzira et al. 2020). *Faxonius limosus* is present the pet trade industry in the Czech Republic, Germany, Netherlands and the UK (Chucholl 2013, Faulkes 2015). Should the species be traded illegally as pets, it would be challenging to prevent future introductions, and *Faxonius limosus* might already be in South Africa. Thus, the trading of this species still needs to be assessed thoroughly.	
References: Chucholl C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141. Faulkes, Z, 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

MAN2 Benefits of the Taxon	
MAN2a Socio-economic benefits of the *Taxon*	
Response: None	Confidence: Low
Rationale:	
References:	
MAN2b Environmental benefits of the *Taxon*	
Response: None	Confidence: Low
Rationale:	
References:	

MAN3 Ease of management (Table 4)	
Response: NA	Confidence:
Rationale:	
References:	
MAN3a How accessible are populations?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3b Is detectability critically time-dependent?	
Response: NA	Confidence:
Rationale:	

References:

MAN3c Time to reproduction	
Response: NA	Confidence:
Rationale:	
References:	

MAN3d Propagule persistence	
Response: NA	Confidence:
Rationale:	
References:	

MAN3 Ease of management (Table 4)	
Response: NA	Confidence:
Rationale:	
References:	

MAN4 Has the feasibility of eradication been evaluated?	
Response: No	Confidence: low
Rationale: In areas of introduction, where it has managed to establish populations, there has been no successful eradication attempt. Generally, Once crayfish species have established and is becoming widespread, it is impossible to eradicate (Gherardi et al 2011). They are very hardy and if chemical control is considered large quantities are needed to kill crayfish and biocides have been used to eradicate crayfish populations elsewhere (Gherardi et al. 2011). Furthermore, the chemicals used are not specific to crayfish and can also extirpate other freshwater species within the same freshwater ecosystem (Ghrardi et al. 2011). However, when species are restricted to dams mechanical control via traps, electrofishing could still be feasible (Gherardi et al 2011).	
References: Gherardi F, Aquiloni L, Diéguez-Uribeondo J, Tricarico E. 2011. Managing invasive crayfish: is there a hope?. *Aquatic Sciences* 73**:** 185–200.	

MAN5 Control options and monitoring approaches available for the *Taxon*
Response:
References:

MAN5 Control options and monitoring approaches available for the *Taxon*
Response:
References:

5. Calculations

Likelihood = Very unlikely

Parameter	**Likelihood**	**Stages**	**Final assessment**
LIK1	0.0027	P(entry) = 0.027	P (invasion) = 0.0003
LIK2	0.027		

LIK3	0.5	P(establishment) = 0.5	
LIK4	0.5		
LIK5	0.0027	P (spread) = 0.027	
LIK6	0.027		

Consequence = MR (Major)

Parameter	**Mechanism/sector**	**Response**
CON1	**Maximum environmental impact**	**DD**
CON2	**Maximum socio-economic impact**	**DD**
CON3a	Competition	MO
CON3b	Predation	MR
CON3c	Hybridisation	MO
CON3d	Disease transmission	DD
CON3e	Parasitism	DD
CON3f	Poisoning/toxicity	DD
CON3g	Bio-fouling or other direct physical disturbance	DD
CON3h	Grazing/herbivory/browsing	MR
CON3i	Chemical, physical, structural impact	DD
CON3k	Indirect impacts through interactions with other species	MO
CON3	**Maximum environmental impact (closely related taxa)**	**MO**
CON4a	Safety	DD
CON4b	Material and immaterial assets	DD
CON4c	Health	DD
CON4d	Social, spiritual and cultural relations	MN
CON4	**Maximum socio-economic impact (closely related taxa)**	**MN**
CON5	Potential impact based on traits, experiments, or models	**MR**

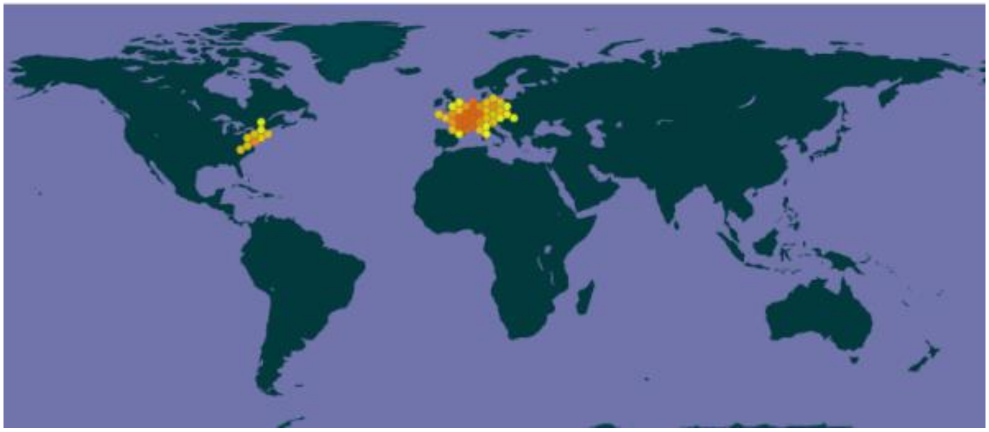
Table S3: Risk score

		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	low	low	low	medium	medium
	Very unlikely	low	low	low	medium	high
	Unlikely	low	low	medium	high	high
	Fairly probable	medium	medium	high	high	high
	Probable	medium	high	high	high	high

Table S4: Ease of management

Parameter	**Question**	**Response**
MAN3a	How accessible are populations?	0
MAN3b	Is detectability critically time-dependent?	0
MAN3c	Time to reproduction	0
MAN3d	Propagule persistence	0
MAN3	**SUM**	0

Appendix BAC7: Global alien range of *Orconectes limosus*
Map from GBIF: *https://www.gbif.org/species/2227000*



Appendix 3.8 Risk analysis report for Rusty crayfish (*Faxonius rusticus*).

Risk Analysis Report

Taxon: *Faxonius rusticus* (Girard, 1852)	***Area:*** South Africa
Compiled by: Lee-Anne Botha	**Approved by:**
Picture of *Taxon*  http://www.iucngisd.org/gisd/species.php?sc=217	**Alien distribution map**  **https://www.gbif.org/species/2227081**

Risk Assessment summary: Rusty crayfish (*Faxonius rusticus*) has not been widely introduced and is currently still restricted to its native continent, North America. Although, it has been translocated within the continent outside of its native range. There are no known populations in neighbouring countries therefore the probability of the species entering South Africa through unaided pathways through connected waterways, is unlikely. *Faxonius rusticus* may be present through the pet trade industry or could be introduced as live bait for fish. These are both relevant pathways and needs to be evaluated. *Faxonius rusticus* is a fierce competitor and has displaced native freshwater crayfish and fish through competition. It is an omnivore and direct predation and intensive grazing have contributed to a decline in freshwater invertebrate populations and macrophyte communities. *Faxonius rusticus* has also been implicated in disrupting recreational activities, leading to economic loss.	**Risk score:** High
Management options summary: *Faxonius rusticus* is not present in the country. In areas of introduction, where it has managed to establish populations, there has been no successful eradication attempt. The use of chemical methods provide not ideal because it was not target -specific. Thus, efforts have been shifted to prevent any introductions and to reduce population densities in its invasive range through a combination of techniques, such as intensive trapping and fish predation.	**Ease of management:** NA
Recommendations: *Faxonius rusticus* is currently listed as Category 1a under NEM:BA Alien and Invasve Species (A&IS) Regulations, and this Risk Analysis recommends removing it from the list because there are no records of its occurrence in either South Africa or neighbouring countries. Illegal pet trade industry still poses a significant risk of intentional release of the species into the wild. There is therefore, a need to assess the trade of, and movement of the species through the pet trade industry.	**Listing under NEM:BA A&IS lists of 2014 as amended 2020:** Category 1a **Recommended listing category:** Remove from list

1. Background

BAC1 Name of assessor(s)		
Name of lead assessor	**Lee-Anne Botha**	
Additional assessor (1)		
Additional assessor (2)		
BAC2 Contact details of assessor (s)		
Lead assessor	Organisational affiliation: Department of Zoology and Entomology, University of Pretoria/South African National Biodiversity Institute (SANBI).	
	email: u18389164@tuks.co.za	
	Phone: 072 833 7952	
Additional assessor (1)	Organisational affiliation:	
	email:	
	Phone:	
Additional assessor (2)	Organisational affiliation:	
	email:	
	Phone:	
BAC3 Name(s) and contact details of expert(s) consulted		
Expert (1)	Name: Dr Tsungai Zengeya	
	email: T.Zengeya@sanbi.org.za	
	Phone: 021 799 8408	
Expert (2)	Name:	
	email:	
	Phone:	
Comments: Dr Tsungai Zengeya works for the South African National Biodiversity Institute (SANBI). His research interests are in freshwater ecology and biological invasions. He provided comments and inputs throughout the compilation of this risk analysis that improved its quality.		
BAC4 Scientific name of *Taxon* under assessment		
Taxon name: *Faxonius rusticus*		Authority: (Girard, 1852)
Comments: *Faxonius rusticus* has been reclassified in 2019 (Crandall and De Grave 2017). The group of surface-dwelling crayfish in the *Orconectes* genus was moved to *Faxonius* (Crandall and De Grave 2017, CABI 2019).		
References: Crandall KA, De Grave S, 2017. An updated classification of the freshwater crayfishes (Decapoda: Astacidea) of the world, with a complete species list. *Journal of Crustacean Biology* 27: 615–653. https://www.cabi.org/isc/datasheet/72037,		
BAC5 Synonym(s) considered		
Synonyms: *Orconectes rusticus*		
Comments: The crayfish inhibiting caves and the surface dwelling crayfish was split into two groups (Crandall and De Grave 2017). The non-cave dwelling crayfish in the *Orconectes* genus was moved to *Faxonius* (Crandall and De Grave 2017).		
References: Crandall KA, De Grave S, 2017. An updated classification of the freshwater crayfishes (Decapoda: Astacidea) of the world, with a complete species list. *Journal of Crustacean Biology* 27: 615–653. https://www.cabi.org/isc/datasheet/72037		
BAC6 Common name(s) considered		

Common names: Rusty crayfish		
Comments:		
References https://www.cabi.org/isc/datasheet/72037		
BAC7 What is the native range of the *Taxon*? (add map in Appendix BAC7)		
Response: Ohio River drainage, United States of America.		Confidence: High
Comments:		
References: Global Invasive Species Database (GISD) 2015. Species profile *Orconectes rusticus*.Available from: http://www.iucngisd.org/gisd/species.php?sc=217 [Accessed 03 July2018] Olden, JD, McCarthy JM, Maxted JT, Fetzer WW, Van der Zanden MJ. 2006. The rapid spread of rusty crayfish (*Orconectes rusticus*) with observations on native crayfish declines in Wisconsin (U.S.A.) over the past 130 years. *Biological Invasions* 8: 1621–1628.		
BAC8 What is the global alien range of the *Taxon*? (add map in Appendix BAC8)		
Response: Canada, Lake Michigan, United States of America		Confidence: High
Comments: *Faxonius rusticus* is currently still restricted to its native continent, North America; however, it has been translocated within the continent outside of its native range (Lodge et al. 2012).		
References: Adams S, Schuster GA, Taylor CA. 2010. *Orconectes rusticus. The IUCN Red List of Threatened Species 2010*: e.T153835A4551760. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T153835A4551760.en Global Invasive Species Database (GISD) 2015. Species profile *Orconectes rusticus*. Available from: http://www.iucngisd.org/gisd/species.php?sc=217 [Accessed 03 July2018] Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.		
BAC9 Geographic scope = the *Area* under consideration		
Area of assessment: South Africa		
Comments:		
BAC10 Is the *Taxon* present in the *Area*?		
Response: No		Confidence: Low
Comments: There are no records of species being in the country (Lodge et al. 2012, Nunes et al. 2017). *Faxonius rusticus* might be present through the pet trade, although this needs to be assessed (Faulkes 2015).		
References: Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology Evolution Systematics* 43: 449–472. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309-323.		
BAC11 Availability of physical specimen		
Response: NA		Confidence in ID:
Herbarium or museum accession number:		
References:		
BAC12 Is the *Taxon* native to the *Area* or part of the *Area*?		
The *Taxon* is native to (part of) the *Area*.	No	Confidence:

The *Taxon* is alien in (part of) the *Area*.	Yes	Confidence:
Comments: South Africa has no indigenous freshwater crayfish (de Moor 2002, Nunes et al. 2017).		
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African Journal of Aquatic Science 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.		
BAC13 What is the *Taxon*'s introduction status in the *Area*?		
The *Taxon* is in cultivation/containment.	Unknown	Confidence: Low
The *Taxon* is present outside of cultivation/containment.	No	Confidence: Low
The *Taxon* has established/naturalised.	No	Confidence: Low
The *Taxon* is invasive.	No	Confidence: Low
Comments: There are only records for the introduction of four freshwater crayfish into South Africa that include: *Cherax destructor*, *C. cainii/tenuimanus*, *C. quadricarinatus* and *Procrambarus clarkii* (de Moor 2002, Nunes et al. 2017).		
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.		
BAC14 Primary (introduction) pathways		
Release	NA	Confidence:
Escape	Aquarium trade Live bait	Confidence: Medium
Contaminant	NA	Confidence:
Stowaway	NA	Confidence:
Corridor	NA	Confidence:
Unaided	NA	Confidence:
Comments: *Faxonius rusticus* is frequently used as live bait by recreational anglers and this often leads to its release into waterways (Kerr 2014).		
References: Chucholl C. 2013. Invaders for sale: Trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141. Faulkes Z. 2015. The global trade in crayfish as pets.*Crustacean Research* 44: 75–92. Kerr SJ. 2014. The Introduction and Spread of Aquatic Invasive Species through the Recreational Use of Bait: A Literature Review. Report prepared for Biodiversity Branch. Ontario Ministry of Natural Resources. Peterborough, Ontario, Canada.		

2. Likelihood

LIK1 Likelihood of entry via unaided primary pathways	
Response: Very unlikely	Confidence: Low
Rationale: There are no known populations that have established in the wild in neighbouring countries (Lodge et al. 2012, Madzivanzira et al. 2020); therefore the probability of *Faxonius rusticus* entering South Africa through	

unaided pathways (connected waterways) is unlikely.
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.

LIK2 Likelihood of entry via human aided primary pathways	
Response: Fairly probable	Confidence: Medium
Rationale: *Faxonius rusticus* is very popular among anglers that use it at as live bait for recreational fishing (Olden et al. 2009, Kerr 2014). *Faxonius rusticus* is present in the pet trade industry in Germany and the U.S.A (Faulkes 2015). The movement of it in South Africa still needs to be assessed.	
References: Faulkes Z, 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Kerr SJ. 2014. The Introduction and Spread of Aquatic Invasive Species through the Recreational Use of Bait: A Literature Review. Report prepared for Biodiversity Branch. Ontario Ministry of Natural Resources. Peterborough, Ontario, Canada. Olden JD, Adams JW, Larson ER. 2009. First record of *Orconectes rusticus* (Girard, 1852) (Decapoda, Cambaridae) west of the great continental divide in North America. *Crustaceana* 82: 1347–1351.	

LIK3 Habitat suitability	
Response: Fairy probable	Confidence: Low
Rationale: This is a habitat generalist species that inhabits permanent streams and lakes with a range of substrates such as clay, silt, sand, and gravel (GISD 2015). It prefers areas that consist of rocks, logs or other debris that they use to construct shallow excavations underneath (GISD 2015). *Faxonius rusticus* lives in open water during most of its life and burrows only under extreme conditions.	
References: Global Invasive Species Database (GISD) 2015. Species profile *Orconectes rusticus*. Available from: http://www.iucngisd.org/gisd/species.php?sc=217 [Accessed 03 July2018].	

LIK4 Climate suitability	
Response: Fairy probable	Confidence: Low
Rationale: *Orconectes rusticus* prefers well-oxygenated water and optimal water temperature is 20-25° C but it can withstand a wide range of water temperatures (0-39° C) within its native range (GISD 2015). When temperatures exceed 30° C, adults have been observed digging burrows to escape the heat (GISD 2015).	
References: Global Invasive Species Database (GISD) 2015. Species profile *Orconectes rusticus*. Available from: http://www.iucngisd.org/gisd/species.php?sc=217 [Accessed 03 July 2018]	

LIK5 Unaided secondary (dispersal) pathways	
Response: Unlikely	Confidence: Low
Rationale: There are no known populations present in neighbouring countries that could disperse naturally through connected waterways (Madzivanzira et al. 2020). Should the species enter the country however, it is important to note that all crayfish species are mobile and therefore, not restricted to waterways and can migrate overland and colonise new areas (Byron and Wilson 2001).	
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Byron CJ, Wilson K.A. 2001. Rusty crayfish (*Orconectes rusticus*) movement within and between habitats in	

Trout Lake, Vilas County, Wisconsin. *Journal of the North American Benthological Society* 20**:** 606–614.

LIK6 Human aided secondary (dispersal) pathways	
Response: Fairly probable	Confidence: Low
Rationale: In areas of introduction, *Orconectes rusticus* has been released into the wild by humans as unwanted pets and bucket release by anglers into waterways where they are used as bait (Faulkes 2015, Olden et al. 2009).	
References: Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44**:** 75–92. Olden JD, Adams JW, Larson, ER. 2009. First record of *Orconectes rusticus* (Girard, 1852) (Decapoda, Cambaridae) west of the great continental divide in North America. *Crustaceana* 82**:** 1347–1351.	

3. Consequences

A formal environmental impact assessment was done following the Hawkins et al. (2015) framework and guidelines for the Environmental Impact Classification for Alien Taxa (EICAT). Below is a summary of the recorded impacts, their mechanisms and the magnitude of the impacts (L. Botha, Unpublished data).

CON1 Environmental impact	
CON1a: Competition	
Response: MO	Confidence: Medium
Rationale: *Faxonius rusticus* is a fierce competitor and is known to displace native crayfish in areas of introduction through the exclusion of resources (Klocker and Strayer 2004, Lodge et al. 2012). *Faxonius rusticus* is relatively bigger in body size (and has a larger chela) than its native congenerics (Garvey and Stein 1993). A feature which predisposes it to physically out-compete its congenerics for resources. For example, *F. rusticus* has displaced native crayfish (*F. propinquus F. sanborni* and *F. virilis*) in its invasive range through direct competition for food and shelter. In addition, the displaced native species become more susceptible to predation because of a lack of shelter (Garvey and Stein 19993, Byron and Wilson 200, Lodge et al. 2012).	
References: Byron CJ, Wilson KA. 2001. Rusty crayfish (*Orconectes rusticus*) movement within and between habitats in Trout Lake, Vilas County, Wisconsin. *Journal of the North American Benthological Society* 20: 606–614. Garvey JE, Stein RA. 1993. Evaluating how chela size influences the invasion potential of an introduced crayfish (*Orconectes rusticus*). *American Midland Naturalist 129:* 172–181. Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11**:**167–178. Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. https://www.cabi.org/isc/datasheet/72037	
CON1b: Predation	
Response: MR	Confidence: Medium
Rationale: Direct predation by *Faxonius rusticus* on native fauna has caused a decline in population size of at least one native species in areas of introduction (Johnson et al. 2009). For example, predation on fish eggs by *F. rusticus* has led to declines in population size and community composition in Vilas County, Winsconsin, U.S.A (Jonas et al. 2005). *Faxonius rusticus* is also known to feed on invertebrates, and in Trout Lake, Wisconsin, U.S.A, direct predation on invertebrate communities has led to a decrease in the mean abundance of several invertebrates orders such as Odonata, Amphipoda and Trichoptera (Lodge et al. 2005, Klocker and Strayer 2004, Wilson et al. 2004, Kreps et al. 2012).	

References: Johnson PT, Olden JD, Solomon CT, Vander Zanden MJ. 2009. Interactions among Invaders: Community and ecosystem effects of multiple invasive species in an experimental aquatic system. *Oecologia* 159: 161–170. Jonas JL, Claramunt RM, Fitzsimons JD, Marsden JE, Ellrott BJ. 2005. Estimates of egg deposition and effects of lake trout (*Salvelinus namaycush*) egg predators in three regions of the Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 62: 2254–2264. Kreps TA, Baldridge AK, Lodge DM. 2012. The impact of an invasive predator (*Orconectes rusticus*) on freshwater snail communities: Insights on habitat-specific effects from a multilake long-term study. *Canadian Journal of Fisheries and Aquatic Sciences* 69:1164–1173. Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178 Lodge DM, Kershner MW, Aloi JE.1995. Effects of an omnivorous crayfish (*Orconectes rusticus*) on a freshwater littoral food web. *Ecology* 75: 1265–1281. Wilson KA., Magnuson JJ, Lodge DM, Hill AM, Kratz, TK, Perry WL, Willis TV. 2004. A long-term rusty crayfish (*Orconectes rusticus*) invasion: Dispersal patterns and community change in a north temperate lake. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 2255–2266.	
CON1c: Hybridisation	
Response: MO	Confidence: Low
Rationale: Hybridisation is known to occur among congenerics of *F. rusticus* (Perry et al. 2001). However, this is unlikely to occur in South Africa because there are no native crayfish species (Lodge et al. 2012).	
References: Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. Perry WL, Feder JL, Dwyer G, Lodge DM. 2001. Hybrid zone dynamics and species replacement between *Orconectes* crayfishes in a northern Wisconsin lake. *Evolution* 55: 1153–1166. Perry WL, Feder JL, Lodge DM. 2001. Implications of hybridization between introduced and resident *Orconectes* crayfishes. *Conservation Biology* 15: 1656–1666.	
CON1d: Transmission of disease	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (unpublished data).	
CON1e: Parasitism	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1f: Poisoning/toxicity	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1g: Bio-fouling or other direct physical disturbance	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References:	

L. Botha (Unpublished data).

CON1h: Grazing/herbivory/browsing

Response: MR	Confidence: Medium

Rationale:

Faxonius rusticus is a functional omnivore and feed readily on freshwater macrophytes in its invaded range, altering community structure (Roth et al. 2006). For example, in Lake Michigan, U.S.A *F. rusticus* reduced the macrophyte abundance and species richness by 80% (Wilson et al. 2004).

References:

Roth BM, Hein, CL, Vander Zanden MJ, 2006. Using bioenergetics and stable isotopes to assess the trophic role of rusty crayfish (*Orconectes rusticus*) in lake littoral zones. *Canadian Journal of Fisheries and Aquatic Sciences* 63: 335–344.

Wilson KA., Magnuson JJ, Lodge DM, Hill AM, Kratz, TK, Perry WL, Willis TV. 2004. A long-term rusty crayfish (*Orconectes rusticus*) invasion: Dispersal patterns and community change in a north temperate lake. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 2255–2266.

CON1i: Chemical, physical or structural impact on ecosystem

Response: DD	Confidence: Low

Rationale:

No information is available to assess the level of impact.

References:

L. Botha (Unpublished data).

CON1k: Indirect impacts through interactions with other species

Response: MO	Confidence: Medium

Rationale:

In its invasive range, *Faxonius rusticus* may occur with other alien species, and interactions with other these species could facilitate impacts that ultimately lead to a decline in population size of native fauna.

In the United States of America, *F. rusticus* occurs with another invasive snail, *Bellamya chinesis* that has a thick shell that prevents predation from rusty crayfish (Johnson et al. 2009). However, competition and predation pressure from both invasive species have reduced native snail biomass immensely (Johnson et al. 2009).

References:

Johnson PT, Olden JD, Solomon CT, Vander Zanden MJ. 2009. Interactions among Invaders: Community and ecosystem effects of multiple invasive species in an experimental aquatic system. *Oecologia* 159: 161–170.

CON1 Maximum environmental impact (Figure S3)

Response: MO	Confidence: Medium

Rationale:

In areas of introduction, direct predation, competition for food, shelter and spawning sites have led to local extinctions and a decrease in the abundance of native crayfish and fish species (Garvey and Stein 1993, Klocker and Strayer 2004).

References:

Garvey JE, Stein RA. 1993. Evaluating how chela size influences the invasion potential of an introduced crayfish (*Orconectes rusticus*). *American Midland Naturalist* 129: 172–181.

Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178.

Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.

CON2 Socio-economic impact

CON2a: Safety

Response: DD	Confidence: Low

Rationale:

No information is available to assess the level of impact.
References: L. Botha (Unpublished data).

CON2b: Material and immaterial assets	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON2c: Health	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON2d: Social, spiritual and cultural relations	
Response: MO	Confidence: Low
Rationale: *Faxonius rusticus* invasions can disrupt recreational activities in the invaded range. This can ultimately affect the well-being of humans because they can no longer participate in these activities (Keller et al. 2008). In Vilas County, *F. rusticus* has reduced sport fish populations though egg predation and/or competition with juveniles. Consequently, this leads to an estimated annual loss of 1.5 million US dollars (Keller et al. 2008).	
References: Keller RP, Frang K, Lodge DM. 2008. Preventing the spread of invasive species: Economic benefits of intervention guided by ecological predictions. *Conservation Biology* 22: 80–88.	

CON2 Maximum socio-economic impact (Figure S3)	
Response: MO	Confidence: Low
Rationale: *Faxonius rusticus* invasions have caused disruption in recreational activities by reducing sport fish populations though egg predation and/or competition with juveniles (Keller et al. 2008).	
References: Keller RP, Frang K, Lodge DM. 2008. Preventing the spread of invasive species: Economic benefits of intervention guided by ecological predictions. *Conservation Biology* 22: 80–88.	

CON3 Closely related species' environmental impact	
Response:	Confidence:
Rationale:	
References:	

CON4 Closely related species' socio-economic impact	
Response:	Confidence:
Rationale:	
References:	

CON5 Potential impact	
Response: MR	Confidence: Medium
Rationale: There are no known populations of *Faxonius rusticus* outside of its native continent, North America, although, it has been moved around outside of its native range (Lodge et al. 2012). Based on the information gathered in the risk assessment, *F. rusticus* has been implicated in causing impacts in areas of introduction, displacing native species through multiple mechanisms (Holdich and Reeve 1991). *Faxonius rusticus* is	

highly fecund and very aggressive (Garvey and Stein 1993). It may out-compete native freshwater crab species in South Africa, displacing them in freshwater ecosystems (Jackson et al. 2016, Twardochleb et al. 2018). Being a functional omnivore, *F. rusticus* may also have detrimental impacts on macroinvertebrates and macrophyte communities when occurring in high densities (Wilson et al. 2004, Roth et al. 2006). *Faxonius rusticus* is capable of reducing invertebrate communities, changing their composition in the area invaded (Klocker and Strayer 2004, Johnson et al. 2009). Furthermore, being a vector for the crayfish plague is another cause of concern, as it may be transferable and could be detrimental to native freshwater crustaceans in South Africa (Twardochleb et al. 2013).
References: Garvey JE, Stein RA. 1993. Evaluating how chela size influences the invasion potential of an introduced crayfish (*Orconectes rusticus*). *American Midland Naturalist* 129: 172–181. Holdich DM, Reeve ID. 1991. Distribution of freshwater crayfish in the British Isles, with particular reference to crayfish plague, alien introductions and water quality. *Aquatic Conservation: Marine and Freshwater Ecosystems* 1: 139–158. Johnson PT, Olden JD, Solomon CT, Vander Zanden MJ. 2009. Interactions among Invaders: Community and ecosystem effects of multiple invasive species in an experimental aquatic system. *Oecologia* 159: 161–170. Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178. Roth BM, Hein, CL, Vander Zanden MJ, 2006. Using bioenergetics and stable isotopes to assess the trophic role of rusty crayfish (*Orconectes rusticus*) in lake littoral zones. *Canadian Journal of Fisheries and Aquatic Sciences* 63: 335–344. Twardochleb LA, Olden JD, Larson, ER. 2013. A global meta-analysis of the ecological impacts of nonnative crayfish. *Freshwater Science* 32: 1367–1382. Wilson KA., Magnuson JJ, Lodge DM, Hill AM, Kratz, TK, Perry WL, Willis TV. 2004. A long-term rusty crayfish (*Orconectes rusticus*) invasion: Dispersal patterns and community change in a north temperate lake. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 2255–2266.

4. Management

MAN1 What is the feasibility to stop future immigration?	
Response: Low	Confidence: Low
Rationale: *Faxonius rusticus* is present the pet trade industry in the Germany and the U.S.A (Chucholl 2013, Faulkes 2015). Should the species be traded illegally as pets, it would be challenging to prevent future introductions, and *Faxonius rusticus* might already be in South Africa. Thus, the trading of this species still needs to be assessed thoroughly. Intentional stocking by fishermen is another concern; it is a popular bait species among anglers (Kerr 2014).	
References: Chucholl C. 2013. Invaders for sale: Trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141. Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Kerr SJ. 2014. The Introduction and Spread of Aquatic Invasive Species through the Recreational Use of Bait: A Literature Review. Report prepared for Biodiversity Branch. Ontario Ministry of Natural Resources. Peterborough, Ontario, Canada.	

MAN2 Benefits of the Taxon	
MAN2a Socio-economic benefits of the *Taxon*	
Response: None	Confidence: Low
Rationale: None	
References:	
MAN2b Environmental benefits of the *Taxon*	

Response:	Confidence:
Rationale:	
References:	

MAN3 Ease of management	
MAN3a How accessible are populations?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3b Is detectability critically time-dependent?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3c Time to reproduction	
Response: NA	Confidence:
Rationale:	
References:	
MAN3d Propagule persistence	
Response: NA	Confidence:
Rationale:	
References:	
MAN3 Ease of management (SUM from Table S4)	
Response: NA	Confidence:
Rationale:	
References:	

MAN4 Has the feasibility of eradication been evaluated?	
Response: No	Confidence: Low
Rationale: To date, there is no known method that has been successful in the complete removal of *Faxonius rusticus* in the invaded area. Two methods proved to be effective in reducing the population densities of *F. rusticus* in Wisconsin, USA. Predation by fish caused a larger decline in the crayfish population, whereas intensive trapping caused the largest decline in crayfish growth rate by removing individuals with the highest reproductive value. Therefore, the results of a three-year experiment indicate that a combination of intensive trapping and predation by fish would be the most effective. Crayfish in general are very hardy and if chemical control is considered, large quantities are needed to kill crayfish. The chemicals used are not specific to crayfish and can also harm other freshwater species within the same freshwater ecosystem.	
References: Hein CL, Roth BM, Ives AR, Vander Zanden MJ. 2006. Fish predation and trapping for rusty crayfish (*Orconectes rusticus*) control: A whole-lake experiment. *Canadian Journal Fisheries and Aquatic Sciences*. 63: 383–393. https://www.cabi.org/isc/datasheet/72037	

MAN5 Control options and monitoring approaches available for the *Taxon*
Response:
References:

MAN6 Any other management considerations to highlight? (if yes, fill in Appendix MAN6)

Response	Yes / No

5. Calculations

Likelihood = Fairly probable

Parameter	**Likelihood**	**Stages**	**Final assessment**
LIK1	0.0027	P (entry) = 0.5	P (invasion) = 0.125
LIK2	0.5		
LIK3	0.5	P (establishment)= 0.5	
LIK4	0.5		
LIK5	0.0027	P (spread) = 0.5	
LIK6	0.5		

Consequence =
(fill in the responses)

Parameter	**Mechanism/sector**	**Response**
CON1a	Competition	MO
CON1b	Predation	MO
CON1c	Hybridisation	MO
CON1d	Disease transmission	DD
CON1e	Parasitism	DD
CON1f	Poisoning/toxicity	DD
CON1g	Bio-fouling or other direct physical disturbance	DD
CON1h	Grazing/herbivory/browsing	MO
CON1i	Chemical, physical, structural impact	DD
CON1k	Indirect impacts through interactions with other species	MO
CON1	**Maximum environmental impact**	**MO**
CON2a	Safety	DD
CON2b	Material and immaterial assets	DD
CON2c	Health	DD
CON2d	Social, spiritual and cultural relations	MN
CON2	**Maximum socio-economic impact**	**MN**
CON3	Environmental impact of closely related taxa (only score if CON1a-k are all DD, otherwise NA)	NA
CON4	Socio-economic impact of closely related taxa (only score if CON2a-g are all DD, otherwise NA)	NA
CON5	Potential impact based on traits, experiments, or models	**MR**

Table S3: Risk score
(highlight the respective fields)

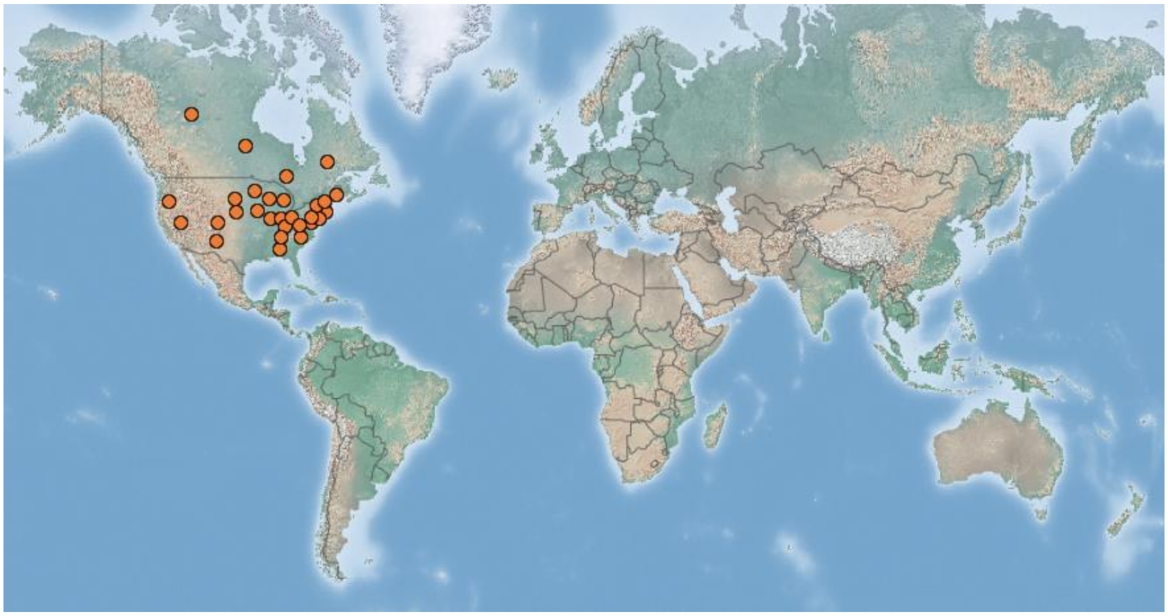
		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	Low	Low	Low	Medium	Medium
	Very unlikely	Low	Low	Low	Medium	High
	Unlikely	Low	Low	Medium	High	High
	Fairly probable	Medium	Medium	High	High	High
	Probable	Medium	High	High	High	High

Table S4: Ease of management
(fill in numbers in table below)

Parameter	**Question**	**Response**

MAN3a	How accessible are populations?	NA
MAN3b	Is detectability critically time-dependent?	NA
MAN3c	Time to reproduction	NA
MAN3d	Propagule persistence	NA
MAN3	**SUM**	

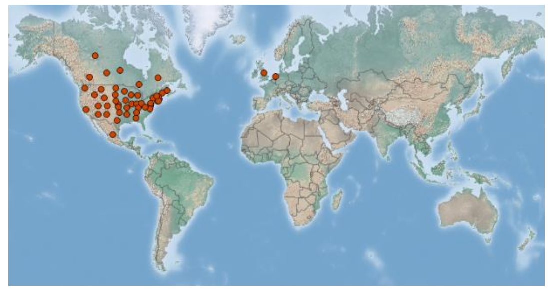
Appendix BAC8(a): Global alien range of *Faxonius rusticus.* Map from CABI*:* *https://www.cabi.org/isc/datasheet/72037*



Appendix 3.9 Risk analysis report for Virile crayfish (*Faxonius virilis*).

Risk Analysis Report

<table>
<tr><td>Taxon:
Faxonius virilis (Hagen, 1870)</td><td>Area:
South Africa</td></tr>
<tr><td>Compiled by:
Lee-Anne Botha</td><td>Approved by:</td></tr>
<tr><td>Picture of Taxon

Ahern et al. 2008.</td><td>Alien distribution map

Sourced from CABI (2019):
https://www.cabi.org/ISC/datasheet/72034</td></tr>
<tr><td>Risk Assessment summary:
The current distribution of the Virile crayfish (Faxonius virilis) is restricted to North America and Europe. The likelihood of entry into South Africa via unaided pathways is very unlikely because there are no known neighbouring countries where connected waterways may act as a source of entry. It is present in the pet trade in a few countries, thus the illegal pet trade still remain a cause for concern. There are no documented impacts from F. virilis, and potential impacts were inferred from Faxonius rusticus, a closely related species, has been implicated in causing detrimental impacts in its invaded range. Native fish and crayfish species have been displaced by F. rusticus as a result of competition. The opportunistic feeding behavior of F. rusticus has contributed to the decline in freshwater macrophytes (grazing) and invertebrate communities (direct predation). Faxonius virilis is likely to have similar impacts in areas of introduction. It is likely to have similar impacts in areas of introduction. Faxonius virilis is also a vector for the crayfish plague which may be transferred to native decapod species. It is known to burrow in its home ranges which may result in the destabilization of riverbanks, causing erosion.</td><td>Risk score:
High</td></tr>
<tr><td>Management options summary:
The species not in present in South Africa. Management effort should therefore be directed at preventing introduction. It may be possible to control established as demonstrated by the reduction of population densities of F. rusticus through a combination of techniques, for example, intensive trapping and fish predation its invasive range.</td><td>Ease of management:
NA</td></tr>
<tr><td>Recommendations:
Species is currently not listed under the NEM:BA Alien and Invasive Species (A&IS) regulations. There are no records of its occurrence in either South Africa or neighbouring countries The results from this Risk Analysis recommend this species to be listed as prohibited to prevent any future introductions. Illegal pet trade industry still poses a significant risk of intentional release of the species into the wild. There is therefore, a need to assess the trade of, and movement of the species through the pet trade and bait industry.</td><td>Listing under NEM:BA A&IS lists of 2014 as amended 2020:
Not listed
Recommended listing category:
No change</td></tr>
</table>

1. Background

BAC1 Name of assessor(s)	
Name of lead assessor	**Lee-Anne Botha**
Additional assessor (1)	**Tsungai Zengeya**
Additional assessor (2)	
BAC2 Contact details of assessor (s)	
Lead assessor	Organisational affiliation: University of Pretoria, Department of Zoology and Entomology/ SANBI
	email: u18389164@tuks.co.za
	Phone: 072 833 7952
Additional assessor (1)	Organisational affiliation: Kirstenbosch Research Centre, Newlands, Cape Town/ University of Pretoria, Department of Zoology and Entomology
	email: T.Zengeya@sanbi.org.za
	Phone: 021 799 8408
Additional assessor (2)	Organisational affiliation:
	email:
	Phone:
BAC3 Name(s) and contact details of expert(s) consulted	
Expert (1)	Name:
	email:
	Phone:
Expert (2)	Name:
	email:
	Phone:
Comments:	
BAC4 Scientific name of *Taxon* under assessment	
Taxon name: *Faxonius virilis*	Authority: (Hagen, 1870)
Comments: *Faxonius virilise* has been reclassified in 2019 (Crandall and De Grave 2017). The group of surface-dwelling crayfish in the *Orconectes* genus was moved to *Faxonius* (Crandall and De Grave 2017, CABI 2019).	
References: Crandall KA, De Grave S, 2017. An updated classification of the freshwater crayfishes (Decapoda: Astacidea) of the world, with a complete species list. *Journal of Crustacean Biology* 27: 615–653.	
BAC5 Synonym(s) considered	
Synonyms: *Cambarus virilis, Orconectes virilis*	

Comments: The crayfish inhibiting caves and the surface dwelling crayfish was split into two groups (Crandall and De Grave 2017). The non-cave dwelling crayfish in the *Orconectes* genus was moved to *Faxonius* (Crandall and De Grave 2017).	
References: Crandall KA, De Grave S, 2017. An updated classification of the freshwater crayfishes (Decapoda: Astacidea) of the world, with a complete species list. *Journal of Crustacean Biology* 27: 615–653.	
BAC6 Common name(s) considered	
Common names: Virile crayfish, Northern crayfish	
Comments:	
References: Adams S, Schuster GA, Taylor CA. 2010. *Orconectes virilis. The IUCN Red List of Threatened Species 2010*: e.T153831A4551026.	
BAC7 What is the native range of the *Taxon*? (add map in Appendix BAC7)	
Response: USA and Canada Missouri, Mississippi, Ohio, and Great Lakes drainages of the United States	Confidence: Low
Comments:	
References: Adams S, Schuster GA, Taylor CA. 2010. *Orconectes virilis. The IUCN Red List of Threatened Species 2010*: e.T153831A4551026. Global Invasive Species Database (GISD) 2015. Species profile *Orconectes virilis* Available from: http://www.iucngisd.org/gisd/species.php?sc=218 [Accessed 03 July 2018].	
BAC8 What is the global alien range of the *Taxon*? (add map in Appendix BAC8)	
Response: **Europe**: Netherlands, United Kingdom, **North America**: Wyoming, West Virginia, Vermont, Utah, Tennesse, Rhode Island, Pensylvania, New Mexico, New Hampshire, Montana, Massachusettes, Maryland, Kansas, Idaho, Connecticut, Colorado, California, Arizona, Alabama, Mexico,	Confidence: Medium
Comments: *Faxonius virilis* has been translocated within the United States of America outside of its native range. Wild populations are present in Europe.	
References: Adams S, Schuster GA, Taylor CA. 2010. *Orconectes virilis. The IUCN Red List of Threatened Species 2010*: e.T153831A4551026. Global Invasive Species Database (GISD) 2015. Species profile *Orconectes virilis*.Available from: http://www.iucngisd.org/gisd/species.php?sc=218 [Accessed 03 July 2018]	
BAC9 Geographic scope = the *Area* under consideration	
Area of assessment: South Africa	
Comments:	
BAC10 Is the *Taxon* present in the *Area*?	
Response: No	Confidence: low
Comments: There are no records of species being in the country (Lodge et al. 2012, Nunes et al. 2017). *Faxonius rusticus* might be present through the pet trade, although this needs to be assessed (Faulkes 2015).	

References:

Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92.

Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology Evolution Systematics* 43: 449–472.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

BAC11 Availability of physical specimen

Response: NA	Confidence in ID:

Herbarium or museum accession number:

References:

BAC12 Is the *Taxon* native to the *Area* or part of the *Area*?

The *Taxon* is native to (part of) the *Area*.	No	Confidence: High
The *Taxon* is alien in (part of) the *Area*.	Yes	Confidence: High

Comments:
South Africa has no indigenous freshwater crayfish (de Moor 2002, Nunes et al. 2017).

References:

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African Journal of Aquatic Science 27: 125–139.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

BAC13 What is the *Taxon*'s introduction status in the *Area*?

The *Taxon* is in cultivation/containment.	Unknown	Confidence: Low
The *Taxon* is present in the wild.	No	Confidence: Low
The *Taxon* has established/naturalised.	No	Confidence: Low
The *Taxon* is invasive.	No	Confidence: Low

Comments:
There are only records for the introduction of four freshwater crayfish into South Africa that include: *Cherax destructor*, *C. cainii/tenuimanus*, *C. quadricarinatus* and *Procrambarus clarkii* (de Moor 2002, Nunes et al. 2017).

References:

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

BAC14 Primary (introduction) pathways

Release	NA	Confidence:
Escape	Aquarium trade	Confidence: High
Contaminant	NA	Confidence:
Stowaway	NA	Confidence:
Corridor	NA	Confidence:
Unaided	NA	Confidence:

Comments: *Faxonius virilis* is present in the pet trade (Chucholl 2013; Faulkes 2015).
References: Chucholl C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141. Faulkes, Z, 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92

2. Likelihood

LIK1 Likelihood of entry via unaided primary pathways	
Response: Very unlikely	Confidence: Low
Rationale: Entry via unaided pathways is very unlikely due to no occurrence records indicating populations in South Africa or neighbouring countries that could act as source for unaided introductions through connected waterways (Nunes et al. 2017; Madzivanzira et al. 2020).	
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

LIK2 Likelihood of entry via human aided primary pathways	
Response: Unlikely	Confidence: Low
Rationale: *Faxonius virilis* is present in the trade but it is not as popular as other crayfish (Soes and Koese 2010; Chucholl 2013). *Faxonius virilis* is present in the pet trade in Netherlands and Germany (Faulkes 2015). The movement of it in South Africa still needs to be assessed	
References: Chucholl C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141. Faulkes, Z, 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Soes M, Koese B. 2010. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis.	

LIK3 Habitat suitability	
Response: Fairly probable	Confidence: Low
Rationale: *Faxonius virilis* may inhabit rivers, streams, lakes, marshes and ponds that are permanent and well-oxygenated (GISD 2015). They prefer warm waters of moderate turbidity with cobble or rocky substrates and abundant logs, rocks, vegetation, and other debris to use as refuge (Soes and Koese 2010).	
References: Global Invasive Species Database (GISD) 2015. Species profile *Orconectes virilis*. Available from: http://www.iucngisd.org/gisd/species.php?sc=218 [Accessed 03 July 2018]. Soes M, Koese B. 2010. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis.	

LIK4 Climate suitability	
Response: Fairly probable	Confidence: Medium
Rationale: *Faxonius virilis* can survive a temperature range of 0-32°C and has a preferred temperature range of 24-25°C (GISD 2015). Its movement is halted at temperatures is below 10°C (GISD 2015).	
References: Global Invasive Species Database (GISD) 2015. Species profile *Orconectes virilis*. Available from: http://www.iucngisd.org/gisd/species.php?sc=218 [Accessed 03 July 2018]	

LIK5 Unaided secondary (dispersal) pathways	
Response: Very unlikely	Confidence: Medium
Rationale: Since there are no wild populations in South Africa or neighbouring countries unaided secondary dispersal through connected waterways is very unlikely (Nunes et al. 2017; Madzivanzira et al. 2020).	
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020. A Review of Freshwater Crayfish Introductions in Africa. Reviews in fisheries science & aquaculture 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

LIK6 Human aided secondary (dispersal) pathways	
Response: Fairly probable	Confidence: low
Rationale: *Orconectes virilis* has been released into the wild by humans as unwanted pets in areas of introduction (Holdich et al 2009; Soes and Koese 2010).	
References: Holdich DM, Reynolds, JD, Souty-Grosset C, Sibley PJ, 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and management of aquatic ecosystems* 11: 394–395. Soes M, Koese B. 2010. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis.	

3. Consequences

CON1 Environmental impact	
CON1a: Competition	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON1b: Predation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1c: Hybridisation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1d: Transmission of disease	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1e: Parasitism	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1f: Poisoning/toxicity	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1g: Bio-fouling or other direct physical disturbance	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	

References: L. Botha (Unpublished data).

CON1h: Grazing/herbivory/browsing	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1i: Chemical, physical or structural impact on ecosystem	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1 Maximum environmental impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact	
References: L. Botha (Unpublished data).	

CON2 Socio-economic impact	
CON2a: Safety	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data	
CON2b: Material and immaterial assets	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2c: Health	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2d: Social, spiritual and cultural relations	
Response: DD	Confidence: Low
Rationale:	
References: L. Botha (Unpublished data)	
CON2 Maximum socio-economic impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON3 Closely related species' Environmental impact	
CON3a: Competition	
Response: MO	Confidence: Medium
Rationale: *Faxonius rusticus* is a fierce competitor and is known to displace native crayfish in areas of introduction through the exclusion of resources (Klocker and Strayer 2004, Lodge et al. 2012). *Faxonius rusticus* is relatively bigger in body size (and has a larger chela) than its native congenerics (Garvey and Stein 1993). A feature which predisposes it to physically out-compete its congenerics for resources. For example, *F. rusticus* has displaced native crayfish (*F. propinquus F. sanborni* and *F. virilis*) in its invasive range through direct competition for food and shelter. In addition, the displaced native species become more susceptible to predation because of a lack of shelter (Garvey and Stein 19993, Byron and Wilson 200, Lodge et al. 2012).	

References:	
Byron CJ, Wilson KA. 2001. Rusty crayfish (*Orconectes rusticus*) movement within and between habitats in Trout Lake, Vilas County, Wisconsin. *Journal of the North American Benthological Society* 20: 606–614. Garvey JE, Stein RA. 1993. Evaluating how chela size influences the invasion potential of an introduced crayfish (*Orconectes rusticus*). *American Midland Naturalist 129:* 172–181. Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178. Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. https://www.cabi.org/isc/datasheet/72037	
CON3b: Predation	
Response: MO	Confidence: Medium
Rationale: Direct predation by *Faxonius rusticus* on native fauna has caused a decline in population size of at least one native species in areas of introduction (Johnson et al. 2009). For example, predation on fish eggs by *F. rusticus* has led to declines in population size and community composition in Vilas County, Winsconsin, U.S.A (Jonas et al. 2005). *Faxonius rusticus* is also known to feed on invertebrates, and in Trout Lake, Wisconsin, U.S.A, direct predation on invertebrate communities has led to a decrease in the mean abundance of several invertebrates orders such as Odonata, Amphipoda and Trichoptera (Lodge et al. 2005, Klocker and Strayer 2004, Wilson et al. 2004, Kreps et al. 2012).	
References: Johnson PT, Olden JD, Solomon CT, Vander Zanden MJ. 2009. Interactions among Invaders: Community and ecosystem effects of multiple invasive species in an experimental aquatic system. *Oecologia* 159: 161–170. Jonas JL, Claramunt RM, Fitzsimons JD, Marsden JE, Ellrott BJ. 2005. Estimates of egg deposition and effects of lake trout (*Salvelinus namaycush*) egg predators in three regions of the Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 62: 2254–2264. Kreps TA, Baldridge AK, Lodge DM. 2012. The impact of an invasive predator (*Orconectes rusticus*) on freshwater snail communities: Insights on habitat-specific effects from a multilake long-term study. *Canadian Journal of Fisheries and Aquatic Sciences* 69:1164–1173. Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178 Lodge DM, Kershner MW, Aloi JE.1995. Effects of an omnivorous crayfish (*Orconectes rusticus*) on a freshwater littoral food web. *Ecology* 75: 1265–1281. Wilson KA., Magnuson JJ, Lodge DM, Hill AM, Kratz, TK, Perry WL, Willis TV. 2004. A long-term rusty crayfish (*Orconectes rusticus*) invasion: Dispersal patterns and community change in a north temperate lake. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 2255–2266.	
CON3c: Hybridisation	
Response: MO	Confidence: Low
Rationale: Hybridisation is known to occur among congenerics of *F. rusticus* (Perry et al. 2001). However, this is unlikely to occur in South Africa because there are no native crayfish species (Lodge et al. 2012).	
References: Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. Perry WL, Feder JL, Dwyer G, Lodge DM. 2001. Hybrid zone dynamics and species replacement between *Orconectes* crayfishes in a northern Wisconsin lake.*Evolution* 55: 1153–1166.	

Perry WL, Feder JL, Lodge DM. 2001. Implications of hybridization between introduced and resident *Orconectes* crayfishes. *Conservation Biology* 15: 1656–1666.	
CON3d: Transmission of disease	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (unpublished data).	
CON3e: Parasitism	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON3f: Poisoning/toxicity	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON3g: Bio-fouling or other direct physical disturbance	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON3h: Grazing/herbivory/browsing	
Response: MO	Confidence: Medium
Rationale: *Faxonius rusticus* is a functional omnivore and feed readily on freshwater macrophytes in its invaded range, altering community structure (Roth et al. 2006). For example, in Lake Michigan, U.S.A *F. rusticus* reduced the macrophyte abundance and species richness by 80% (Wilson et al. 2004).	
References: Roth BM, Hein, CL, Vander Zanden MJ, 2006. Using bioenergetics and stable isotopes to assess the trophic role of rusty crayfish (*Orconectes rusticus*) in lake littoral zones.*Canadian Journal of Fisheries and Aquatic Sciences* 63: 335–344. Wilson KA., Magnuson JJ, Lodge DM, Hill AM, Kratz, TK, Perry WL, Willis TV. 2004. A long-term rusty crayfish (*Orconectes rusticus*) invasion: Dispersal patterns and community change in a north temperate lake. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 2255–2266.	
CON3i: Chemical, physical or structural impact on ecosystem	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1k: Indirect impacts through interactions with other species	
Response: MO	Confidence: Medium
Rationale: In its invasive range, *Faxonius rusticus* may occur with other alien species, and interactions with other these species could facilitate impacts that ultimately lead to a decline in population size of native fauna. In the United States of America, *F. rusticus* occurs with another invasive snail, *Bellamya chinesis* that has a thick shell that prevents predation from rusty crayfish (Johnson et al. 2009). However, competition and predation pressure from both invasive species have reduced native snail biomass immensely (Johnson et al. 2009).	
References:	

Johnson PT, Olden JD, Solomon CT, Vander Zanden MJ. 2009. Interactions among Invaders: Community and ecosystem effects of multiple invasive species in an experimental aquatic system. *Oecologia* 159: 161–170.

CON1 Maximum environmental impact (Figure S3)	
Response: MO	Confidence: Medium
Rationale: In areas of introduction, direct predation, competition for food, shelter and spawning sites have led to local extinctions and a decrease in the abundance of native crayfish and fish species (Garvey and Stein 1993, Klocker and Strayer 2004).	
References: Garvey JE, Stein RA. 1993. Evaluating how chela size influences the invasion potential of an introduced crayfish (*Orconectes rusticus*). *American Midland Naturalist* 129: 172–181. Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178. Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.	

CON4 Closely related species' Socio-economic impact	
CON4a: Safety	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON4b: Material and immaterial assets	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON4c: Health	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON4d: Social, spiritual and cultural relations	
Response: MO	Confidence: Low
Rationale: *Faxonius rusticus* invasions can disrupt recreational activities in the invaded range. This can ultimately affect the well-being of humans because they can no longer participate in these activities (Keller et al. 2008). In Vilas County, *F. rusticus* has reduced sport fish populations though egg predation and/or competition with juveniles. Consequently, this leads to an estimated annual loss of 1.5 million US dollars (Keller et al. 2008).	
References: Keller RP, Frang K, Lodge DM. 2008. Preventing the spread of invasive species: Economic benefits of intervention guided by ecological predictions. *Conservation Biology* 22: 80–88.	
CON4 Maximum socio-economic impact (Figure S3)	
Response: MO	Confidence: Low
Rationale:	

Faxonius rusticus invasions have caused disruption in recreational activities by reducing sport fish populations though egg predation and/or competition with juveniles (Keller et al. 2008).
References: Keller RP, Frang K, Lodge DM. 2008. Preventing the spread of invasive species: Economic benefits of intervention guided by ecological predictions. *Conservation Biology* 22: 80–88.

CON5 Potential impact	
Response: MR	Confidence: High
Rationale: Based on the impacts caused by closely-related species, *Faxonius rusticus, F. virilis* can impact invaded ecosystems through multiple mechanisms (Lodge et al. 2012). *Faxonius virilis* can displace native species when competing for resources (Klocker and Strayer 2004; Soes and Koese 2010). Direct predation and intensive grazing may change species composition of indigenous microinvertebrates and aquatic macrophytes (Roth et al. 2006; Kreps and Lodge 2012). *Faxonius virilis* is also a vector of crayfish plague and was found to have one of the highest infestation rates of any population of crayfish found in the UK (Holdich et al. 2009). This is a major cause for concern as it may be transferred to native crustacean species (Lodge et al. 2012). They are known to burrow in their home ranges which could lead to destabilization of riverbanks causing erosion (Soes and Koese 2010). *Faxonius virilis* therefore highly likely for it to have detrimental impacts in areas where it manages to establish populations (Lodge et al 2012).	
References: Klocker CA, Strayer, DL. 2004. Interactions among an invasive crayfish (*Orconectes rusticus*), a native crayfish (*Orconectes limosus*), and native bivalves (Sphaeriidae and Unionidae). *Northeastern Naturalist* 11:167–178. Kreps TA, Baldridge AK, Lodge DM. 2012. The impact of an invasive predator (*Orconectes rusticus*) on freshwater snail communities: Insights on habitat-specific effects from a multilake long-term study. *Canadian Journal of Fisheries and Aquatic Sciences* 69:1164–1173. Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. Roth BM, Hein, CL, Vander Zanden MJ, 2006. Using bioenergetics and stable isotopes to assess the trophic role of rusty crayfish (*Orconectes rusticus*) in lake littoral zones. *Canadian Journal of Fisheries and Aquatic Sciences* 63: 335–344. Soes M, Koese B. 2010. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis.	

4. Management

MAN1 What is the feasibility to stop future immigration?	
Response: Medium	Confidence: Low
Rationale: There are no known populations in neighbouring countries, thus species entering via unaided primary pathways is very low (Nunes et al. 2017; Madzivanzira 2020). *Faxonius virilis* is however present the pet trade industry in the Czech Republic, Germany and the UK (Chucholl 2013, Faulkes 2015). Should the species be traded illegally as pets, it would be challenging to prevent future introductions, and *Faxonius virilis* might already be in South Africa. Thus, the trading of this species still needs to be assessed thoroughly.	
References: Chucholl C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141. Faulkes Z, 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020. A Review of Freshwater Crayfish Introductions in Africa. Reviews in fisheries science & aquaculture 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past,	

present and potential future. *African Journal of Aquatic Science* 42: 309– 323.

MAN2 Benefits of the Taxon	
MAN2a Socio-economic benefits of the *Taxon*	
Response: None	Confidence: low
Rationale:	
References:	
MAN2b Environmental benefits of the *Taxon*	
Response: None	Confidence: low
Rationale:	
References:	

MAN3 Ease of management (Table 4)	
Response: NA	Confidence:
Rationale:	
References:	
MAN3a How accessible are populations?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3b Is detectability critically time-dependent?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3c Time to reproduction	
Response: NA	Confidence:
Rationale:	
References:	
MAN3d Propagule persistence	
Response: NA	Confidence:
Rationale:	
References:	
MAN3 Ease of management (Table 4)	
Response: NA	Confidence:
Rationale:	
References:	

MAN4 Has the feasibility of eradication been evaluated?	
Response: No	Confidence: Low

Rationale: In areas of introduction, where it has managed to establish populations, there has been no successful eradication attempt. Generally, Once crayfish species have established and is becoming widespread, it is impossible to eradicate (Gherardi et al 2011). They are very hardy and if chemical control is considered large quantities are needed to kill crayfish and biocides have been used to eradicate crayfish populations elsewhere (Gherardi et al. 2011). Furthermore, the chemicals used are not specific to crayfish and can also extirpate other freshwater species within the same freshwater ecosystem (Ghrardi et al. 2011). However, when species are restricted to dams, mechanical control via traps, electrofishing could still be feasible (Gherardi et al 2011).
References: Gherardi F, Aquiloni L, Diéguez-Uribeondo J, Tricarico E. 2011. Managing invasive crayfish: Is there a hope?.*Aquatic Sciences* 73: 185–200.

MAN5 Control options and monitoring approaches available for the *Taxon*
Response:
References:

MAN6 Any other management considerations to highlight? (if yes, fill in Appendix MAN6)	
Response	Yes / No

5. Calculations

Likelihood = Fairly probable

Parameter	**Likelihood**	**Stages**	**Final assessment**
LIK1	0.0027	P(entry) = 0.027	P (invasion) =0.006
LIK2	0.027		
LIK3	0.5	P(establishment) = 0.5	
LIK4	0.5		
LIK5	0.0027	P (spread) = 0.5	
LIK6	0.5		

Consequence = MR (Major)

Parameter	**Mechanism/sector**	**Response**
CON1	**Maximum environmental impact**	**DD**
CON2	**Maximum socio-economic impact**	**DD**
CON3a	Competition	MO
CON3b	Predation	MO
CON3c	Hybridisation	MO
CON3d	Disease transmission	DD
CON3e	Parasitism	DD
CON3f	Poisoning/toxicity	DD
CON3g	Bio-fouling or other direct physical disturbance	DD
CON3h	Grazing/herbivory/browsing	MO
CON3i	Chemical, physical, structural impact	DD
CON3k	Indirect impacts through interactions with other species	MO
CON3	**Maximum environmental impact (closely related taxa)**	**MO**
CON4a	Safety	DD
CON4b	Material and immaterial assets	DD
CON4c	Health	DD
CON4d	Social, spiritual and cultural relations	MN
CON4	**Maximum socio-economic impact (closely related taxa)**	**MN**

CON5	Potential impact based on traits, experiments, or models	**MO**

Table S3: Risk score

		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	low	low	low	medium	medium
	Very unlikely	low	low	low	medium	high
	Unlikely	low	low	medium	high	high
	Fairly probable	medium	medium	high	high	high
	Probable	medium	high	high	high	high

Table S4: Ease of management

Parameter	Question	Response
MAN3a	How accessible are populations?	0
MAN3b	Is detectability critically time-dependent?	0
MAN3c	Time to reproduction	0
MAN3d	Propagule persistence	0
MAN3	**SUM**	0

Supplementary to add to answer sheet
Appendix BAC7: Global alien range of *Orconectes virilis.* Map form CABI:
https://www.cabi.org/ISC/datasheet/72034

Appendix 3.10 Risk analysis report for Signal crayfish (*Pacifastacus leniusculus*).

Risk Analysis Report

<table>
<tr><td>Taxon:
Pacifastacus leniusculus (Dana, 1852)</td><td colspan="2">Area:
South Africa</td></tr>
<tr><td>Compiled by:
Lee-Anne Botha</td><td colspan="2">Approved by:</td></tr>
<tr><td>Picture of Taxon

Sourced from NAS: https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID =200</td><td colspan="2">Alien distribution map

Sourced from CABI: https://www.cabi.org/isc/datasheet/70581</td></tr>
<tr><td colspan="2">Risk Assessment summary:
Globally, the signal crayfish (Pacifastacus leniusculus) has been widely introduced for aquaculture and is also known to be available in the pet trade industry. Given that there are no known populations of P. leniusuculus in South Africa’s neighbouring countries, it may be unlikely for the species to enter South Africa through unaided pathways such as connected waterways. If the species was to enter the country however, it would likely spread rapidly, and has the potential to migrate overland to colonize new areas. The illegal pet trade industry remains a concern because signal crayfish may likely be moved around by humans. Where introduced, P. leniusculus has been implicated in the displacement of several indigenous freshwater crayfish and other native fauna. It has a relatively larger body size and is more aggressive and therefore, likely to out-compete native species for food and shelter. Pacifastacus leniusculus is a functional omnivore and has significant negative impacts on macroinvertebrates, reducing their numbers when occurring in high densities through direct predation. It is also a vector for the crayfish plague that was responsible for the decline of many European freshwater crayfish impacting the aquaculture industry.</td><td>Risk score:

High</td></tr>
<tr><td colspan="2">Management options summary:
There are no records of the occurrence of P. leniusculus in South Africa. It is however, susceptible to biocides and in Scotland, populations restricted to small ponds have been successfully eradicated. Although, the biocide used was not crayfish-specific, and some native fauna were affected.</td><td>Ease of management:
NA</td></tr>
<tr><td colspan="2" rowspan="2">Recommendations:
In South Africa, P. leniusculus is currently listed as Category 1a under the NEM:BA Alien and Invasive Species A&IS Regulations. This Risk Analysis recommends removing it from the list because there are no known records of wild populations of the species either in South Africa or neighbouring countries. There is a critical need for measures to be implemented to prevent the species from entering the country especially through the illegal pet trade industry which poses a significant risk for the intentional release of species into the wild.</td><td>Listing under NEM:BA A&IS lists of 2014 as amended 2020:
Category 1a</td></tr>
<tr><td>Recommended listing category:
Remove from list</td></tr>
</table>

1. Background

BAC1 Name of assessor(s)	
Name of lead assessor	Lee-Anne Botha
Additional assessor (1)	
Additional assessor (2)	
BAC2 Contact details of assessor (s)	
Lead assessor	Organisational affiliation: Department of Zoology and Entomology, University of Pretoria/South African National Biodiversity Institute (SANBI).
	email: u18389164@tuks.co.za
	Phone: 072 833 7952
Additional assessor (1)	Organisational affiliation:
	email:
	Phone:
Additional assessor (2)	Organisational affiliation:
	email:
	Phone:
BAC3 Name(s) and contact details of expert(s) consulted	
Expert (1)	Name: Dr Tsungai Zengeya
	email: T.Zengeya@sanbi.org.za
	Phone: 021 799 8408
Expert (2)	Name:
	email:
	Phone:
Comments: Dr Tsungai Zengeya works for the South African National Biodiversity Institute (SANBI). His research interests are in freshwater ecology and biological invasions. He provided comments and inputs throughout the compilation of this risk analysis that improved its quality.	
BAC4 Scientific name of *Taxon* under assessment	
Taxon name: *Pacifastacus leniusculus*	Authority: (Dana, 1852)
Comments: *Pacifastacus leniusculus* has three subspecies that include: *Pacifastacus leniusculus klamathensis* (Stimpson, 1857) *Pacifastacus leniusculus leniusculus* (Dana, 1852) *Pacifastacus leniusculus trowbridgii* (Stimpson, 1857)	
References: Agerberg A, Jansson H. 1995. Allozymic comparisons between three subspecies of the freshwater crayfish *Pacifastacus leniusculus* (Dana) and between populations introduced to Sweden. *Hereditas* 122: 33–39. Larson ER, Abbott CL, Usio N, Azuma N, Wood KA, Herborg LM, Olden JD. 2012. The signal crayfish is not a single species: Cryptic diversity and invasions in the Pacific Northwest range of *Pacifastacus leniusculus*. *Freshwater Biology* 57: 1823–1838.	
BAC5 Synonym(s) considered	
Synonyms:	
Comments:	

References:
BAC6 Common name(s) considered
Common names: Signal crayfish, Columbia River signal crayfish, Klamath signal crayfish.
Comments:
References: Schuster GA, Taylor, CA, Cordeiro J. 2010. *Pacifastacus leniusculus. The IUCN Red List of Threatened Species 2010*: e.T153648A4526314. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T153648A4526314.en [Accessed 31 January 2019]

BAC7 What is the native range of the *Taxon*? (add map in Appendix BAC7)	
Response: North-western U.S.A. and south-western Canada.	Confidence: High
Comments:	
References: Global Invasive Species Database (GISD) 2015. Species profile *Pacifastacus leniusculus*. Available from: http://www.iucngisd.org/gisd/species.php?sc=725[Accessed 02 July 2018] Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann, ME. & Zeng Y. 2012. Global Introductions of Crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.	
BAC8 What is the global alien range of the *Taxon*? (add map in Appendix BAC8)	
Response: Austria; Belgium; Cyprus; Denmark; Finland; France; Germany; Greece; Italy; Japan; Latvia; Lithuania; Luxembourg; Netherlands; Poland; Portugal; Russian Federation; Spain; Sweden; Switzerland; United Kingdom.	Confidence: Low
Comments:	
References: Schuster GA, Taylor CA, Cordeiro J. 2010. *Pacifastacus leniusculus. The IUCN Red List of Threatened Species 2010*: e.T153648A4526314. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T153648A4526314.en [Accessed 31 January 2019]	
BAC9 Geographic scope = the *Area* under consideration	
Area of assessment: South Africa	
Comments:	
BAC10 Is the *Taxon* present in the *Area*?	
Response: No	Confidence: Low
Comments: Although *P. leniusculus* has not been recorded to occur in South Africa, it may however be available through the pet trade industry, and this needs to be assessed (de Moor 2002, Faulkes 2015).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.	
BAC11 Availability of physical specimen	
Response: NA	Confidence in ID:
Herbarium or museum accession number:	
References:	

BAC12 Is the *Taxon* native to the *Area* or part of the *Area*?		
The *Taxon* is native to (part of) the *Area*.	No	Confidence: High

The *Taxon* is alien in (part of) the *Area*.	Yes	Confidence: High
Comments: Not indigenous freshwater crayfish occur in South Africa (de Moor 2002, Nunes et al. 2017).		
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.		
BAC13 What is the *Taxon*'s introduction status in the *Area*?		
The *Taxon* is in cultivation/containment.	Unknown	Confidence: Low
The *Taxon* is present outside of cultivation/containment.	Unknown	Confidence: Low
The *Taxon* has established/naturalised.	Unknown	Confidence: Low
The *Taxon* is invasive.	Unknown	Confidence: Low
Comments: There are only records for the introduction of four freshwater crayfish species in South Africa that include: *Cherax destructor*, *C. cainii/tenuimanus*, *C. quadricarinatus*, and *Procrambarus clarkii* (de Moor 2002, Nunes et al. 2017).		
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.		
BAC14 Primary (introduction) pathways		
Release		Confidence:
Escape	Aquaculture Pet trade	Confidence: Medium
Contaminant		Confidence:
Stowaway		Confidence:
Corridor		Confidence:
Unaided		Confidence:
Comments: Although globally, *P. leniuscilus* is predominantly used for aquaculture (Holdich 1993, Holdich et al. 2009), it is also available in the pet trade industry (Chucholl 2013, Faulkes 2015).		

References: Chucholl C. 2013. Invaders for sale: Trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasion s*15: 125–141. Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Holdich DM. 1993. A review of astaciculture: Freshwater crayfish farming. *Aquatic Living Resources* 6: 307–317. Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems* 11*:*1–46.

2. Likelihood

LIK1 Likelihood of entry via unaided primary pathways	
Response: Very unlikely	Confidence: Low
Rationale: There are no known populations of *P. leniusculus* in South Africa's neighbouring countries, therefore, its entry into the country through unaided pathways such as connected waterways is very unlikely (Nunes et al. 2017, Madzivanzira et al. 2020).	
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–24. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

LIK2 Likelihood of entry via human aided primary pathways	
Response: Fairly probable	Confidence: Low
Rationale: Globally, the pathway of introduction for *P. leniusculus* has been reported to include escapees from aquaculture facilities and intentional release into the wild by humans as unwanted pets (Chucholl 2013, Faulkes 2015).	
References: Chucholl C. 2013. Invaders for sale: Trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141. Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92.	

LIK3 Habitat suitability	
Response: Fairly probable	Confidence: Low
Rationale: *Pacifastacus leniusculus* occurs in both lentic and lotic habitats. Examples include coastal and mountain streams, lakes, reservoirs, and saline waters in river deltas, and is also tolerant of brackish water and high temperatures (Soes and Koese 2010).	
References: Soes DM, Koese B. 2010. Invasive crayfish in the Netherlands: A preliminary risk analysis. *Interim report, Bureau Waardenburg bv, Stichting EIS-Nederland, Invasive Alien Species Team, Waardenburg*.	

LIK4 Climate suitability	
Response: Fairly probable	Confidence: Low
Rationale: *Pacifastacus leniusculus* can withstand wide range of water temperature. Although the optimal temperature for growth is approximately 20°C, the species can tolerate temperature of up to 33° C (GISD 2015).	

References: Global Invasive Species Database (GISD) 2015. Species profile *Pacifastacus leniusculus*. Schuster GA, Taylor CA, Cordeiro J. 2010. *Pacifastacus leniusculus. The IUCN Red List of Threatened Species 2010*: e.T153648A4526314.

LIK5 Unaided secondary (dispersal) pathways	
Response: Very unlikely	Confidence: Low
Rationale: Although *P. leniusculus* can migrate overland to colonise new area s(Holdich et al. 2009, Hudina et al. 2010), this is very unlikely as there are no wild populations occur in South Africa's neighboring countries that could disperse naturally through connected waterways (Madzivanzira et al. 2020).	
References: Bubb DH, Thom TJ, Lucas MC. 2004. Movement and dispersal of the invasive signal crayfish *Pacifastacus leniusculus* in upland rivers. *Freshwater Biology* 49: 357–368. Hudina S, Faller M, Lucić A, Klobučar G, Maguire I. 2009. Distribution and dispersal of two invasive crayfish species in the Drava River basin, Croatia. *Knowledge and Management of Aquatic Ecosystems* 9: 394–395. Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems* 11*:*1–46. Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–24.	

LIK6 Human aided secondary (dispersal) pathways	
Response: Fairly probable	Confidence: Low
Rationale: *Pacifastacus leniusculus* can intentionally be released into the wild as unwanted pets and may already be available in the pet trade industry (Holdich et al. 2009, Chucholl 2013, Faulkes 2015).	
References: Chucholl C. 2013. Invaders for sale: Trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141. Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosysems* 11*:*1–46.	

3. Consequences

CON1 Environmental impact	
CON1a: Competition	
Response: MR	Confidence: Low
Rationale: *Pacifastacus leniusculus* contributes to the decline of several indigenous species in areas of introduction through competition for resources (Weinlader and Furerfer 2002, Dana et al. 2010, Lodge et al. 2012). Significant competition and reproductive interference often results in the displacement and extinction of native species where it out-competes native crayfish species *(Astacus astacus, Austropotamobius torrentium, Cambaroides japonicas, Pacifastacus nigrescens*) for shelter, making them more susceptible to predation (Pockl and Pekny 2002, Westman et al. 2002, Huber and Schubart 2005) .	
References: Dana ED, López-Santiago J, García-de-Lomas J, García-Ocaña DM, Gámez V, OrtegaF. 2010. Long-term management of the invasive *Pacifastacus leniusculus* (Dana, 1852) in a small mountain stream. *Aquatic Invasions* 5: 317–322. Huber M.G, Schubart C.D. 2005. Distribution and reproductive biology of *Austropotamobius torrentium*	

in Bavaria and documentation of a contact zone with the alien crayfish *Pacifastacus leniusculus*. *Bulletin Français de la Pêche et de la Pisciculture* 376: 759–776.
Lodge DM, Deines A, Gherardi, F, Yeo, DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology Evolution Systematics* 43: 449–472.
Pöckl M, Pekny R. 2002. Interaction between native and alien species of crayfish in Austria: case studies. *Bulletin Français de la Pêche et de la Pisciculture* 367: 763–776.
Weinländer M, Füreder L. 2009. The continuing spread of *Pacifastacus leniusculus* in Carinthia (Austria). *Knowledge and Management of Aquatic Ecosystems* 17: 394–395.
Westman K, Savolainen R, Julkunen M. 2002. Replacement of the native crayfish *Astacus astacus* by the introduced species *Pacifastacus leniusculus* in a small, enclosed Finnish lake: A 30-year study. *Ecography* 25: 53–73.

CON1b: Predation

Response: MO	Confidence: Low

Rationale:
Pacifastacus leniusculus is a functional omnivore feeding on plant material, zoobenthos, detritus, fish, and sometimes other crayfish (Dana et al. 2010, Moorhouse 2018). It tends to consume more animal than plant material and impact invertebrate densities through direct predation (Crawford et al. 2006, Moorhouse 2018). In areas of invasion, there is an overall decrease in native species (snails, leeches, caddisflies, newts, and fish) richness that leads to their population decline (Crawford et al. 2006, Girdner et al 2018).

References:
Crawford L, Yeomans WE, Adams CE. 2006. The impact of introduced signal crayfish *Pacifastacus leniusculus* on stream invertebrate communities. *Aquatic Conservation: Marine and Freshwater Ecosystems* 16: 611–621.
Dana ED, López-Santiago J, García-de-Lomas J, García-Ocaña DM, Gámez V, Ortega F.2010. Long-term management of the invasive *Pacifastacus leniusculus* (Dana, 1852) in a small mountain stream. *Aquatic Invasions* 5: 317–322.
Girdner SF, Ray AM, Buktenica MW, Hering DK, Mack JA, Umek JW. 2018. Replacement of a unique population of newts (*Taricha granulosa mazamae*) by introduced signal crayfish (*Pacifastacus leniusculus*) in Crater Lake, Oregon. *Biological Invasions* 20: 721–740.
Moorhouse TP, Poole AE, Evans LC, Bradley DC, Macdonald DW. 2014. Intensive removal of signal crayfish (*Pacifastacus leniusculus*) from rivers increases numbers and taxon richness of macroinvertebrate species. *Ecology and Evolution* 4: 494–504.

CON1c: Hybridisation

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data).

CON1d: Transmission of disease

Response: MV	Confidence: Medium

Rationale:
Pacifastacus leniusculus is a vector for crayfish plague, a disease caused by the parasitic oomycete, *Aphanomyces astaci* (Longshaw 2011, Lodge et al. 2012). In Europe, the transmission of crayfish plague by *P. leniusculus* to native crayfish species has been linked to a decline in populations of several native species of crayfish such as *Astacus astacus*, *Austropotamobius pallipes*, and *Austropotamobius torrentium* (Holdich and Reeve 1991,Dunn et al. 2009, Holdich et al. 2009).

References:
Dunn JC, McClymont HE, Christmas M, Dunn AM. 2009. Competition and parasitism in the native white clawed crayfish *Austropotamobius pallipes* and the invasive signal crayfish *Pacifastacus leniusculus* in the UK. *Biological Invasions* 11: 315–324.

Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems* 11:1–46.

Holdich DM, Reeve ID. 1991. Distribution of freshwater crayfish in the British Isles, with particular reference to crayfish plague, alien introductions and water quality. *Aquatic Conservation: Marine and Freshwater Ecosystems* 1: 139–158.

Lodge DM, Deines A, Gherardi, F, Yeo, DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology Evolution Systematics* 43: 449–472.

CON1e: Parasitism

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data).

CON1f: Poisoning/toxicity

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data).

CON1g: Bio-fouling or other direct physical disturbance

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (unpublished data).

CON1h: Grazing/herbivory/browsing

Response: DD	Confidence: Low

Rationale:
Although there is no information available assess the level of impact, *P. leniusculus* is a functional omnivore feeding on plant material (Guan and Wiles 1998).

References:
Guan R, Wiles PR. 1998. Feeding ecology of the signal crayfish *Pacifastacus leniusculus* in a British lowland river. *Aquaculture* 168: 177–193.

CON1i: Chemical, physical or structural impact on ecosystem

Response: MN	Confidence: Medium

Rationale:
Burrowing activities of *P. leniusculus* can cause structural damage to river banks and increase bank erosion (Holdich et al. 2009). Although it is considered to be a non-burrowing species, in its invaded range, it constructs burrows under rocks and river banks (Dana et al. 2010). In Europe, the burrows can reach high densities, and can have a severe impact on river bank geomorphology, causing them to collapse (Holdich et al. 2009). On River Lark in the UK, burrowing by *P. leniusculus* has been reported to cause erosion at the rate of 1 m per year (Guan 2010).

References:
Dana ED, López-Santiago J, García-de-Lomas J, García-Ocaña DM, Gámez V, OrtegaF. 2010. Long-term management of the invasive *Pacifastacus leniusculus* (Dana, 1852) in a small mountain stream. *Aquatic Invasions* 5: 317–322.

Guan RZ. 2010. Burrowing behaviour of signal crayfish, *Pacifastacus leniusculus* (Dana) in the River Great Ouse, England. In *Freshwater Forum* 4:155–168.

Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic*

Ecosystems 11:1–46.	
CON1k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1 Maximum environmental impact (Figure S3)	
Response: MV	Confidence: Low
Rationale: Direct predation and competition for food and shelter by *P. leniusculus* have led to local extinctions and a decrease in the abundance of native newts and crayfish species (Crawford et al. 2006, Lodge et al. 2012), and these impacts have been recorded in Europe, Japan, and the U.S.A (Holdich et al. 2009). The species is a vector for crayfish plague that was responsible for the decline of the European crayfish populations (Holdich et al. 2009, Lodge et al. 2012).	
References: Crawford L, Yeomans WE, Adams CE. 2006. The impact of introduced signal crayfish *Pacifastacus leniusculus* on stream invertebrate communities. *Aquatic Conservation: Marine and Freshwater Ecosystems* 16: 611–621. Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems* 11*:* 1–46. Lodge DM, Deines A, Gherardi, F, Yeo, DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.	

CON2 Socio-economic impact	
CON2a: Safety	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON2b: Material and immaterial assets	
Response: MN	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON2c: Health	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON2d: Social, spiritual and cultural relations	
Response: MN	Confidence: Low
Rationale: *Pacifastacus leniusculus* is known to be an ideal species for aquaculture and has been introduced in Europe to alleviate the pressure on native crayfish (Holdich 1993). This introduction has contributed to further decline in native crayfish populations. For example, the indigenous noble crayfish (*Astacus astacus*) has	

been replaced by signal crayfish due to its rapid spread in its areas of introduction (Dana et al. 2010). The noble crayfish is considered to be more valuable than *P. leniusculus* and generates higher revenue, but the economic loss caused by this displacement remains unknown (Johnsen and Taugbol 2010).
References: Dana ED, López-Santiago J, García-de-Lomas J, García-Ocaña DM, Gámez V, OrtegaF. 2010. Long-term management of the invasive *Pacifastacus leniusculus* (Dana, 1852) in a small mountain stream. *Aquatic Invasions* 5: 317–322. Holdich DM. 1993. A review of astaciculture: Freshwater crayfish farming. *Aquatic Living Resources* 6: 307–317. Johnsen SI, Taugbøl T. (2010): NOBANIS – Invasive Alien Species Fact Sheet – *Pacifastacus leniusculus*. Online Database of the European Network on Invasive Alien Species – NOBANIS www.nobanis.org. [Date of access 13/11/2019].

CON2 Maximum socio-economic impact (Figure S3)	
Response: MN	Confidence: Low
Rationale: See above	
References: Johnsen SI, Taugbøl T. (2010): NOBANIS – Invasive Alien Species Fact Sheet – *Pacifastacus leniusculus*. Online Database of the European Network on Invasive Alien Species – NOBANIS www.nobanis.org. [Date of access 13/11/2019].	

CON3 Closely related species' environmental impact	
Response: NA	Confidence:
Rationale:	
References:	

CON4 Closely related species' socio-economic impact	
Response: NA	Confidence:
Rationale:	
References:	

CON5 Potential impact	
Response: MR	Confidence: Low
Rationale: *Pacifastacus leniusculus* is a significant competitor and has displaced several species of indigenous freshwater crayfish and other fauna in recipient areas of introduction (Huber and Schubart 2005, Dunn et al. 2009). While South Africa may not have indigenous freshwater crayfish, closely related decapods such as crabs, may have a resource overlap with *P. leniusculus* which may result in inter-specific competition (Jackson et al. 2016). The species is a vector for crayfish plague that is responsible for the fatalities of several freshwater crayfish species in Europe (Holdich and Reeves 1991, Dana et al. 2010). The plague may be transferable and detrimental to native freshwater crustaceans in South Africa, and being a facultative omnivore, it may also have the potential to cause negative impacts on macroinvertebrates and macrophyte communities (Guan and Wiles 1998, Westman et al. 2002, Dunn et al. 2009). In areas outside of its native range, *P. leniusculus* constructs burrows which can weaken riverbanks and dam walls, changing their bank geomorphology, leading to erosion (Guan 2010).	
References: Dana ED, López-Santiago J, García-de-Lomas J, García-Ocaña DM, Gámez V, Ortega F. 2010. Long-term management of the invasive *Pacifastacus leniusculus* (Dana, 1852) in a small mountain stream. *Aquatic Invasions* 5: 317–322. Dunn JC, McClymont HE, Christmas M, Dunn AM. 2009. Competition and parasitism in the native white	

clawed crayfish *Austropotamobius pallipes* and the invasive signal crayfish *Pacifastacus leniusculus* in the UK. *Biological Invasions* 11: 315–324.
Guan RZ. 1994. Burrowing behaviour of signal crayfish, Pacifastacus leniusculus (Dana) in the River Great Ouse, England. In *Freshwater Forum* 4: 155–168.
Huber MG, Schubart CD. 2005. Distribution and reproductive biology of Austropotamobius torrentium in Bavaria and documentation of a contact zone with the alien crayfish *Pacifastacus leniusculus*. *Bulletin Français de la Pêche et de la Pisciculture* 376: 759–776.
Holdich DM, Reeve ID. 1991. Distribution of freshwater crayfish in the British Isles, with particular reference to crayfish plague, alien introductions and water quality. *Aquatic Conservation: Marine and Freshwater Ecosystems* 1: 139–158.
Pöckl M, Pekny R. 2002. Interaction between native and alien species of crayfish in Austria: Case studies. *Bulletin Français de la Pêche et de la Pisciculture* 367: 763–776.
Westman K, Savolainen R, Julkunen M. 2002. Replacement of the native crayfish *Astacus astacus* by the introduced species *Pacifastacus leniusculus* in a small, enclosed Finnish lake: A 30–year study. *Ecography* 25: 53–73.

4. Management

MAN1 What is the feasibility to stop future immigration?	
Response: Medium	Confidence: Low
Rationale: *Pacifastacus leniusculus* is known to be available in the pet trade industry in the Czech Republic, Germany, and the U.K (Faulkes 2015). Should the species be traded illegally as pets, it would be challenging to prevent future introductions. It is possible that the species may already be in South Africa and its trading still needs to be assessed.	
References: Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44**:** 75–92.	

MAN2 Benefits of the Taxon	
MAN2a Socio-economic benefits of the *Taxon*	
Response: None	Confidence: Low
Rationale: *Pacisastacus leniusculus* is used for aquaculture globally. The available information however is not sufficient to estimate the economic value generated through its aquaculture.	
References: L. Botha (Unpublished data).	
MAN2b Environmental benefits of the *Taxon*	
Response: None	Confidence: Low
Rationale:	
References:	

MAN3 Ease of management	
MAN3a How accessible are populations?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3b Is detectability critically time-dependent?	
Response: NA	Confidence:
Rationale:	

References:	
MAN3c Time to reproduction	
Response: NA	Confidence:
Rationale:	
References:	
MAN3d Propagule persistence	
Response: NA	Confidence:
Rationale:	
References:	
MAN3 Ease of management (SUM from Table S4)	
Response: NA	Confidence:
Rationale:	
References:	

MAN4 Has the feasibility of eradication been evaluated?	
Response: No	Confidence: Low
Rationale: Generally, once *P. leniusculus* has become established and widespread, its eradication is not feasible (Gherardi et al. 2011). Eradication plans are therefore, usually aimed at populations restricted to small dams/ponds, where in Scotland for example, its eradication was successful through the use of biocides (Ballantyne et al. 2019). The efficacy of the biocides was monitored for five years until all *P. leniusculus* crayfish were removed (Ballantyne et al. 2019). The use of biocides, however, is not crayfish-specific, and therefore, some native fauna were affected (Ballantyne et al. 2019).	
References: Ballantyne L, Baum D, Bean CW, Long J, Whitaker S. 2019. Successful eradication of signal crayfish (*Pacifastacus leniusculus*) using a non-specific biocide in a small isolated water body in Scotland. *Island invasives: scaling up to meet the challenge* 62:443–446. Gherardi F, Aquiloni L, Diéguez-Uribeondo J, Tricarico E. 2011. Managing invasive crayfish: Is there a hope? *Aquatic Sciences* 73: 185–200.	

MAN5 Control options and monitoring approaches available for the *Taxon*
Response:
References:

MAN6 Any other management considerations to highlight? (if yes, fill in Appendix MAN6)	
Response	No

5. Calculations

Likelihood = Probable

Parameter	Likelihood	Stages	Final assessment
LIK1	0.0027	P(entry) = 0.5	P(invasion) = 1.25
LIK2	0.5		
LIK3	0.5	P(establishment) = 0.5	
LIK4	0.5		
LIK5	0.0027	P(spread) = 0.5	
LIK6	0.05		

Consequence = MR
(fill in the responses)

Parameter	Mechanism/sector	Response
CON1a	Competition	MR
CON1b	Predation	MO
CON1c	Hybridisation	DD
CON1d	Disease transmission	MV
CON1e	Parasitism	DD
CON1f	Poisoning/toxicity	DD
CON1g	Bio-fouling or other direct physical disturbance	DD
CON1h	Grazing/herbivory/browsing	MC
CON1i	Chemical, physical, structural impact	MN
CON1k	Indirect impacts through interactions with other species	DD
CON1	**Maximum environmental impact**	**MR**
CON2a	Safety	DD
CON2b	Material and immaterial assets	DD
CON2c	Health	DD
CON2d	Social, spiritual and cultural relations	MN
CON2	**Maximum socio-economic impact**	**MN**
CON3	Environmental impact of closely related taxa (only score if CON1a-k are all DD, otherwise NA)	NA
CON4	Socio-economic impact of closely related taxa (only score if CON2a-g are all DD, otherwise NA)	NA
CON5	Potential impact based on traits, experiments, or models	**MR**

Table S3: Risk score
(highlight the respective fields)

		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	Low	Low	Low	Medium	Medium
	Very unlikely	Low	Low	Low	Medium	High
	Unlikely	Low	Low	Medium	High	High
	Fairly probable	Medium	Medium	High	High	High
	Probable	Medium	High	High	High	High

Table S4: Ease of management
(fill in numbers in table below)

Parameter	Question	Response
MAN3a	How accessible are populations?	NA
MAN3b	Is detectability critically time-dependent?	NA NA
MAN3c	Time to reproduction	NA
MAN3d	Propagule persistence	NA
MAN3	**SUM**	

Appendix BAC8(a): Global alien range of *Pacifastacus leniusculus*. Map from CABI: https://www.cabi.org/isc/datasheet/70581

Appendix 3.11 Risk analysis report for Narrow-clawed crayfish (*Pontastacus leptodactylus*).

Risk Analysis Report

***Taxon*:** *Pontastacus leptodactylus* (Eschscholtz, 1823)	***Area*:** South Africa
Compiled by: Lee-Anne Botha	**Approved by:**
Picture of *Taxon*  Perdikaris and Georgiadis (2017)	**Alien distribution map**  https://www.gbif.org/species/8946295

Risk Assessment summary: Currently, there are no feral populations of the narrow-clawed crayfish (*Pontastacus leptodactylus*) in neighbouring countries, therefore it is very unlikely for the species to enter via unaided pathways such as connected waterways which will also be the case for unaided secondary dispersal. The species could be sold as pets. Thus, the pet trade is a relevant pathway of introduction because it could still be moved by humans. There are no documented impacts from *P. leptodactylus*, and potential impacts were inferred from *Pacifastacus leniusculus*, a closely related species, is a fierce competitor and has been implicated in the displacement of several indigenous freshwater crayfish in recipient areas of introduction. It is usually larger in body size and more aggressive, therefore, out-competes native crayfish species. *Pontastacus leptodactylus* can reduce macrophyte densities, exerts heavy predation pressure not only on microinvertebrates but also on fish eggs. Apart from being very aggressive, it is also a prolific breeder, therefore, should it be introduced and establish populations it may out-compete and displace native crustaceans such as crabs.	**Risk score:** High
Management options summary: The species not present in South Africa. Its closely related species, (*P. leniusculus*) is susceptible to biocides and in Scotland, populations restricted to small ponds have been successfully eradicated. The biocide used was not crayfish-specific, and therefore, some native fauna were affected.	**Ease of management:** NA
Recommendations: *Pontastacus leptodactylus* is currently listed Category 1a under the NEM:BA Alien and Invasive Species A&IS Regulations. However there are no past or present records of wild populations in South Africa. Therefore, it is recommended that *P. leptodactylus* should be removed from the list. There is a critical need for measures to be implemented to prevent the species from entering the country especially through the illegal pet trade industry which poses a significant risk for the intentional release of species into the wild.	**Listing under NEM:BA A&IS lists of 2014 as amended 2020:** Category 1a **Recommended listing category:** Remove from list

1. Background

BAC1 Name of assessor(s)	
Name of lead assessor	**Lee-Anne Botha**
Additional assessor (1)	
Additional assessor (2)	
BAC2 Contact details of assessor (s)	
Lead assessor	Organisational affiliation: University of Pretoria, Department of Zoology and Entomology/ SANBI
	email: u18389164@tuks.co.za
	Phone: 072 833 7952
Additional assessor (1)	Organisational affiliation:
	email:
	Phone:
Additional assessor (2)	Organisational affiliation:
	email:
	Phone:
BAC3 Name(s) and contact details of expert(s) consulted	
Expert (1)	Name: Dr Tsungai Zengeya
	email: T.Zengeya@sanbi.org.za
	Phone: 021 799 8408
Expert (2)	Name:
	email:
	Phone:
Comments: Dr Tsungai Zengeya works for the South African National Biodiversity Institute (SANBI). His research interests are in freshwater ecology and biological invasions. He provided comments and inputs throughout the compilation of this risk analysis that improved its quality.	
BAC4 Scientific name of *Taxon* under assessment	
Taxon name: *Pontastacus leptodactylus*	Authority: (Girard, 1852)
Comments:	
References:	
BAC5 Synonym(s) considered	
Synonyms: Astacus leptodactylus ssp. kessleri Karaman, 1963 Astacus leptodactylus ssp. eichwaldi Karaman, 1963 Astacus leptodactylus Eschscholtz, 1823	

Comments: "*Astacus leptodactylus* is referred to as a species complex. In the 1950s this species was believed to belong to the subgenus *Astacus* (*Potastacus*) along with *A. (P.) pachypus*, *A. (P.) pylzowi and A. (P.) kessleri*. The following four subspecies were attributed to *A. (P.) leptodactylus: eichwaldi*, *cubanicus*, *salinus*, and *leptodactylus*. Karaman (1962, 1963) however does not acknowledge *A. (P.) cubanicus* as a subspecies. In the 1970s, *Pontastacus* was raised to generic level. In the 1980s, Brodskij made a number of revisions within Pontastacus but the number of taxa varied within papers. In the mid 1990s Starobogatov (1995) split *Pontastacu*s into two genera: *Pontastacus - P. angulosus* (Rathke, 1837); *P. cubanicus* (Birstein & Winogradow, 1934); *P. danubialis* (Brodskij, 1967); *P. eichwaldi* (Bott, 1950); *P. intermedius* (Bott, 1950); *P. kessleri* (Schimkewitsch, 1886); *P. pyzlowi* (Skorikov, 1911); *P. salinus* (Nordmann, 1942), and *Caspiastacus* with two species. However, there is great deal of criticism over the recent revision in taxonomy made by Ukranian and Russian taxonomists as it appears to be based on little evidence"
References: Gherardi F, Souty-Grosset C. 2017. *Pontastacus leptodactylus. The IUCN Red List of Threatened Species 2017*: e.T153745A120103207. http://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T153745A120103207.en.
BAC6 Common name(s) considered
Common names: Danube crayfish, Galican Crayfish, Long-clawed Crayfish, Narrow-clawed Crayfish, Pond Crayfish, Slender-clawed Crayfish, Swamp Crayfish, Turkish Crayfish
Comments:
References: Gherardi F, Souty-Grosset C. 2017. *Pontastacus leptodactylus. The IUCN Red List of Threatened Species 2017*: e.T153745A120103207.

BAC7 What is the native range of the *Taxon*? (add map in Appendix BAC7)	
Response: Austria; Azerbaijan; Belarus; Bosnia and Herzegovina; Bulgaria; Croatia; Georgia; Greece; Hungary; Iran, Islamic Republic of; Israel; Kazakhstan; Kyrgyzstan; Moldova; Romania; Russian Federation; Serbia (Serbia); Slovakia; Turkey (Turkey-in-Asia, Turkey-in-Europe); Turkmenistan; Ukraine"	Confidence: Low
Comments:	
References: Gherardi F, Souty-Grosset C. 2017. *Pontastacus leptodactylus. The IUCN Red List of Threatened Species 2017*: e.T153745A120103207.	
BAC8 What is the global alien range of the *Taxon*? (add map in Appendix BAC8)	
Response: Armenia, Belgium, Czech Republic, Denmark, Finland, France, Germany, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Switzerland, United Kingdom (Great Britain), Uzbekistan	Confidence: Low
Comments: *Pontastacus leptodactylus* has been introduced into western European countries, however It is considered indigenous in the eastern part of its range.	
References: Gherardi F, Souty-Grosset C. 2017. *Pontastacus leptodactylus. The IUCN Red List of Threatened Species 2017*: e.T153745A120103207.	
BAC9 Geographic scope = the *Area* under consideration	
Area of assessment: South Africa	
Comments:	
BAC10 Is the *Taxon* present in the *Area*?	

Response: No	Confidence: Low

Comments:
There are no records of species being in the country (Lodge et al. 2012, Nunes et al. 2017). *Pontasatcus leptodactylus* might be present through the pet trade, although this needs to be assessed (Faulkes 2015).

References:

Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92.
Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology Evolution Systematics* 43: 449–472.
Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

BAC11 Availability of physical specimen

Response: NA	Confidence in ID:

Herbarium or museum accession number:

References:

BAC12 Is the *Taxon* native to the *Area* or part of the *Area*?

The *Taxon* is native to (part of) the *Area*.	No	Confidence: High
The *Taxon* is alien in (part of) the *Area*.	Yes	Confidence: High

Comments:
South Africa has no indigenous freshwater crayfish (de Moor 2002, Nunes et al. 2017).

References:

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125-139.
Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

BAC13 What is the *Taxon*'s introduction status in the *Area*?

The *Taxon* is in cultivation/containment.	Don't know	Confidence: low
The *Taxon* is present in the wild.	No	Confidence: low
The *Taxon* has established/naturalised.	No	Confidence: low
The *Taxon* is invasive.	No	Confidence: low

Comments:
There are only records for the introduction of four freshwater crayfish into South Africa that include: *Cherax destructor*, *C. cainii/tenuimanus*, *C. quadricarinatus* and *Procrambarus clarkii* (de Moor 2002, Nunes et al. 2017).

References:

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.
Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

BAC14 Primary (introduction) pathways

Release	NA	Confidence:

Escape	Aquaculture Pet trade	Confidence: High
Contaminant	NA	Confidence:
Stowaway	NA	Confidence:
Corridor	NA	Confidence:
Unaided	NA	Confidence:
Comments: *Pontastacus leptodactylus* are stocked deliberately for the consumption trade and are also available in the pet trade in Europe (Chucholl 2013; Faulkes 2015). In Turkey, it was also stocked in some areas to replenish stocks that have been lost by the crayfish plague (Harlioğlu and Harlioğlu 2004).		
References: Chucholl C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141 Faulkes Z, 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Harlioğlu MM, Harlioğlu AG. 2004. The harvest of freshwater crayfish, Astacus leptodactylus (Eschscholtz, 1823) in Turkey. *Reviews in Fish Biology and Fisheries* 14: 415–419.		

2. Likelihood

LIK1 Likelihood of entry via unaided primary pathways	
Response: Very unlikely	Confidence: Low
Rationale: Currently there are no wild populations in neighbouring countries that could act as source for unaided introductions through connected waterways (Nunes et al. 2017, Madzivanzira et al. 2020).	
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–24. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

LIK2 Likelihood of entry via human aided primary pathways	
Response: Fairly probable	Confidence: Low
Rationale: *Pontastacus leptodactylus* is generally introduced for the use of aquaculture that requires a permit in South Africa. The pet trade still poses a risk, however the species is considered rare and is only present in two countries.	
References: Chucholl C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141 Faulkes Z, 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92.	

LIK3 Habitat suitability	
Response: Fairly probable	Confidence: Low
Rationale: This species inhabit fresh and brackish waters, both lentic and lotic systems. In Europe, the species occur in lakes, canals and rivers. *Pontastacus leptodactylus* is known to occur in saline conditions such as estuaries Gherardi and Souty-Grosset 2017).	
References: Gherardi F, Souty-Grosset C. 2017. *Pontastacus leptodactylus. The IUCN Red List of Threatened Species 2017*: e.T153745A120103207. http://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T153745A120103207.en	

LIK4 Climate suitability	
Response:	Confidence: low

Rationale: No data available on climate suitability *Pacifastacus leniusculus* (closely-related species) can withstand wide range of water temperature. Although the optimal temperature for growth is approximately 20°C, the species can tolerate temperature of up to 33° C (GISD 2015).
References: Global Invasive Species Database (GISD) 2015. Species profile *Pacifastacus leniusculus*. Schuster GA, Taylor CA, Cordeiro J. 2010. *Pacifastacus leniusculus. The IUCN Red List of Threatened Species 2010*: e.T153648A4526314.

LIK5 Unaided secondary (dispersal) pathways	
Response: Very unlikely	Confidence: Low
Rationale: Since there are no wild populations in South Africa or neighbouring countries, thus unaided secondary dispersal through connected waterways is very unlikely (Madzivanzira et al. 2020).	
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020. A Review of Freshwater Crayfish Introductions in Africa. *Reviews in fisheries science & aquaculture* 1–21.	

LIK6 Human aided secondary (dispersal) pathways	
Response: Unlikely	Confidence: Low
Rationale: Crayfish can be released into the wild as unwanted pets. *Pontastacus leptodactylus* is not very common in the pet trade industry (Chucholl 2013; Faulkes 2015).	
References: Chucholl, C. 2013. Invaders for sale: trade and determinants of introduction of ornamental freshwater crayfish. *Biological Invasions* 15: 125–141 Faulkes, Z, 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92.	

3. Consequences

CON1 Environmental impact	
CON1a: Competition	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON1b: Predation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1c: Hybridisation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1d: Transmission of disease	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1e: Parasitism	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1f: Poisoning/toxicity	
Response: DD	Confidence: Low

Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1g: Bio-fouling or other direct physical disturbance	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1h: Grazing/herbivory/browsing	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1i: Chemical, physical or structural impact on ecosystem	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1 Maximum environmental impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact	
References: L. Botha (Unpublished data).	

CON2 Socio-economic impact	
CON2a: Safety	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data	
CON2b: Material and immaterial assets	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2c: Health	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2d: Social, spiritual and cultural relations	
Response: DD	Confidence: Low
Rationale:	
References: L. Botha (Unpublished data)	
CON2 Maximum socio-economic impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON3 Closely related species' Environmental impact	
CON3a: Competition	
Response: MR	Confidence: Low
Rationale: *Pacifastacus leniusculus* contributes to the decline of several indigenous species in areas of introduction through competition for resources (Weinlader and Furerfer 2002, Dana et al. 2010, Lodge et al. 2012).	

Significant competition and reproductive interference often results in the displacement and extinction of native species where it out-competes native crayfish species *(Astacus astacus, Austropotamobius torrentium, Cambaroides japonicas, Pacifastacus nigrescens*) for shelter, making them more susceptible to predation (Pockl and Pekny 2002, Westman et al. 2002, Huber and Schubart 2005) .	
References: Dana ED, López-Santiago J, García-de-Lomas J, García-Ocaña DM, Gámez V, OrtegaF. 2010. Long-term management of the invasive *Pacifastacus leniusculus* (Dana, 1852) in a small mountain stream. *Aquatic Invasions* 5: 317–322. Huber M.G, Schubart C.D. 2005. Distribution and reproductive biology of *Austropotamobius torrentium* in Bavaria and documentation of a contact zone with the alien crayfish *Pacifastacus leniusculus*. *Bulletin Français de la Pêche et de la Pisciculture* 376: 759–776. Lodge DM, Deines A, Gherardi, F, Yeo, DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology Evolution Systematics* 43: 449–472. Pöckl M, Pekny R. 2002. Interaction between native and alien species of crayfish in Austria: case studies. *Bulletin Français de la Pêche et de la Pisciculture* 367: 763–776. Weinländer M, Füreder L. 2009. The continuing spread of *Pacifastacus leniusculus* in Carinthia (Austria). *Knowledge and Management of Aquatic Ecosystems* 17: 394–395. Westman K, Savolainen R, Julkunen M. 2002. Replacement of the native crayfish *Astacus astacus* by the introduced species *Pacifastacus leniusculus* in a small, enclosed Finnish lake: A 30-year study. *Ecography* 25: 53–73.	
CON3b: Predation	
Response: MO	Confidence: Low
Rationale: *Pacifastacus leniusculus* is a functional omnivore feeding on plant material, zoobenthos, detritus, fish, and sometimes other crayfish (Dana et al. 2010, Moorhouse 2018). It tends to consume more animal than plant material and impact invertebrate densities through direct predation (Crawford et al. 2006, Moorhouse 2018). In areas of invasion, there is an overall decrease in native species (snails, leeches, caddisflies, newts, and fish) richness that leads to their population decline (Crawford et al. 2006, Girdner et al 2018).	
References: Crawford L, Yeomans WE, Adams CE. 2006. The impact of introduced signal crayfish *Pacifastacus leniusculus* on stream invertebrate communities. *Aquatic Conservation: Marine and Freshwater Ecosystems* 16: 611–621. Dana ED, López-Santiago J, García-de-Lomas J, García-Ocaña DM, Gámez V, OrtegaF.2010. Long-term management of the invasive *Pacifastacus leniusculus* (Dana, 1852) in a small mountain stream. *Aquatic Invasions* 5: 317–322. Girdner SF, Ray AM, Buktenica MW, Hering DK, Mack JA, Umek JW. 2018. Replacement of a unique population of newts (*Taricha granulosa mazamae*) by introduced signal crayfish (*Pacifastacus leniusculus*) in Crater Lake, Oregon. *Biological Invasions* 20: 721–740. Moorhouse TP, Poole AE, Evans LC, Bradley DC, Macdonald DW. 2014. Intensive removal of signal crayfish (*Pacifastacus leniusculus*) from rivers increases numbers and taxon richness of macroinvertebrate species. *Ecology and Evolution* 4: 494–504.	
CON3c: Hybridisation	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON3d: Transmission of disease	
Response: MV	Confidence: Medium
Rationale:	

Pacifastacus leniusculus is a vector for crayfish plague, a disease caused by the parasitic oomycete, *Aphanomyces astaci* (Longshaw 2011, Lodge et al. 2012). In Europe, the transmission of crayfish plague by *P. leniusculus* to native crayfish species has been linked to a decline in populations of several native species of crayfish such as *Astacus astacus*, *Austropotamobius pallipes*, and *Austropotamobius torrentium* (Holdich and Reeve 1991,Dunn et al. 2009, Holdich et al. 2009).

References:

Dunn JC, McClymont HE, Christmas M, Dunn AM. 2009. Competition and parasitism in the native white clawed crayfish *Austropotamobius pallipes* and the invasive signal crayfish *Pacifastacus leniusculus* in the UK. *Biological Invasions* 11: 315–324.

Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems* 11:1–4.

Holdich DM, Reeve ID. 1991. Distribution of freshwater crayfish in the British Isles, with particular reference to crayfish plague, alien introductions and water quality. *Aquatic Conservation: Marine and Freshwater Ecosystems* 1: 139–158.

Lodge DM, Deines A, Gherardi, F, Yeo, DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology Evolution Systematics* 43: 449–472.

CON3e: Parasitism

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data).

CON3f: Poisoning/toxicity

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data).

CON3g: Bio-fouling or other direct physical disturbance

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (unpublished data).

CON3h: Grazing/herbivory/browsing

Response: DD	Confidence: Low

Rationale:
Although there is no information available assess the level of impact, *P. leniusculus* is a functional omnivore feeding on plant material (Guan and Wiles 1998).

References:
Guan R, Wiles PR. 1998. Feeding ecology of the signal crayfish *Pacifastacus leniusculus* in a British lowland river. *Aquaculture* 168: 177–193.

CON3i: Chemical, physical or structural impact on ecosystem

Response: MN	Confidence: Medium

Rationale:
Burrowing activities of *P. leniusculus* can cause structural damage to river banks and increase bank erosion (Holdich et al. 2009). Although it is considered to be a non-burrowing species, in its invaded range, it constructs burrows under rocks and river banks (Dana et al. 2010). In Europe, the burrows can reach high densities, and can have a severe impact on river bank geomorphology, causing them to collapse (Holdich et al. 2009). On River Lark in the UK, burrowing by *P. leniusculus* has been reported to cause erosion at the

rate of 1 m per year (Guan 2010).
References: Dana ED, López-Santiago J, García-de-Lomas J, García-Ocaña DM, Gámez V, Ortega F. 2010. Long-term management of the invasive *Pacifastacus leniusculus* (Dana, 1852) in a small mountain stream. *Aquatic Invasions* 5: 317–322. Guan RZ. 2010. Burrowing behaviour of signal crayfish, *Pacifastacus leniusculus* (Dana) in the River Great Ouse, England. In *Freshwater Forum* 4:155–168. Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems* 11:1–46.

CON3k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON3 Maximum environmental impact (Figure S3)	
Response: MV	Confidence: Low
Rationale: Direct predation and competition for food and shelter by *P. leniusculus* have led to local extinctions and a decrease in the abundance of native newts and crayfish species (Crawford et al. 2006, Lodge et al. 2012), and these impacts have been recorded in Europe, Japan, and the U.S.A (Holdich et al. 2009). The species is a vector for crayfish plague that was responsible for the decline of the European crayfish populations (Holdich et al. 2009, Lodge et al. 2012).	
References: Crawford L, Yeomans WE, Adams CE. 2006. The impact of introduced signal crayfish *Pacifastacus leniusculus* on stream invertebrate communities. *Aquatic Conservation: Marine and Freshwater Ecosystems* 16: 611–621. Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems* 11*:* 1–46. Lodge DM, Deines A, Gherardi, F, Yeo, DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology*, *Evolution and Systematics* 43: 449–72.	

CON4 Closely related species' Socio-economic impact	
CON4a: Safety	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON4b: Material and immaterial assets	
Response: MN	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON4c: Health	
Response: DD	Confidence: Low

Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON4d: Social, spiritual and cultural relations	
Response: MN	Confidence: Low
Rationale: *Pacifastacus leniusculus* is known to be an ideal species for aquaculture and has been introduced in Europe to alleviate the pressure on native crayfish (Holdich 1993). This introduction has contributed to further decline in native crayfish populations. For example, the indigenous noble crayfish (*Astacus astacus*) has been replaced by signal crayfish due to its rapid spread in its areas of introduction (Dana et al. 2010). The noble crayfish is considered to be more valuable than *P. leniusculus* and generates higher revenue, but the economic loss caused by this displacement remains unknown (Johnsen and Taugbol 2010).	
References: Dana ED, López-Santiago J, García-de-Lomas J, García-Ocaña DM, Gámez V, Ortega F. 2010. Long-term management of the invasive *Pacifastacus leniusculus* (Dana, 1852) in a small mountain stream. *Aquatic Invasions* 5: 317–322. Holdich DM. 1993. A review of astaciculture: Freshwater crayfish farming. *Aquatic Living Resources* 6: 307–317. Johnsen SI, Taugbøl T. (2010): NOBANIS – Invasive Alien Species Fact Sheet – *Pacifastacus leniusculus.* Online Database of the European Network on Invasive Alien Species – NOBANIS www.nobanis.org. [Date of access 13/11/2019].	
CON4 Maximum socio-economic impact (Figure S3)	
Response: MN	Confidence: Low
Rationale: See above	
References: Johnsen SI, Taugbøl T. (2010): NOBANIS – Invasive Alien Species Fact Sheet – *Pacifastacus leniusculus.* Online Database of the European Network on Invasive Alien Species – NOBANIS www.nobanis.org. [Date of access 13/11/2019].	

CON5 Potential impact	
Response: MR	Confidence: High
Rationale: Based on the information gathered fromm the impact assessment for *P. leniusculus*, *Pontastacus leptodactylus has* the potential to cause negative impacts in its invaded range (Chucholl 2016). It can outcompete native species for shared resources leading to reproductive interference and decline in numbers) (Weinlader and Furerfer 2002, Dana et al. 2010, Lodge et al. 2012. *Pontastacus leptdactylus* can impact invertebrate densities through direct predation (Crawford et al. 2006, Moorhouse 2018). Unlike to *P.leniusculus, P.leptodactylus* is not a vector for the crayfish plague (Harlioğlu1996).	
References: Chucholl C. 2016. The bad and the super-bad: prioritising the threat of six invasive alien to three imperiled native crayfishes. *Biological Invasions* 18:1967–1988. Dana ED, López-Santiago J, García-de-Lomas J, García-Ocaña DM, Gámez V, OrtegaF. 2010. Long-term management of the invasive *Pacifastacus leniusculus* (Dana, 1852) in a small mountain stream. *Aquatic Invasions* 5: 317–322. Harlioğlu MM. 1996. *Comparative biology of the signal crayfish, Pacifastacus leniusculus (Dana), and the narrow-clawed crayfish, Astacus leptodactylus Eschscholtz* (Doctoral dissertation, University of Nottingham). Lodge DM, Deines A, Gherardi, F, Yeo, DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. Weinländer M, Füreder L. 2009. The continuing spread of *Pacifastacus leniusculus* in Carinthia (Austria).	

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4. Management

MAN1 What is the feasibility to stop future immigration?	
Response: Medium	Confidence: Low
Rationale: There are no known populations in neighbouring countries, thus species entering via unaided primary pathways is very low (Nunes et al. 2017; Madzivanzira et al. 2020) . Pet trade still poses a problem due to illegal selling of species and the risk of owners releasing species into the wild (Faulkes 2015).	
References: Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75-92. Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–24. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

MAN2 Benefits of the Taxon	
MAN2a Socio-economic benefits of the *Taxon*	
Response: None	Confidence: low
Rationale:	
References:	
MAN2b Environmental benefits of the *Taxon*	
Response: None	Confidence: low
Rationale:	
References:	

MAN3 Ease of management	
MAN3a How accessible are populations?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3b Is detectability critically time-dependent?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3c Time to reproduction	
Response: NA	Confidence:
Rationale:	
References:	
MAN3d Propagule persistence	
Response: NA	Confidence:
Rationale:	
References:	
MAN3 Ease of management (SUM from Table S4)	
Response: NA	Confidence:

Rationale
References:

MAN4 Has the feasibility of eradication been evaluated?	
Response: No	Confidence: Low
Rationale: In areas of introduction, where it has managed to establish populations, there has been no successful eradication attempt. An eradication attempt of closely-related species, *Pacisastacus leniusculus* was successful through the use of biocides (Ballantyne et al. 2019). The efficacy of the biocides was monitored for five years until all *P. leniusculus* crayfish were removed (Ballantyne et al. 2019). The use of biocides, however, is not crayfish-specific, and therefore, some native fauna were affected (Ballantyne et al. 2019). Generally, once crayfish species have established and become widespread, it is impossible to eradicate them (Gherardi et al 2011). They are very hardy and if chemical control is considered large quantities are needed to kill crayfish and biocides have been used to eradicate crayfish populations elsewhere (Gherardi et al. 2011). Furthermore, the chemicals used are not specific to crayfish and can also extirpate other freshwater species within the same freshwater ecosystem (Ghrardi et al. 2011). However, when species are restricted to dams mechanical control via traps, electrofishing could still be feasible (Gherardi et al 2011).	
References: Ballantyne L, Baum D, Bean CW, Long J, Whitaker S. 2019. Successful eradication of signal crayfish (*Pacifastacus leniusculus*) using a non-specific biocide in a small isolated water body in Scotland. *Island invasives: scaling up to meet the challenge* 62:443–446. Gherardi F, Aquiloni L, Diéguez-Uribeondo J, Tricarico E. 2011. Managing invasive crayfish: Is there a hope?. *Aquatic Sciences* 73:185–200.	

MAN5 Control options and monitoring approaches available for the *Taxon*
Response: Not assessed
References:

MAN6 Any other management considerations to highlight? (if yes, fill in Appendix MAN6)	
Response	No

5. Calculations

Likelihood = Very unlikely

Parameter	Likelihood	Stages	Final assessment
LIK1	0.0027	P(entry) = 0.027	P (invasion) = 0.0003
LIK2	0.027		
LIK3	0.5	P(establishment) =0.5	
LIK4	0.5		
LIK5	0.0027	P (spread) = 0.027	
LIK6	0.027		

Consequence = MV (Massive)

Parameter	Mechanism/sector	Response

CON1	**Maximum environmental impact**	**DD**
CON2	**Maximum socio-economic impact**	**DD**
CON3a	Competition	MR
CON3b	Predation	MO
CON3c	Hybridisation	DD
CON3d	Disease transmission	MV
CON3e	Parasitism	DD
CON3f	Poisoning/toxicity	DD
CON3g	Bio-fouling or other direct physical disturbance	DD
CON3h	Grazing/herbivory/browsing	MC
CON3i	Chemical, physical, structural impact	MN
CON3k	Indirect impacts through interactions with other species	DD
CON3	**Maximum environmental impact (closely related taxa)**	**MR**
CON4a	Safety	DD
CON4b	Material and immaterial assets	DD
CON4c	Health	DD
CON4d	Social, spiritual and cultural relations	MN
CON4	**Maximum socio-economic impact (closely related taxa)**	**MN**
CON5	Potential impact based on traits, experiments, or models	**MR**

Table S3: Risk score

		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	low	low	low	medium	medium
	Very unlikely	low	low	low	medium	high
	Unlikely	low	low	medium	high	high
	Fairly probable	medium	medium	high	high	high
	Probable	medium	high	high	high	high

Table S4: Ease of management

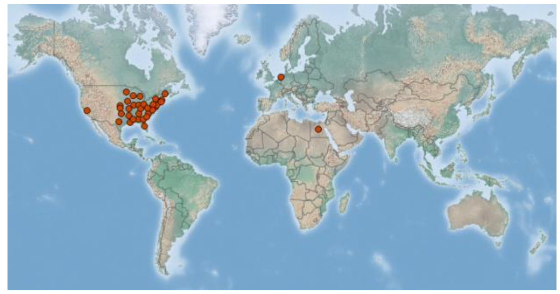
Parameter	Question	Response
MAN3a	How accessible are populations?	0
MAN3b	Is detectability critically time-dependent?	0
MAN3c	Time to reproduction	0
MAN3d	Propagule persistence	0
MAN3	**SUM**	0

Appendix BAC7: Global alien range of *Pontastacus leptodactylus Map from GBIF:*
https://www.gbif.org/species/8946295

Appendix 3.12 Risk analysis report for White River crayfish (*Procambarus acutus*).

Risk Analysis Report

<table>
<tr><td colspan="2">Taxon:
Procambarus acutus (Girard, 1852)</td><td colspan="2">Area:
South Africa</td></tr>
<tr><td colspan="2">Compiled by:
Lee-Anne Botha</td><td colspan="2">Approved by:</td></tr>
<tr><td colspan="2">Picture of Taxon

https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=216</td><td colspan="2">Alien distribution map

https://www.cabi.org/isc/datasheet/67841</td></tr>
<tr><td colspan="3">Risk Assessment summary:
The White River crayfish (Procambarus acutus) is not widely distributed and the only alien population is known from Netherlands. There are no records of the species in any of the neighbouring countries, therefore, introduction via unaided pathways is very unlikely. Furthermore, P. acutus is considered rare in the pet trade industry and there are few confirmed records of it being sold as a pet. This pathway of introduction however, still remains a cause for concern because it could still be moved by humans. There are no documented impacts from P. acutus, and potential impacts were inferred from Procambarus clarkii, a closely-related species, is a facultative omnivore and an aggressive competitor that often displaces native species in areas of introduction through predation, competitive exclusions, and transmission of diseases. Procambarus clarkii has also been implicated in causing habitat alteration through excessive grazing of macrophytes, and its burrowing activities increase rates of soil erosion, and cause physical damage to agricultural infrastructure such as irrigation canals. It serves as a vector for several parasites and diseases some of which are zoonotic. Procambarus acutus shares various traits with P.clarkii (such as feeding and burrowing behavior) and is therefore, capable of causing detrimental impacts in its invaded range</td><td>Risk score:
Medium</td></tr>
<tr><td colspan="3">Management options summary:
Species not present in South Africa. A variety of methods could be evaluated such as chemical, manual, or a combination of the two methods. When evaluating suitable methods however, it is important to take into account the burrowing behaviour of the species. The species is popular in the aquarium trade and as a result, the potential of accidental or intentional release of the species into new areas by humans is high.</td><td>Ease of management:
NA</td></tr>
<tr><td colspan="3" rowspan="2">Recommendations:
The species is not currently listed under NEM:BA Alien and Invasive Species (A&IS) Regulations. The results from this Risk Analysis support the listing because there are no known population in South Africa. The illegal pet trade industry still poses a significant risk for intentional and accidental release of the species into the wild. There is therefore, a need to assess the trade of, and movement of the species through the aquarium trade in order to implement appropriate management strategies.</td><td>Listing under NEM:BA A&IS lists of 2014 as amended 2020:
Not listed</td></tr>
<tr><td>Recommended listing category:
No change</td></tr>
</table>

1. Background

BAC1 Name of assessor(s)		
Name of lead assessor	**Lee-Anne Botha**	
Additional assessor (1)	**Tsungai Zengeya**	
Additional assessor (2)		
BAC2 Contact details of assessor (s)		
Lead assessor	Organisational affiliation: University of Pretoria, Department of Zoology and Entomology	
	email: u18389164@tuks.co.za	
	Phone: 072 833 7952	
Additional assessor (1)	Organisational affiliation: Kirstenbosch Research Centre, Newlands, Cape Town/ University of Pretoria, Department of Zoology and Entomology.	
	email: T.Zengeya@sanbi.org.za	
	Phone: 021 799 8408	
Additional assessor (2)	Organisational affiliation:	
	email:	
	Phone:	
BAC3 Name(s) and contact details of expert(s) consulted		
Expert (1)	Name: Dr Tsungai Zengeya	
	email: T.Zengeya@sanbi.org.za	
	Phone: 021 799 8408	
Expert (2)	Name:	
	email:	
	Phone:	
Comments: Dr Tsungai Zengeya works for the South African National Biodiversity Institute (SANBI). His research interests are in freshwater ecology and biological invasions. He provided comments and inputs throughout the compilation of this risk analysis that improved its quality.		
BAC4 Scientific name of *Taxon* under assessment		
Taxon name: *Procambarus acutus*		Authority: (Girard, 1852).
Comments:		
References: Crandall KA, De Grave S, 2017. An updated classification of the freshwater crayfishes (Decapoda: Astacidea) of the world, with a complete species list. *Journal of Crustacean Biology* 27: 615–653.		
BAC5 Synonym(s) considered		
Synonyms:		
Comments:		

References:	
BAC6 Common name(s) considered	
Common names: White River crayfish	
Comments:	
References: Soes DM, Koese B. 2010. Invasive crayfish in the Netherlands: a preliminary risk analysis. *Interim report, Bureau Waardenburg bv, Stichting EIS-Nederland, Invasive Alien Species Team, Waardenburg*.	
BAC7 What is the native range of the *Taxon*? (add map in Appendix BAC7)	
Response: Coastal plain from Maine to Georgia, and from the Florida panhandle to Texas, and Minnesota to Ohio.	Confidence: Low
Comments:	
References: Crandall KA. 2010. Procambarus acutus. The IUCN Red List of Threatened Species 2010: e.T154022A4577805. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T154022A4577805.en	
BAC8 What is the global alien range of the *Taxon*? (add map in Appendix BAC8)	
Response: Europe	Confidence: Medium
Comments: Outside the USA, it is known from the River Nile in Egypt, where it co-occurs with *P. clarkia* and from the Netherlands, where it has been present since 2005. However, whether these latter populations belong to *P. acutus* or *P. zonangulus* is unknown.	
References: Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowl. Manag. Aquat. Ecosyst.* 394–95:11p1–46 Soes DM, Koese B. 2010. Invasive crayfish in the Netherlands: a preliminary risk analysis. *Interim report, Bureau Waardenburg bv, Stichting EIS-Nederland, Invasive Alien Species Team, Waardenburg*.	
BAC9 Geographic scope = the *Area* under consideration	
Area of assessment: South Africa	
Comments:	
BAC10 Is the *Taxon* present in the *Area*?	
Response: No	Confidence: High
Comments: There are no records of species being in the country (Lodge et al. 2012, Nunes et al. 2017). *Faxonius rusticus* might be present through the pet trade, although this needs to be assessed (Faulkes 2015).	
References: Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Lodge DM, Deines A, Gherardi, F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology Evolution Systematics* 43: 449–472. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

<table>
<tr><td colspan="3">BAC11 Availability of physical specimen</td></tr>
<tr><td colspan="2">Response:</td><td>Confidence in ID:</td></tr>
<tr><td colspan="3">Herbarium or museum accession number:</td></tr>
<tr><td colspan="3">References:</td></tr>
<tr><td colspan="3">BAC12 Is the Taxon native to the Area or part of the Area?</td></tr>
<tr><td>The Taxon is native to (part of) the Area.</td><td>No</td><td>Confidence: High</td></tr>
<tr><td>The Taxon is alien in (part of) the Area.</td><td>Yes</td><td>Confidence: High</td></tr>
<tr><td colspan="3">Comments:
South Africa has no indigenous freshwater crayfish (de Moor 2002, Nunes et al. 2017).</td></tr>
<tr><td colspan="3">References:
de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African Journal of Aquatic Science 27: 125–139.
Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. African Journal of Aquatic Science 42: 309–323.</td></tr>
<tr><td colspan="3">BAC13 What is the Taxon’s introduction status in the Area?</td></tr>
<tr><td>The Taxon is in cultivation/containment.</td><td>Unknown</td><td>Confidence: Low</td></tr>
<tr><td>The Taxon is present in the wild.</td><td>Unknown</td><td>Confidence: Low</td></tr>
<tr><td>The Taxon has established/naturalised.</td><td>Unknown</td><td>Confidence: Low</td></tr>
<tr><td>The Taxon is invasive.</td><td>Unknown</td><td>Confidence: Low</td></tr>
<tr><td colspan="3">Comments:
There are only records for the introduction of four freshwater crayfish into South Africa that include: Cherax destructor, C. cainii/tenuimanus, C. quadricarinatus and Procrambarus clarkii (de Moor 2002, Nunes et al. 2017).</td></tr>
<tr><td colspan="3">References:
de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African Journal of Aquatic Science 27: 125–139.
Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. African Journal of Aquatic Science 42: 309–323.</td></tr>
<tr><td colspan="3">BAC14 Primary (introduction) pathways</td></tr>
<tr><td>Release</td><td>NA</td><td>Confidence:</td></tr>
<tr><td>Escape</td><td>Pet trade
Aquaculture
Live food and bait</td><td>Confidence: Low</td></tr>
<tr><td>Contaminant</td><td>NA</td><td>Confidence:</td></tr>
<tr><td>Stowaway</td><td>NA</td><td>Confidence:</td></tr>
<tr><td>Corridor</td><td>NA</td><td>Confidence:</td></tr>
<tr><td>Unaided</td><td>NA</td><td>Confidence:</td></tr>
<tr><td colspan="3">Comments:
P. acutus acutus has been introduced intentionally into California and New England for aquaculture purposes and used as live bait. The possibility remains that it has been moved unintentionally as a contaminant of P. clarkii’s stocks. Nothing is known about the time of introduction. Natural dispersal may occur within the same basin, but nothing is known about its migration ability</td></tr>
</table>

References: Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowl. Manag. Aquat. Ecosyst.* 11:1–46 Soes DM, Koese B. 2010. Invasive crayfish in the Netherlands: a preliminary risk analysis. *Interim report, Bureau Waardenburg bv, Stichting EIS-Nederland, Invasive Alien Species Team, Waardenburg*. https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=216

2. Likelihood

LIK1 Likelihood of entry via unaided primary pathways	
Response: Very unlikely	Confidence: High
Rationale: There are no wild populations in neighbouring countries that could act as source for unaided introductions (Nunes et al. 2017; Madzivanzira et al. 2020).	
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

LIK2 Likelihood of entry via human aided primary pathways	
Response: Unlikely	Confidence: low
Rationale: *Procambarus acutus* is also not very popular in the aquarium pet trade (Faulkes 2015), however it may be moved around by humans if present in South Africa.	
References: Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowl. Manag. Aquat. Ecosyst.* 11:1–46. Soes DM, Koese B. 2010. Invasive crayfish in the Netherlands: a preliminary risk analysis.*Interim report, Bureau Waardenburg bv, Stichting EIS-Nederland, Invasive Alien Species Team, Waardenburg*.	

LIK3 Habitat suitability	
Response: Fairly probable	Confidence: High
Rationale: *P. acutus acutus* is a habitat generalist and is widely tolerant in most lentic situations and in sluggish streams and prefers still or slow flowing waters and mud, sand or gravel substrate (Soes and Kose 2010). In Missouri, it is most often found in sloughs, marshes, and natural lakes along the flood plains of streams (Crandall 2010). The species constructs simple shallow burrows to survive temporary harsh environmental conditions (Crandall 2010; Soes and Koese 2010).	
References: Crandall KA. 2010. Procambarus acutus. The IUCN Red List of Threatened Species 2010: e.T154022A4577805. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T154022A4577805.en Soes DM, Koese B. 2010. Invasive crayfish in the Netherlands: a preliminary risk analysis. *Interim report, Bureau Waardenburg bv, Stichting EIS-Nederland, Invasive Alien Species Team, Waardenburg*.	

LIK4 Climate suitability	
Response: Fairly probable	Confidence: Low
Rationale: There is no data available, its closely-related species however *Procambarus clarkii* can occur throughout South Africa where temperatures do not exceed 35˚ C and optimal conditions are between 20-25˚ C (de Moor 2002). Sub-optimal temperatures (< 12˚ C) inhibit growth but the species can survive lower temperatures	

(>0˚ C) by hibernating in burrows. Several catchment areas in South Africa were predicted to be climatically suitable for *P. clarkii*, and these include the Greater Berg, Bree, Gourits, Kromme, Swartkops, Bushmans, Keiskamma, Great Kei, Mzimvubu, uMngeni and Phongolo Rivers (Nunes et al. 2017b).
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

LIK5 Unaided secondary (dispersal) pathways	
Response: Very unlikely	Confidence: High
Rationale: Currently this is very unlikely due to no feral populations present in neighbouring countries that could disperse naturally through connected waterways (Nunes et al. 2017; Madzivanzira et al. 2020). However, should species enter the country, it is important to note that all crayfish species are mobile and therefore not restricted to waterways and can migrate overland and colonise new areas (Holdich et al 2009; Soes and Koese 2010).	
References: Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowl. Manag. Aquat. Ecosyst.* 11:1–46. Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. Soes DM, Koese B. 2010. Invasive crayfish in the Netherlands: a preliminary risk analysis.*Interim report, Bureau Waardenburg bv, Stichting EIS-Nederland, Invasive Alien Species Team, Waardenburg*.	

LIK6 Human aided secondary (dispersal) pathways	
Response: Unlikely	Confidence: High
Rationale: Crayfish can be released into the wild by humans that have them as pets and bucket release by anglers into waterways is also probable, however, *P. acutus* is also not very popular in the aquarium pet trade.	
References: Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92.	

3. Consequences

CON1 Environmental impact	
CON1a: Competition	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON1b: Predation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1c: Hybridisation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1d: Transmission of disease	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	

References: L. Botha (Unpublished data).	
CON1e: Parasitism	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1f: Poisoning/toxicity	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1g: Bio-fouling or other direct physical disturbance	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1h: Grazing/herbivory/browsing	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1i: Chemical, physical or structural impact on ecosystem	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1 Maximum environmental impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact	
References: L. Botha (Unpublished data).	

CON2 Socio-economic impact	
CON2a: Safety	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data	
CON2b: Material and immaterial assets	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2c: Health	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2d: Social, spiritual and cultural relations	
Response: DD	Confidence: Low
Rationale:	
References: L. Botha (Unpublished data)	
CON2 Maximum socio-economic impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON3 Closely related species' Environmental impact	
CON3a: Competition	
Response: MR	Confidence: Medium
Rationale: *Procambarus clarkii* is very aggressive and usually out-competes native species for shelter and spawning sites, and these often lead to reproductive interference. In areas of introduction, some amphibian species (e.g., *Bufo bufo*, *B. calamita*, *Rana* sp., *Taricha torosa* and *Triturus vulgaris*) have been excluded or displaced from their natural habitats, resulting in local extinctions through either larval predation or amphibians spawning in areas that do not offer sufficient protection to avoid interaction with *P.clarkii*, resulting in low recruitment (Cruz et al. 2006, Lodge et al. 2012). In addition, as a result of direct competition, there has been a decrease in the distributional ranges and abundance of native crayfish populations (*Astacus astacus*, *Austropotamobius pallipes* and *A. torrentium*) in some areas in Europe and Japan (Cruz et al. 2006, Lodge et al. 2012). Furthermore, direct competition for food has caused dietary niche constriction and declines in populations of native crabs in some areas invaded by *P. clarkia* (Jackson et al. 2016).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338 Jackson MC, Grey J, Miller K, Britton, JR, Donohue, I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology*, 85:1098–1107. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–472.	
CON3b: Predation	
Response: MR	Confidence: Medium
Rationale: In its invasive range, there is evidence that predation by *P. clarkii* can result in the local or population extinctions of at least one native species (Lodge et al. 2012, Souty-grosset et al. 2016). For example, *P. clarkii* has been implicated in causing population declines of several species of fish and amphibians by reducing their breeding success through predation on eggs and larval amphibians (Cruz et al. 2006, Francesco et al. 2011). Indirect effects of predation can also cause trophic cascades that can lead to changes in ecosystem structure and function. For example, predation on invertebrates can release algae from grazing pressure and lead to changes in the abundance and dominance of species in algal communities (Gherardi and Barbaresi 2008).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338. Ficetola GF, Siesa ME, Manenti R, Bottoni L, De Bernardi F, Padoa-Schioppa E. 2011. Early assessment of the impact of alien species: Differential consequences of an invasive crayfish on adult and larval amphibians. *Diversity and Distributions* 17:1141–1151. Gherardi F, Barbaresi S. 2008. Feeding opportunism of the red swamp crayfish Procambarus clarkia, an invasive species. *Freshwater crayfish* 16: 77–85. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–472. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON3c: Hybridisation	
Response: MC	Confidence: Low
Rationale: This is unlikely in South Africa because there are no native crayfish species (de Moor 2002, Nunes et al. 2017b).	

References:

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

CON3d: Transmission of disease

Response: MR	Confidence: Medium

Rationale:

Procambarus clarkii can harbour many pathogens, parasites, and diseases that can be transmitted to other congeneric species (Longshaw 2011, Lodge et al. 2012). There is evidence that transmission of diseases and parasites by *P. clarkii* to native species has caused local or population extinctions of at least one native species, leading to changes in community composition (Lodge et al. 2012). For example, *P. clarkii* is a vector of crayfish plague, a disease caused by the parasitic oomycete, *Aphanomyces astaci* (Longshaw 2011, Souty-grosset et al. 2016). In Europe, transmission of crayfish plague by *P. clarkii* to native crayfish species has been linked to a decline in populations of several native species of crayfish such as *Astacus astacus*, *Austropotamobius pallipes* and *A. torrentium* (Holdich et al. 2009, Longshaw 2011). *Procambarus clarkii* can also harbour white spot syndrome disease – a viral infections of crustaceans, and fungal pathogens such as *Batrachochytrium dendrobatids* that causes chytridiomycosis – a lethal skin infection in amphibians (Longshaw 2011, McMahon et al. 2013).

References:

Aquiloni L, Martín MP, Gherardi F, Diéguez-Uribeondo J. 2011. The North American crayfish *Procambarus clarkii* is the carrier of the oomycete *Aphanomyces astaci* in Italy. *Biological Invasions* 13: 359–367.

Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449 –72.

Longshaw M. 2011. Diseases of crayfish: A review. *Journal of Invertebrate Pathology* 106: 54–70.

McMahon TA, Brannelly LA, Chatfield MW, Johnson PT, Joseph MB, McKenzie VJ, Richards-Zawacki CL, Venesky MD, Rohr JR. 2013. Chytrid fungus *Batrachochytrium dendrobatidis* has non-amphibian hosts and releases chemicals that cause pathology in the absence of infection. *Proceedings of the National Academy of Sciences of the United States of America* 110: 210–215.

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON3e: Parasitism

Response: DD	Confidence: Low

Rationale:

No information is available to assess the level of impact.

References:

L. Botha (Unpublished data).

CON3f: Poisoning/toxicity

Response: MN	Confidence: Low

Rationale:

See CON4c

References:

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

Gherardi F, Britton JR, Mavuti KM, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological* Conservation 144: 2585–2596.

Putra MD, Bláha M, Wardiatno Y, Krisanti M, Bystřický PK, Kouba A, Kalous L, Petrusek A, Patoka J. 2017. *Procambarus clarkii* (Girard, 1852) and crayfish plague as new threats for biodiversity in Indonesia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 28: 1434–1440.

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON3g: Bio-fouling or other direct physical disturbance

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data).

CON3h: Grazing/herbivory/browsing

Response: MO	Confidence: Medium

Rationale:
Grazing by *P. clarkii* can lead to habitat loss and modification through the removal of macrophytes. Habitat loss can lead to a decline in populations of species that utilise the macrophyte stands as a food source, nesting sites, and as refugia from predation (Rosenthal et al 2005). *Procambarus clarkii* can also cause changes to community composition through trophic cascades (Gherardi and Aquistapace 2007, Souty-grosset et al. 2016). For example, in Lake Chozas (northwest Spain), grazing by *P. clarkii* caused a reduction in macrophyte communities and this impact cascaded up the food chain with declines in invertebrates, amphibians, and waterfowl (Rodriguez et al 2003). Grazing can also cause changes to community composition and structure, such as changing ecosystems from macrophyte-dominated areas with clear water, to turbid phytoplankton-dominated areas (Matsizaki et al. 2009). Excessive grazing can also lead to accelerated rates of important processes such as litter breakdown and decomposition.

References:
Gherardi F, Acquistapace P. 2007. Invasive crayfish in Europe: The impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. *Freshwater Biology* 52: 1249–59.
Matsuzaki SS, Usio N, Takamura N, Washitani I. 2009. Contrasting impacts of invasive engineers on freshwater ecosystems: An experiment and meta-analysis. *Oecologia* 158: 673–686.
Rodríguez CF, Bécares E, Fernández-Aláez M. 2003. Shift from clear to turbid phase in Lake Chozas (NW Spain) due to the introduction of American red swamp crayfish (*Procambarus clarkii*). *Hydrobiologia* 506: 421–26.
Rosenthal SK, Lodge DM, Mavuti KM, Muohi W, Ochieng P, Mungai BN, Mkoji GM. 2005. Comparing macrophyte herbivory by introduced Louisiana crayfish (*Procambarus clarkii*) (Crustacea: Cambaridea) and native Dytiscid beetles (*Cybister tripunctatus*) (Coleoptera: Dytiscidae), in Kenya. *African Journal of Aquatic Science* 30: 157–62.
Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON3i: Chemical, physical or structural impact on ecosystem

Response: MO	Confidence: Medium

Rationale:
Water quality: *Procambarus clarkii* is often considered an ecosystem engineer due to its ability to change ecosystems through its burrowing activities (Souty-grosset et al. 2016). For example, its burrowing activities can cause a decrease in the water quality through bioturbation leading to increased turbidity and influx release of nutrients from sediments, often leading to algal blooms (Angeler et al. 2001, Yamamoto 2010). The impaired water quality also affects the quality of the habitats for other aquatic fauna (Angeler et al. 2001, Rodriguez et al. 2003). For example, increased turbidity can impede foraging and respiratory processes of fish (Rodriguez et al. 2003).
Erosion: Burrowing activities can cause structural damage to river banks and increase bank erosion, and also cause damage to water retention infrastructure such as dam walls and dykes (Souty-grosset et al. 2016).

References:
Angeler DG, Sánchez-Carrillo S, García G, Alvarez-Cobelas M. 2001. The influence of *Procambarus clarkii* (Cambaridae, Decapoda) on water quality and sediment characteristics in a Spanish floodplain wetland. *Hydrobiologia* 464: 89–98.
Rodríguez CF, Bécares E, Fernández-Aláez M. 2003. Shift from clear to turbid phase in Lake Chozas (NW Spain) due to the introduction of American red swamp crayfish (*Procambarus clarkii*). *Hydrobiologia* 506: 421–26.
Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red

swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.
Yamamoto Y. 2010. Contribution of bioturbation by the red swamp crayfish *Procambarus clarkii* to the recruitment of bloom-forming cyanobacteria from sediment. *Journal of Limnology* 69: 102– 111.

CON3k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON3 Maximum environmental impact (Figure S3)	
Response: MR	Confidence: High
Rationale Direct predation and competition for food, shelter, and spawning sites have led to local extinctions and a decrease in the abundance of native amphibians and crayfish species(Cruz et al. 2006, Gherardi & Acquistapace 2007). Impacts have been recorded in the Iberian Peninsula, Sweden, Italy (Gherardi and Acquistapace 2007), Japan, and U.S.A. (California) (Holdich et al. 2009, Lodge et al. 2012).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338. Gherardi F, Acquistapace P. 2007. Invasive crayfish in Europe: The impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. *Freshwater Biology* 52: 1249–59. Jackson MC, Grey J, Miller K, Britton, JR, Donohue, I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology*, 85:1098–1107. Longshaw M. 2011. Diseases of crayfish: A review. *Journal of Invertebrate Pathology* 106: 54–70. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	

CON4 Closely related species' Socio-economic impact	
CON4a: Safety	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON4b: Material and immaterial assets	
Response: MO	Confidence: Medium
Rationale: *Procambarus clarkii* often inhabits agricultural fields and their burrowing activities can cause damage to infrastructure such as irrigation canals and dam walls (Lodge et al. 2012, Arce and Diéguez-Uribeondo 2015). Burrowing activities can also alter soil hydrology leading to water loss. Grazing causes crop damage and reduces yield (Anastácio et al. 2005). In Europe for example, *P. clarkii* affects rice production through field water loss, damage to rice field banks and ditches, direct consumption of rice seed and plants, and clogging of pipes (Souty-grosset et al. 2016).	
References: Anastácio PM. Correia AM, Menino JP. 2005. Processes and patterns of plant destruction by crayfish: effects of crayfish size and developmental stages of rice. *Archiv für Hydrobiologie* 162: 37–51. Arce JA, Diéguez-Uribeondo J. 2015. Structural damage caused by the invasive crayfish *Procambarus clarkii* (Girard, 1852) in rice fields of the Iberian Peninsula: A study case. *Fundamental and Applied Limnology* 186: 259–269. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y.	

2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON4c: Health	
Response: MN	Confidence: Low
Rationale: *Procambarus clarkii* can bio-accumulate toxins and metals from the environment (Gherardi et al. 2011, Souty-grosset et al. 2016). These pollutants are often harmful and can be transferred to higher food web levels through the consumption of affected crayfish by humans and predators such as otters, birds, and fish (Gherardi et al. 2011, Lodge et al. 2012). *Procambarus clarkii* serves as vector for several parasites and diseases some of which are zoonotic, for example the parasitic fluke flatworms (*Paragonimus* spp.) that causes lung fluke disease in humans, tularemia-causing bacterium *Francisella tularensis*, rat lungworm *Angiostrongylus cantonensis* that causes meningitis, and the nematode *Gnathostoma spinigerum* that causes human gnathostomiasis (de Moor 2002, Souty-grosset et al. 2016, Putra et al. 2017).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Gherardi F, Britton JR, Mavuti KM, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological* Conservation 144: 2585–2596. Putra MD, Bláha M, Wardiatno Y, Krisanti M, Bystřický PK, Kouba A, Kalous L, Petrusek A, Patoka J. 2017. *Procambarus clarkii* (Girard, 1852) and crayfish plague as new threats for biodiversity in Indonesia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 28: 1434–1440. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON4d: Social, spiritual and cultural relations	
Response: MO	Confidence:
Rationale: *Procambarus clarkii* affects the fishing industry by damaging gill nets and spoiling the fish caught in the nets (Gherardi et al. 2011).	
References: Gherardi F, Robert FJ, Kenneth BB, Mavuti M, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological Conservation* 144: 2585–2596.	
CON4 Maximum socio-economic impact (Closely-related taxa) (Figure S3)	
Response: MO	Confidence: Medium
Rationale: In its invaded range *P. clarkii* had caused harmful impacts in agricultural fields (Anastácio et al. 2005) and has disrupted some recreational activities leading to economic loss Gherardi et al. 2011).	
References: Anastácio PM. Correia AM, Menino JP. 2005. Processes and patterns of plant destruction by crayfish: effects of crayfish size and developmental stages of rice. Archiv für Hydrobiologie 162: 37–51. Gherardi F, Robert FJ, Kenneth BB, Mavuti M, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological Conservation* 144: 2585–2596.	

CON5 Potential impact	
Response: MR	Confidence:
Rationale: *Procambarus acutus* and *Procambarus clarkii* share ecological traits (Soes and Koese 2010). This species is	

an omnivore with high tolerance to environmental conditions, its aggressive nature proved that it could outcompete native species and replace them within an ecosystem. Its intensive grazing and stalk cutting is also a threat to macrophyte communities (Gherardi 2011). *Procambarus acutus acutus* have similar life strategy, therefore it may have the same detrimental impacts in areas of introduction as its invasive congener. Being a functional omnivore, this species may also have detrimental impacts on macroinvertebrates and macrophyte communities in areas where invaded (Gherardi et al. 2011).
References: Gherardi F, Britton JR, Mavuti KM, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological* Conservation 144: 2585–2596 Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. Soes DM, Koese B. 2010. Invasive crayfish in the Netherlands: a preliminary risk analysis.*Interim report, Bureau Waardenburg bv, Stichting EIS-Nederland, Invasive Alien Species Team, Waardenburg*.

4. Management

MAN1 What is the feasibility to stop future immigration?	
Response: High	Confidence: Low
Rationale: There are no known populations in neighbouring countries, thus species entering via unaided primary pathways is very low. However, if it were in neighbouring countries it would be hard to stop natural dispersal. Illegal pet trade still poses a problem due to illegal selling of species and the risk of owners releasing species into the wild.	
References: Holdich DM, Reynolds JD, Souty-Grosset C, Sibley PJ. 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowl. Manag. Aquat. Ecosyst.* 11:1–46 Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. Soes DM, Koese B. 2010. Invasive crayfish in the Netherlands: a preliminary risk analysis. *Interim report, Bureau Waardenburg bv, Stichting EIS-Nederland, Invasive Alien Species Team, Waardenburg*.	

MAN2 Benefits of the Taxon	
MAN2a Socio-economic benefits of the *Taxon*	
Response: None	Confidence:
Rationale:	
References:	
MAN2b Environmental benefits of the *Taxon*	
Response: None	Confidence:
Rationale:	
References:	

MAN3 Ease of management	
MAN3a How accessible are populations?	
Response:	Confidence: Medium
Rationale:	
References:	

MAN3b Is detectability critically time-dependent?	
Response: 0	Confidence: High
Rationale:	
References:	
MAN3c Time to reproduction	
Response:	Confidence: High
Rationale:	
References:	
MAN3d Propagule persistence	
Response: NA	Confidence:
Rationale:	
References:	
MAN3 Ease of management (SUM from Table S4)	
Response: NA	Confidence:
Rationale:	
References:	

MAN4 Has the feasibility of eradication been evaluated?	
Response: No	Confidence: Low
Rationale: In areas of introduction, where it has managed to establish populations, there has been no successful eradication attempt. Generally, once crayfish species have established and become widespread, it is impossible to eradicate them (Gherardi et al 2011). They are very hardy and if chemical control is considered large quantities are needed to kill crayfish and biocides have been used to eradicate crayfish populations elsewhere (Gherardi et al. 2011). Furthermore, the chemicals used are not specific to crayfish and can also extirpate other freshwater species within the same freshwater ecosystem (Ghrardi et al. 2011). However, when species are restricted to dams, mechanical control via traps, electrofishing could still be feasible (Gherardi et al 2011).	
References: Gherardi F, Aquiloni L, Diéguez-Uribeondo J, Tricarico E. 2011. Managing invasive crayfish: is there a hope?.*Aquatic Sciences*73: 185–200.	

MAN5 Control options and monitoring approaches available for the *Taxon*
Response:
References:

MAN6 Any other management considerations to highlight? (if yes, fill in Appendix MAN6)	
Response	Yes / No

5. Calculations

Likelihood = Unlikely

Parameter	**Likelihood**	**Stages**	**Final assessment**

LIK1	0.0027	P(entry) = 0.027	P (invasion) = 0.0036
LIK2	0.027		
LIK3	0.5	P(establishment) = 0.5	
LIK4	0.5		
LIK5	0.0027	P (spread) = 0.027	
LIK6	0.027		

Consequence = MR (Major)

Parameter	**Mechanism/sector**	**Response**
CON1	**Maximum environmental impact**	**DD**
CON2	**Maximum socio-economic impact**	**DD**
CON3a	Competition	MR
CON3b	Predation	MR
CON3c	Hybridisation	MC
CON3d	Disease transmission	MR
CON3e	Parasitism	DD
CON3f	Poisoning/toxicity	MN
CON3g	Bio-fouling or other direct physical disturbance	DD
CON3h	Grazing/herbivory/browsing	MO
CON3i	Chemical, physical, structural impact	MO
CON3k	Indirect impacts through interactions with other species	DD
CON3	**Maximum environmental impact (closely related taxa)**	**MR**
CON4a	Safety	DD
CON4b	Material and immaterial assets	MO
CON4c	Health	MN
CON4d	Social, spiritual and cultural relations	MO
CON4	**Maximum socio-economic impact (closely related taxa)**	**MO**
CON5	Potential impact based on traits, experiments, or models	**MR**

Table S3: Risk score

Risk = Medium

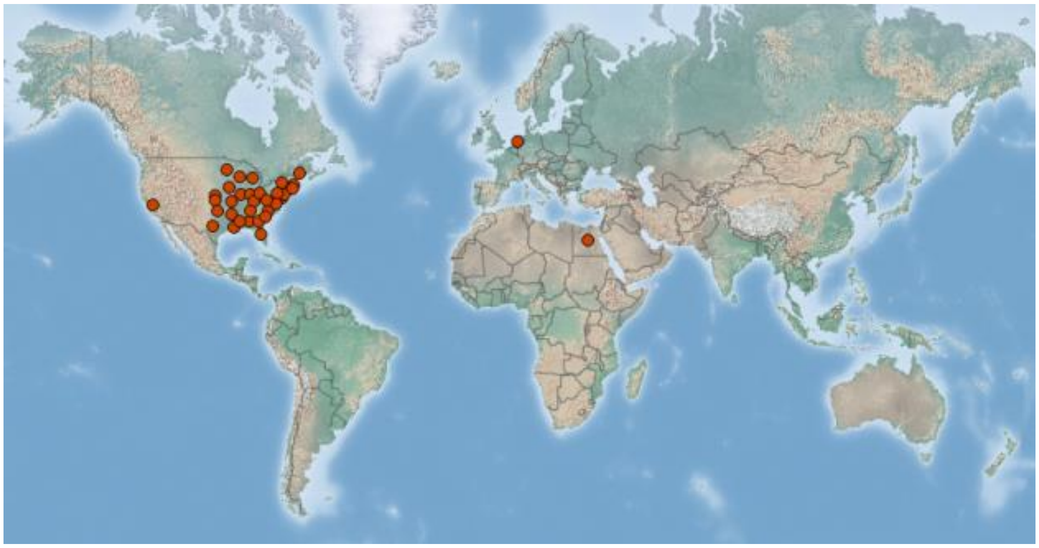
		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	low	low	low	medium	medium
	Very unlikely	low	low	low	medium	high
	Unlikely	low	low	medium	high	high
	Fairly probable	medium	medium	high	high	high
	Probable	medium	high	high	high	high

Table S4: Ease of management

Parameter	**Question**	**Response**
MAN3a	How accessible are populations?	
MAN3b	Is detectability critically time-dependent?	
MAN3c	Time to reproduction	
MAN3d	Propagule persistence	
MAN3	**SUM**	

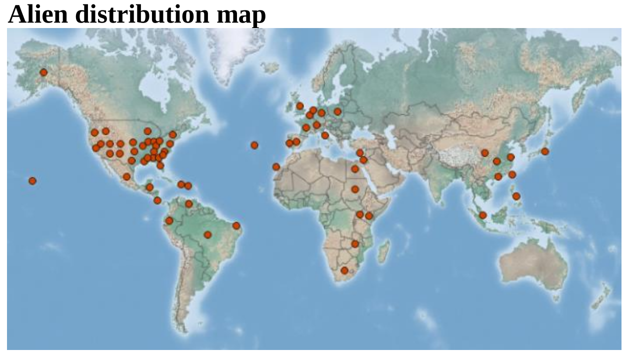
Appendix

BAC7: Global alien range of *Procambarus acutus acutus.* Map from CABI: https://www.cabi.org/isc/datasheet/67841



Appendix 3.13 Risk analysis report for Red swamp crayfish (*Procambarus clarkii*).

Risk Analysis Report

Taxon: *Procambarus clarkii* (Girard, 1852)	***Area:*** South Africa
Compiled by: Lee-Anne Botha	**Approved by:**
Picture of *Taxon*  Antunes et al. (2020)	**Alien distribution map**  Sourced from CABI (2019): https://www.cabi.org/ISC/datasheet/67878
Risk Assessment summary: The Red swamp crayfish (*Procambarus clarkii*) has been introduced worldwide for aquaculture and ornamental pet trade. It is already present in South Africa, and is known to have established in the wild at at least two locations in Mpumalanga and Free State (Driehoek farm and Mimiso Dam) Provinces. Unconfirmed records also indicate that it is present in the pet trade industry. The potential of further spread is therefore, high because it is likely to be moved by humans in the aquarium trade industry and through short-range self-dispersal may be possible because of its ability to move over land. *Procambarus clarkii* is a facultative omnivore and an aggressive competitor that often displaces native species in areas of introduction through predation, competitive exclusions, and the transmission of diseases. It has also been implicated in causing habitat alteration through excessive grazing of macrophytes, and its burrowing activities increase rates of soil erosion and, cause physical damage to agricultural infrastructure such as irrigation canals. *Procambarus clarkii* serves as vector for several parasites and diseases, some of which are zoonotic.	**Risk score:** High
Management options summary: The current distribution of *P. clarkii* in the wild is localised to two known locations in Mpumalanga (Inkomti River) and Free State (Driehoek farm and Mimosa dam) Provinces therefore, eradication is still highly feasible. A variety of methods could be evaluated such as chemical, manual, or a combination of the two methods. When evaluating suitable methods however, it is important to take into account the burrowing behaviour of the species. The species is popular in the aquarium trade and as a result, the potential of accidental or intentional release of the species into new areas by humans is high.	**Ease of management:** Medium
Recommendations: *Procambarus clarkii* is currently not listed under NEM:BA regulations. The results from this Risk Analysis recommend listing it as a Category 1a species, and that an eradication feasibility plan should be evaluated. Management efforts should focus on preventing the species from spreading into new areas. The illegal pet trade industry still poses a significant risk for intentional and accidental release of the species into the wild. There is therefore, a need to assess the trade of, and movement of the species through the aquarium trade in order to implement appropriate management strategies. Public engagement should also be a priority to advocate that translocation of the species is prohibited in order to prevent further spread.	**Listing under NEM:BA A&IS lists of 2014 as amended 2020:** Not listed **Recommended listing category:** 1a

1. Background

BAC1 Name of assessor(s)	
Name of lead assessor	Lee-Anne Botha
Additional assessor (1)	
Additional assessor (2)	
BAC2 Contact details of assessor (s)	
Lead assessor	Organisational affiliation: Department of Zoology and Entomology, University of Pretoria/South African National Biodiversity Institute (SANBI).
	email: u18389164@tuks.co.za
	Phone: 072 833 7952
Additional assessor (1)	Organisational affiliation:
	email:
	Phone:
Additional assessor (2)	Organisational affiliation:
	email:
	Phone:
BAC3 Name(s) and contact details of expert(s) consulted	
Expert (1)	Name: Dr Tsungai Zengeya
	email: T.Zengeya@sanbi.org.za
	Phone: 021 799 8408
Expert (2)	Name:
	email:
	Phone:
Comments: Dr Tsungai Zengeya works for the South African National Biodiversity Institute (SANBI). His research interests are in freshwater ecology and biological invasions. He provided comments and inputs throughout the compilation of this risk analysis that improved its quality.	
BAC4 Scientific name of *Taxon* under assessment	
Taxon name: *Procambarus clarkii*	Authority: (Girard, 1852)
Comments:	
References: Crandall KA, De Grave S, 2017. An updated classification of the freshwater crayfishes (Decapoda: Astacidea) of the world, with a complete species list. *Journal of Crustacean Biology* 27: 615–653.	
BAC5 Synonym(s) considered	
Synonyms:	
Comments:	
References:	
BAC6 Common name(s) considered	
Common names: Red swamp crayfish, Louisiana crayfish	
Comments:	
References: Gherardi F. 2006. Crayfish invading Europe: The case study of *Procambarus clarkii*. *Hydrobiologia* 595: 295–301.	

BAC7 What is the native range of the *Taxon*? (add map in Appendix BAC7)	
Response: North eastern Mexico and South-central U.S.A.	Confidence: High
Comments:	
References: Gherardi F. 2006. Crayfish invading Europe: The case study of *Procambarus clarkii*. *Hydrobiologia* 595: 295–301. Hobbs H. 1989. A review of global crayfish introductions with particular emphasis on twoNorth American species (Decapoda, Cambaridae). *Crustaceana* 56: 299–316.	
BAC8 What is the global alien range of the *Taxon*? (add map in Appendix BAC8)	
Response: Belgium; Belize; Brazil; Chile; China; Colombia; Costa Rica; Cyprus; Dominican Republic; Ecuador; Egypt; France; Georgia; Germany; Italy; Japan; Kenya; Mexico; Netherlands; Philippines; Portugal; South Africa; South Sudan; Spain; Sudan; Switzerland; Taiwan; Uganda; United Kingdom; United States of America (in the States of Alabama, Arizona, Arkansas, California, Florida - Native, Hawaii, Idaho, Illinois - Native, Indiana, Maryland, Nevada, New Mexico - Native, North Carolina, Ohio, Oklahoma - Native, Oregon, South Carolina, Tennessee - Native, Texas - Native, Utah, Virginia, West Virginia - Present - Origin uncertain); Venezuela (Bolivarian Republic); Zambia.	Confidence: Medium
Comments: *Procambarus clarkii* has established populations on all continents, except Australia and Antarctica (Lodge et al. 2012).	
References: Chucholl C. 2011. Population ecology of an alien "warm water" crayfish (*Procambarus clarkii*) in a new cold habitat. *Knowledge and Management of Aquatic Ecosystems* 401:29. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology*, *Evolution and Systematics* 43: 449–472.	
BAC9 Geographic scope = the *Area* under consideration	
Area of assessment: South Africa	
Comments:	
BAC10 Is the *Taxon* present in the *Area*?	
Response: Yes	Confidence: High
Comments: *Procambarus clarkii* is known to occur at two sites; The Driehoek Farm located *ca*. 10 km from the town of Dullstroom (25°28′24.50″S, 30°07′23.61″E) in Mpumalanga Province (de Moor 2002, Nunes et al. 2017a), and Mimosa Dam (27°58′56.28″S, 26°44′16.79″E) in the Free State Province (Weyl et al. 2020).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Hoffman CA, Zengeya TA, Measey GJ, Weyl OLF. 2017. Red swamp crayfish, *Procambarus clarkii*, found in South Africa 22 years after attempted eradication. *Aquatic Conservation: Marine Freshwater Ecosystem* 27: 1334–1340. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. https://www.environment.gov.za/mediarelease/freestategoldfields_freshawater_invasivecrayfish	
BAC11 Availability of physical specimen	
Response: Yes	Confidence in ID:

Herbarium or museum accession number:
A sample was collected in one of the sites were the species has established (Driehoek Farm). This will be sent to Albany Museum.

References:

BAC12 Is the *Taxon* native to the *Area* or part of the *Area*?

The *Taxon* is native to (part of) the *Area*.	No	Confidence: High
The *Taxon* is alien in (part of) the *Area*.	Yes	Confidence: High

Comments:
No crayfish are native to continental Africa (de Moor 2002, Nunes et al. 2017b).

References:

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

Nunes AL, Hoffman CA, Zengeya TA, Measey GJ, Weyl OLF. 2017. Red swamp crayfish, *Procambarus clarkii*, found in South Africa 22 years after attempted eradication. *Aquatic Conservation: Marine Freshwater Ecosystem* 27: 1334–1340.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

BAC13 What is the *Taxon*'s introduction status in the *Area*?

The *Taxon* is in cultivation/containment.	Unknown	Confidence: Low
The *Taxon* is present outside of cultivation/containment.	Yes	Confidence: High
The *Taxon* has established/naturalised.	Yes	Confidence: High
The *Taxon* is invasive.	Yes	Confidence: High

Comments:
A 2016 survey at Driehoek Farm, near the town of Dullstroom found a specimen of *P. clarkii* 22 years after an eradication attempt of the population at the farm (Nunes et al. 2017a). The specimen was reproductively active, indicating that a small but viable population may still be present. In 2018, *P. clarkii* was found in Mimosa Dam in the Free State Province and indications are that the population is established and breeding (Madzivanzira et al. 2020). The species may also be present in the aquarium trade but this has not been verified (Nunes et al. 2017b, 2017a).

References:

Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21.

Nunes AL, Hoffman CA, Zengeya TA, Measey GJ, Weyl OLF. 2017. Red swamp crayfish, *Procambarus clarkii*, found in South Africa 22 years after attempted eradication. *Aquatic Conservation: Marine Freshwater Ecosystem* 27: 1334–1340.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

BAC14 Primary (introduction) pathways

Release	NA	Confidence:
Escape	Aquarium /Pet trade Aquaculture Live food and bait	Confidence: High
Contaminant	NA	Confidence:
Stowaway	NA	Confidence:
Corridor	NA	Confidence:
Unaided	NA	Confidence:

Comments:
Primary pathway of introduction is escape from confinement through the aquaculture (Holdich et al. 2009) and pet trade industries (Patoka et al. 2018) and intentional release as bait for fish (Nunes et al. 2017a).
References: Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

2. Likelihood

LIK1 Likelihood of entry via unaided primary pathways	
Response: Probable	Confidence: Medium
Rationale: *Procambarus clarkii* is already present in the country and neighbouring countries (Nunes et al. 2017a, Douthwaite et al. 2018). It is known to disperse over long distances on land in order to find suitable habitats (Barbaresi & Gherardi 2000).	
References: Douthwaite RJ, Jones EW, Tyser AB, Vrdoljak SM. 2018. The introduction, spread and ecology of redclaw crayfish *Cherax quadricarinatus* in the Zambezi catchment. *African Journal of Aquatic Science* 43: 353–366. Nunes AL, Hoffman CA, Zengeya TA, Measey GJ, Weyl OLF. 2017. Red swamp crayfish, *Procambarus clarkii*, found in South Africa 22 years after attempted eradication. *Aquatic Conservation: Marine Freshwater Ecosystem* 27: 1334–1340. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

LIK2 Likelihood of entry via human aided primary pathways	
Response: Probable	Confidence: Medium
Rationale: The primary pathway of introduction includes escapees from aquaculture facilities, pet trade industry, and accidental introduction as bait for fish (Faulkes 2015, Nunes et al. 2017b).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Faulkes Z. 2015. The global trade in crayfish as pets.*Crustacean Research* 44: 75–92. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

LIK3 Habitat suitability	
Response: Probable	Confidence: Medium
Rationale: *Procambarus clarkii* is tolerant to a wide range of environmental conditions ranging from low salinity, oxygen levels, and extreme temperatures(de Moor 2002). It can occur in a wide range of habitats that include rivers, lakes, ponds, streams, canals, and seasonally flooded swamps, marshes, and estuaries (de Moor 2002, Souty-grosset et al. 2016). In Portugal and Italy, *P. clarkii* is known to occur in caves (Souty-grosset et al. 2016). In South Africa, *P. clarkii* has established in impoundments (de Moor 2002, Madzivanzira et al. 2020).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. African *Journal of Aquatic Science* 27: 125–139. Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21.	

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

LIK4 Climate suitability	
Response: Probable	Confidence: Medium
Rationale: *Procambarus clarkii* can occur throughout South Africa where temperatures do not exceed 35˚ C and optimal conditions are between 20-25˚ C (de Moor 2002). Sub-optimal temperatures (< 12˚ C) inhibit growth but the species can survive lower temperatures (>0˚ C) by hibernating in burrows. Several catchment areas in South Africa were predicted to be climatically suitable for *P. clarkii*, and these include the Greater Berg, Bree, Gourits, Kromme, Swartkops, Bushmans, Keiskamma, Great Kei, Mzimvubu, uMngeni and Phongolo Rivers (Nunes et al. 2017b).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

LIK5 Unaided secondary (dispersal) pathways	
Response: Fairly probable	Confidence: Medium
Rationale: *Procambarus clarkii* can travel long distances overland to get to water, so it is very likely for the species to move into new areas. It has two patterns of movement (stationary and nomadic phases) (Gherardi 2007a). During the nomadic phase, breeding males have been reported to travel up to 17 km in four days, and to survive up to 10 hours outside water (Gherardi 2007a, Souty-grosset et al. 2016). Juveniles can also be translocated to new areas by water birds.	
References: Gherardi F. 2007. Crayfish invading Europe: The case study of *Procambarus clarkii*. *Marine and Freshwater Behaviour and Physiology* 39: 175–191. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	

LIK6 Human aided secondary (dispersal) pathways	
Response: Probable	Confidence: Medium
Rationale: *Procambarus clarkii* can be introduced into new areas through aquaculture and the pet trade (Holdich et al. 2009, Faulkes 2015, Madzivanzira et al. 2020). *Procambarus clarkii* is also likely to be translocated intentionally as bait for fishing (Nunes et al. 2017a). In addition, areas with known naturalised populations can act as a source for spreading into other regions in South Africa. It is also important to note the illegal farming of *P. clarkii* crayfish could be prevalent as the species is advertised and available to buy online.	
References: Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Nunes AL, Hoffman CA, Zengeya TA, Measey GJ, Weyl OLF. 2017. Red swamp crayfish, *Procambarus clarkii*, found in South Africa 22 years after attempted eradication. *Aquatic Conservation: Marine Freshwater Ecosystem* 27: 1334–1340. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	

3. Consequences

CON1 Environmental impact

CON1a: Competition	
Response: MR	Confidence: Medium
Rationale: *Procambarus clarkii* is very aggressive and usually out-competes native species for shelter and spawning sites, and these often lead to reproductive interference. In areas of introduction, some amphibian species (e.g., *Bufo bufo*, *B. calamita*, *Rana* sp., *Taricha torosa* and *Triturus vulgaris*) have been excluded or displaced from their natural habitats, resulting in local extinctions through either larval predation or amphibians spawning in areas that do not offer sufficient protection to avoid interaction with *P.clarkii*, resulting in low recruitment (Cruz et al. 2006, Lodge et al. 2012). In addition, as a result of direct competition, there has been a decrease in the distributional ranges and abundance of native crayfish populations (*Astacus astacus*, *Austropotamobius pallipes* and *A. torrentium*) in some areas in Europe and Japan (Cruz et al. 2006, Lodge et al. 2012). Furthermore, direct competition for food has caused dietary niche constriction and declines in populations of native crabs in some areas invaded by *P. clarkia* (Jackson et al. 2016).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338. Jackson MC, Grey J, Miller K, Britton, JR, Donohue, I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology* 85:1098–1107. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–472.	
CON1b: Predation	
Response: MR	Confidence: Medium
Rationale: In its invasive range, there is evidence that predation by *P. clarkii* can result in the local or population extinctions of at least one native species (Lodge et al. 2012, Souty-grosset et al. 2016). For example, *P. clarkii* has been implicated in causing population declines of several species of fish and amphibians by reducing their breeding success through predation on eggs and larval amphibians (Cruz et al. 2006, Francesco et al. 2011). Indirect effects of predation can also cause trophic cascades that can lead to changes in ecosystem structure and function. For example, predation on invertebrates can release algae from grazing pressure and lead to changes in the abundance and dominance of species in algal communities (Gherardi and Barbaresi 2008).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329–338. Ficetola GF, Siesa ME, Manenti R, Bottoni L, De Bernardi F, Padoa-Schioppa E. 2011. Early assessment of the impact of alien species: Differential consequences of an invasive crayfish on adult and larval amphibians. *Diversity and Distributions* 17:1141–1151. Gherardi F, Barbaresi S. 2008. Feeding opportunism of the red swamp crayfish Procambarus clarkia, an invasive species. *Freshwater crayfish* 16: 77–85. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–472. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON1c: Hybridisation	
Response: MC	Confidence: Low
Rationale: This is unlikely in South Africa because there are no native crayfish species (de Moor 2002, Nunes et al. 2017b).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journalof Aquatic*	

Science 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	
CON1d: Transmission of disease	
Response: MR	Confidence: Medium
Rationale: *Procambarus clarkii* can harbour many pathogens, parasites, and diseases that can be transmitted to other congeneric species (Longshaw 2011, Lodge et al. 2012). There is evidence that transmission of diseases and parasites by *P. clarkii* to native species has caused local or population extinctions of at least one native species, leading to changes in community composition (Lodge et al. 2012). For example, *P. clarkii* is a vector of crayfish plague, a disease caused by the parasitic oomycete, *Aphanomyces astaci* (Longshaw 2011, Souty-grosset et al. 2016). In Europe, transmission of crayfish plague by *P. clarkii* to native crayfish species has been linked to a decline in populations of several native species of crayfish such as *Astacus astacus*, *Austropotamobius pallipes* and *A. torrentium* (Holdich et al. 2009, Longshaw 2011). *Procambarus clarkii* can also harbour white spot syndrome disease – a viral infections of crustaceans, and fungal pathogens such as *Batrachochytrium dendrobatids* that causes chytridiomycosis – a lethal skin infection in amphibians (Longshaw 2011, McMahon et al. 2013).	
References: Aquiloni L, Martín MP, Gherardi F, Diéguez-Uribeondo J. 2011. The North American crayfish *Procambarus clarkii* is the carrier of the oomycete *Aphanomyces astaci* in Italy. *Biological Invasions* 13: 359–367. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449 –72. Longshaw M. 2011. Diseases of crayfish: A review. *Journal of Invertebrate Pathology* 106: 54–70. McMahon TA, Brannelly LA, Chatfield MW, Johnson PT, Joseph MB, McKenzie VJ, Richards-Zawacki CL, Venesky MD, Rohr JR. 2013. Chytrid fungus *Batrachochytrium dendrobatidis* has non-amphibian hosts and releases chemicals that cause pathology in the absence of infection. *Proceedings of the National Academy of Sciences of the United States of America* 110: 210–215. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON1e: Parasitism	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact	
References: L. Botha (Unpublished data).	
CON1f: Poisoning/toxicity	
Response: MN	Confidence: Low
Rationale: **See CON2c**	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Gherardi F, Britton JR, Mavuti KM, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological* Conservation 144: 2585–2596. Putra MD, Bláha M, Wardiatno Y, Krisanti M, Bystřický PK, Kouba A, Kalous L, Petrusek A, Patoka J. 2017. *Procambarus clarkii* (Girard, 1852) and crayfish plague as new threats for biodiversity in Indonesia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 28: 1434–1440. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON1g: Bio-fouling or other direct physical disturbance	

Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1h: Grazing/herbivory/browsing	
Response: MO	Confidence: Medium
Rationale: Grazing by *P. clarkii* can lead to habitat loss and modification through the removal of macrophytes. Habitat loss can lead to a decline in populations of species that utilise the macrophyte stands as a food source, nesting sites, and as refugia from predation (Rosenthal et al 2005). *Procambarus clarkii* can also cause changes to community composition through trophic cascades (Gherardi and Aquistapace 2007, Souty-grosset et al. 2016). For example, in Lake Chozas (northwest Spain), grazing by *P. clarkii* caused a reduction in macrophyte communities and this impact cascaded up the food chain with declines in invertebrates, amphibians, and waterfowl (Rodriguez et al 2003). Grazing can also cause changes to community composition and structure, such as changing ecosystems from macrophyte-dominated areas with clear water, to turbid phytoplankton-dominated areas (Matsizaki et al. 2009). Excessive grazing can also lead to accelerated rates of important processes such as litter breakdown and decomposition.	
References: Gherardi F, Acquistapace P. 2007. Invasive crayfish in Europe: The impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. *Freshwater Biology* 52: 1249–59. Matsuzaki SS, Usio N, Takamura N, Washitani I. 2009. Contrasting impacts of invasive engineers on freshwater ecosystems: An experiment and meta-analysis. *Oecologia* 158: 673–686. Rodríguez CF, Bécares E, Fernández-Aláez M. 2003. Shift from clear to turbid phase in Lake Chozas (NW Spain) due to the introduction of American red swamp crayfish (*Procambarus clarkii*). *Hydrobiologia* 506: 421–26. Rosenthal SK, Lodge DM, Mavuti KM, Muohi W, Ochieng P, Mungai BN, Mkoji GM. 2005. Comparing macrophyte herbivory by introduced Louisiana crayfish (*Procambarus clarkii*) (Crustacea: Cambaridea) and native Dytiscid beetles (*Cybister tripunctatus*) (Coleoptera: Dytiscidae), in Kenya. *African Journal of Aquatic Science* 30: 157–62. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON1i: Chemical, physical or structural impact on ecosystem	
Response: MO	Confidence: Medium
Rationale: **Water quality**: *Procambarus clarkii* is often considered an ecosystem engineer due to its ability to change ecosystems through its burrowing activities (Souty-grosset et al. 2016). For example, its burrowing activities can cause a decrease in the water quality through bioturbation leading to increased turbidity and influx release of nutrients from sediments, often leading to algal blooms (Angeler et al. 2001, Yamamoto 2010). The impaired water quality also affects the quality of the habitats for other aquatic fauna (Angeler et al. 2001, Rodriguez et al. 2003). For example, increased turbidity can impede foraging and respiratory processes of fish (Rodriguez et al. 2003). **Erosion**: Burrowing activities can cause structural damage to river banks and increase bank erosion, and also cause damage to water retention infrastructure such as dam walls and dykes (Souty-grosset et al. 2016).	
References: Angeler DG, Sánchez-Carrillo S, García G, Alvarez-Cobelas M. 2001. The influence of *Procambarus clarkii* (Cambaridae, Decapoda) on water quality and sediment characteristics in a Spanish floodplain wetland. *Hydrobiologia* 464: 89–98. Rodríguez CF, Bécares E, Fernández-Aláez M. 2003. Shift from clear to turbid phase in Lake Chozas (NW Spain) due to the introduction of American red swamp crayfish (*Procambarus clarkii*). *Hydrobiologia* 506: 421–26. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	

Yamamoto Y. 2010. Contribution of bioturbation by the red swamp crayfish *Procambarus clarkii* to the recruitment of bloom-forming cyanobacteria from sediment. *Journal of Limnology* 69: 102– 111.	
CON1k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1 Maximum environmental impact (Figure S3)	
Response: MR	Confidence: High
Rationale Direct predation and competition for food, shelter, and spawning sites have led to local extinctions and a decrease in the abundance of native amphibians and crayfish species(Cruz et al. 2006, Gherardi & Acquistapace 2007). Impacts have been recorded in the Iberian Peninsula, Sweden, Italy (Gherardi and Acquistapace 2007), Japan, and U.S.A. (California) (Holdich et al. 2009, Lodge et al. 2012).	
References: Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329-338. Gherardi F, Acquistapace P. 2007. Invasive crayfish in Europe: The impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. *Freshwater Biology* 52: 1249–59. Jackson MC, Grey J, Miller K, Britton, JR, Donohue, I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology*, 85:1098–1107. Longshaw M. 2011. Diseases of crayfish: A review. *Journal of Invertebrate Pathology* 106: 54–70. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	

CON2 Socio-economic impact	
CON2a: Safety	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON2b: Material and immaterial assets	
Response: MO	Confidence: Medium
Rationale: *Procambarus clarkii* often inhabits agricultural fields and their burrowing activities can cause damage to infrastructure such as irrigation canals and dam walls (Lodge et al. 2012, Arce and Diéguez-Uribeondo 2015). Burrowing activities can also alter soil hydrology leading to water loss. Grazing causes crop damage and reduces yield (Anastácio et al. 2005). In Europe for example, *P. clarkii* affects rice production through field water loss, damage to rice field banks and ditches, direct consumption of rice seed and plants, and clogging of pipes (Souty-grosset et al. 2016).	
References: Anastácio PM. Correia AM, Menino JP. 2005. Processes and patterns of plant destruction by crayfish: effects of crayfish size and developmental stages of rice. *Archiv für Hydrobiologie* 162: 37–51. Arce JA, Diéguez-Uribeondo J. 2015. Structural damage caused by the invasive crayfish *Procambarus clarkii* (Girard, 1852) in rice fields of the Iberian Peninsula: A study case. *Fundamental and Applied Limnology* 186: 259–269. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red	

swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON2c: Health	
Response: MN	Confidence: Low
Rationale: *Procambarus clarkii* can bio-accumulate toxins and metals from the environment (Gherardi et al. 2011, Souty-grosset et al. 2016). These pollutants are often harmful and can be transferred to higher food web levels through the consumption of affected crayfish by humans and predators such as otters, birds, and fish (Gherardi et al. 2011, Lodge et al. 2012). *Procambarus clarkii* serves as vector for several parasites and diseases some of which are zoonotic, for example the parasitic fluke flatworms (*Paragonimus* spp.) that causes lung fluke disease in humans, tularemia-causing bacterium *Francisella tularensis*, rat lungworm *Angiostrongylus cantonensis* that causes meningitis, and the nematode *Gnathostoma spinigerum* that causes human gnathostomiasis (de Moor 2002, Souty-grosset et al. 2016, Putra et al. 2017).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Gherardi F, Britton JR, Mavuti KM, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological* Conservation 144: 2585–2596. Putra MD, Bláha M, Wardiatno Y, Krisanti M, Bystřický PK, Kouba A, Kalous L, Petrusek A, Patoka J. 2017. *Procambarus clarkii* (Girard, 1852) and crayfish plague as new threats for biodiversity in Indonesia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 28: 1434–1440. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON2d: Social, spiritual and cultural relations	
Response: MO	Confidence:
Rationale: *Procambarus clarkii* affects the fishing industry by damaging gill nets and spoiling the fish caught in the nets (Gherardi et al. 2011).	
References: Gherardi F, Robert FJ, Kenneth BB, Mavuti M, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological Conservation* 144: 2585–2596.	
CON2 Maximum socio-economic impact (Figure S3)	
Response: MO	Confidence: Medium
Rationale: In its invaded range *P. clarkii* had caused harmful impacts in agricultural fields (Anastácio et al. 2005) and has disrupted some recreational activities leading to economic loss Gherardi et al. 2011).	
References: Anastácio PM. Correia AM, Menino JP. 2005. Processes and patterns of plant destruction by crayfish: effects of crayfish size and developmental stages of rice. Archiv für Hydrobiologie 162: 37–51. Gherardi F, Robert FJ, Kenneth BB, Mavuti M, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological Conservation* 144: 2585–2596.	

CON3 Closely related species' environmental impact	
Response: NA	Confidence:
Rationale:	
References:	

CON4 Closely related species' socio-economic impact

Response: NA	Confidence:
Rationale:	
References:	

CON5 Potential impact	
Response: MR	Confidence: High
Rationale: It is clear from the assessment that *P. clarkii* can becomes invasive in areas of introduction. It can tolerate a wide range of environmental conditions (Nunes et al. 2017b), and it is an aggressive competitor that can out-compete and displace native species in invaded ecosystems (Gherardi et al. 2011, Jackson et al. 2016). It can also cause habitat alteration through intensive grazing of macrophytes and its burrowing activities can destabilise river banks and water infrastructure such as dams and canals. The species is difficult to eradicate once it has established because of its hardy nature, and the use of conventional control methods such as biocides is either not practical or desirable because of the large quantities of toxins required to treat an area and they are not target-specific, and often also adversely affect native fauna (Nunes et al. 2017a).	
References: Gherardi F, Britton JR, Mavuti KM, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological Conservation* 144: 258–2596. Jackson MC, Grey J, Miller K, Britton JR, Donohue, I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology*, 85:1098–1107. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future, *African Journal of Aquatic Science* 42: 309–323. Nunes AL, Hoffman CA, Zengeya TA, Measey GJ, Weyl OLF. 2017. Red swamp crayfish, *Procambarus clarkii*, found in South Africa 22 years after attempted eradication. *Aquatic Conservation: Marine Freshwater Ecosystem* 27: 1334–1340.	

4. Management

MAN1 What is the feasibility to stop future immigration?	
Response: Low	Confidence: Low
Rationale: The pet trade is still a relevant pathway of introductions due to the species still being available to buy online via pet shops (Nunes et al. 2017b, Madzivanzira et al. 2020). Although this pathway is relevant, studies however, need to be undertaken to assess the prominence of the pathway (Nunes et al. 2017b). *Procambarus clarkii* is very popular in the pet trade and is known to be present in nine countries already (Faulkes 2015). Intentional stocking for use as bait by fishermen has happened in the past and could still be occurring (Nunes et al. 2017b, Madzivanzira et al. 2020).	
References: Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92. Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF.2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309– 23.	

MAN2 Benefits of the Taxon	
MAN2a Socio-economic benefits of the *Taxon*	
Response: Medium	Confidence: Low
Rationale: *Procambarus clarkii* is widely used in aquaculture in several countries, with the highest production in China and the U.S.A. In 2005, China produced over 80 000 tonnes (estimated value 303 million US Dollars) and the U.S.A produced roughly 33 000 tonnes (estimated value 48.6 million US Dollars).	

Some fisheries exist in other countries (Costa Rica Kenya, Mexico Portugal, Spain and Zambia) but there are some discrepancies however, in the information provided by different sources. It is therefore, difficult to estimate the monetary value generated. In addition, the benefits derived from the pet trade industry have yet to be evaluated.	
References: Douthwaite RJ, Jones EW, Tyser AB, Vrdoljak SM. 2018. The introduction, spread and ecology of redclaw crayfish *Cherax quadricarinatus* in the Zambezi catchment. *African Journal of Aquatic Science* 43: 353–366. http://www.fao.org/fishery/culturedspecies/Procambarus_clarkii/en Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
MAN2b Environmental benefits of the *Taxon*	
Response: None	Confidence:
Rationale:	
References:	

MAN3 Ease of management	
MAN3a How accessible are populations?	
Response: 1	Confidence: Medium
Rationale: *Procambarus clarkii* is restricted to two sites in Mpumalanga and Free State Provinces. Both populations are confined to dams (Nunes et al. 2017a). One dam however, is on private property, thus the landowner needs to be consulted during the development of management plans and/or eradication protocols (Nunes et al. 2017a).	
References: Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309– 23.	
MAN3b Is detectability critically time-dependent?	
Response: 0	Confidence: High
Rationale: Species can be detected throughout the year, although they also burrow which could deter their detection (de Moor 2002, Nunes et al. 2017b, 2017a).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–23. Nunes AL, Hoffman CA, Zengeya TA, Measey GJ, Weyl OLF. 2017. Red swamp crayfish, *Procambarus clarkii*, found in South Africa 22 years after attempted eradication. *Aquatic Conservation: Marine Freshwater Ecosystems* 27: 1334–1340.	
MAN3c Time to reproduction	
Response: 2	Confidence: High
Rationale: *Procambarus clarkii* is a prolific breeder. Sexual maturity is reached in three months (6-13 cm) and it can spawn twice a year (Ackefors 1999, Barbaresi & Gherardi 2000). Females also display parental care with newly born individuals staying with the mother in burrows up until two moult cycles (Barbaresi & Gherardi 2000).	
References: Ackefors H. 1999. The positive effects of established crayfish introductions in Europe. In Gherardi F and Holdich DM. (eds.) *Crustacean Issues 11: Crayfish in Europe as Alien Species (How to make the best of a bad situation?)* A.A. Balkema, Rotterdam, Netherlands: 49–62. Barbaresi S, Gherardi F. 2000. The invasion of the alien crayfish *Procambarus clarkii* in Europe, with	

particular reference to Italy. *Biological invasions* 2: 259–264.

MAN3d Propagule persistence

Response: NA | Confidence:

Rationale:

References:

MAN3 Ease of management (SUM from Table S4)

Response: Medium | Confidence: Medium

Rationale:

Procambarus clarkii is not widespread, thus eradication is still feasible due to known populations being restricted to impoundments (Nunes et al. 2017b, Weyl et al. 2020). The pet trade industry however still poses a significant risk for future introductions (Faulkes 2015).

References:

Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF.2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

MAN4 Has the feasibility of eradication been evaluated?

Response: NO | Confidence: Low

Rationale:

Procambarus clarkii is established, but not widespread in South Africa (Nunes et al. 2017a, Madzivanzira et al. 2020). The species is localized to two areas, making it ideal to study the feasibility of eradication (Nunes et al. 2017a, Madzivanzira et al. 2020). Eradication seems only possible when the species occurs in enclosed ponds. Although the eradiation method remains unknown, an eradication attempt 22 years ago at the Driehoek Farm however, was not successful (Nunes et al. 2017a). *Procambarus clarkii* burrows and mechanical methods would not have been effective in the removal of individuals (Nunes et al. 2017a). It is also highly likely that the eradication attempt was successful and the results from this survey could be an indication of a new invasion, however there is no evidence to support this.

Furthermore, the ponds at the Driehoek farm are used to stock trout and form part of a code sharing tourist facilities used for fishing by individuals when on holiday. Thus, there might be some resistance from private owners to some of the eradication methods such as complete dewatering or using biocides in the ponds because of the financial and social values attached to the facilities (Nunes et al. 2017a)

References:

Nunes AL, Hoffman CA, Zengeya TA, Measey GJ, Weyl OLF. 2017. Red swamp crayfish, *Procambarus clarkii*, found in South Africa 22 years after attempted eradication. *Aquatic Conservation: Marine Freshwater Ecosystems* 27: 1334–1340.

Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–23.

MAN5 Control options and monitoring approaches available for the *Taxon*

Response:

A variety of methods could be evaluated such as chemical, manual, or a combination of the two methods. When evaluating suitable methods however, it is important to take into account the burrowing behaviour of the species (Nunes et al. 2017a).

Given the burrowing behaviour of *P. clarkii*, mechanical methods (intensive trapping, electrofishing) together with de-watering the ponds (physical removal) should be considered (Nunes et al. 2017a). The method used must be in operation for at least one year. Incessant monitoring to determine if the methods used are having the desired effects should also be implemented throughout the period (Nunes et al. 2017a).

References:

Nunes AL, Hoffman CA, Zengeya TA, Measey GJ, Weyl OLF. 2017. Red swamp crayfish, *Procambarus clarkii*, found in South Africa 22 years after attempted eradication. *Aquatic Conservation: Marine Freshwater Ecosystems* **27**: 1334—1340.

MAN6 Any other management considerations to highlight? (if yes, fill in Appendix MAN6)	
Response	Yes / No

5. Calculations

Likelihood = Probable

Parameter	Likelihood	Stages	Final assessment
LIK1	Probable =1	P(entry) = 1	P (invasion) = 1
LIK2	Probable =1		
LIK3	Probable =1	P(establishment) = 1	
LIK4	Probable =1		
LIK5	Fairly probable =0.5	P (spread) =1	
LIK6	Probable =1		

Consequence = MR

Parameter	Mechanism/sector	Response
CON1a	Competition	MR
CON1b	Predation	MR
CON1c	Hybridisation	MC
CON1d	Disease transmission	MR
CON1e	Parasitism	DD
CON1f	Poisoning/toxicity	MN
CON1g	Bio-fouling or other direct physical disturbance	DD
CON1h	Grazing/herbivory/browsing	MO
CON1i	Chemical, physical, structural impact	MO
CON1k	Indirect impacts through interactions with other species	DD
CON1	**Maximum environmental impact**	**MR**
CON2a	Safety	DD
CON2b	Material and immaterial assets	MO
CON2c	Health	MN
CON2d	Social, spiritual and cultural relations	MO
CON2	**Maximum socio-economic impact**	**MO**
CON3	Environmental impact of closely related taxa (only score if CON1a-k are all DD, otherwise NA)	NA
CON4	Socio-economic impact of closely related taxa (only score if CON2a-g are all DD, otherwise NA)	NA
CON5	Potential impact based on traits, experiments, or models	**MR**

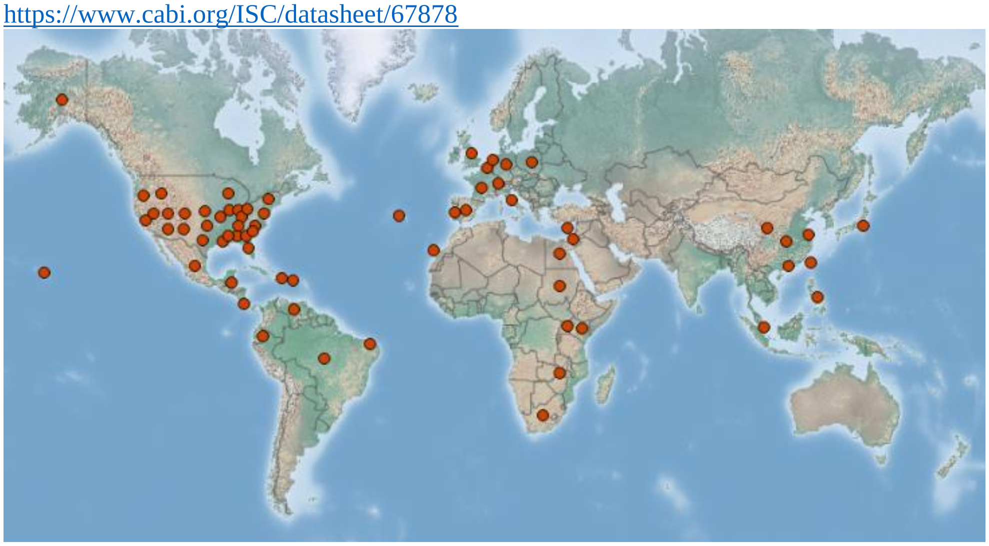
Table S3: Risk score
(highlight the respective fields)

		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	Low	Low	Low	Medium	Medium
	Very unlikely	Low	Low	Low	Medium	High
	Unlikely	Low	Low	Medium	High	High
	Fairly probable	Medium	Medium	High	High	High
	Probable	Medium	High	High	High	High

Table S4: Ease of management
(fill in numbers in table below)

Parameter	Question	Response
MAN3a	How accessible are populations?	1
MAN3b	Is detectability critically time-dependent?	0
MAN3c	Time to reproduction	2
MAN3d	Propagule persistence	0
MAN3	**SUM**	3

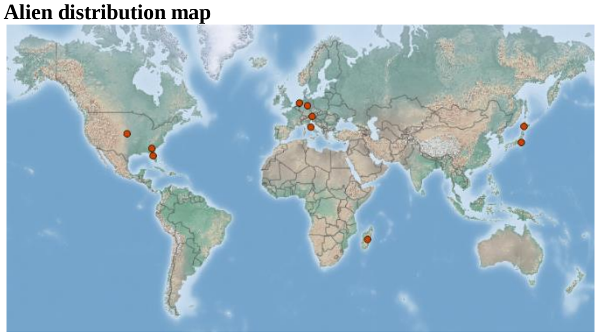
Appendix BAC8(a): Global alien range of *Procambarus clarkii*. Map from CABI: https://www.cabi.org/ISC/datasheet/67878



Appendix 3.14 Risk analysis report for Marmorkrebs (*Procambarus fallax f. virginalis*).

Risk Analysis Report

<table>
<tr><td>Taxon:
Procambarus fallax f. virginalis (Hagen,1870)</td><td>Area:
South Africa</td></tr>
<tr><td>Compiled by:
Lee-Anne Botha</td><td>Approved by:</td></tr>
<tr><td>Picture of Taxon

http://www.sciencemag.org/news/2018/02/aquarium-accident-may-have-given-crayfish-dna-take-over-world</td><td>Alien distribution map

https://www.gbif.org/species/2227309</td></tr>
<tr><td>Risk Assessment summary:
Marmorkrebs (Procambarus fallax f. virginalis), is a parthenogenetic crayfish, the native origin of which is unknown. It has become widely established in Madagascar, however, there are no known populations in South Africa or any neighboring countries. Procambarus fallax f. virginalis is a highly sought after aquarium pet species and is available to buy online in several countries and is likely to be moved by humans through the pet trade. There are no documented impacts from P. fallax f. virginalis and potential impacts were inferred from Procambarus clarkii, a closely-related species, is a facultative omnivore and an aggressive competitor that often displaces native species in areas of introduction through predation, competitive exclusions, and transmission of diseases. It has also been implicated in causing habitat alteration through excessive grazing of macrophytes, and its burrowing activities increase rates of soil erosion and cause physical damage to agricultural infrastructure such as irrigation canals. Procambarus clarkii serves as vector for several parasites and diseases some of which are zoonotic. Procambarus fallax f. virginalis is likely to have similar impacts in recipient areas of introduction.</td><td>Risk score:
High</td></tr>
<tr><td>Management options summary:
There are no records of species being in present in South Africa. When evaluating suitable methods however, it is important to take into account the burrowing behaviour of the species. The species is popular in the aquarium trade, and as a result, the potential of accidental or intentional release of the species into new areas by humans is high.</td><td>Ease of management:
NA</td></tr>
<tr><td rowspan="2">Recommendations:
Procambarus fallax f. virginalis is not currently listed under the NEM:BA Alien and Invasive Species (A&IS) Regulations. The illegal pet trade industry still poses a significant risk for intentional and accidental release of the species into the wild. There is therefore, a need to assess the trade of and movement of the taxon through the aquarium trade in order to implement appropriate management strategies.</td><td>Listing under NEM:BA A&IS lists of 2014 as amended 2020
Not listed</td></tr>
<tr><td>Recommended listing category:
No change</td></tr>
</table>

1. Background

BAC1 Name of assessor(s)	
Name of lead assessor	**Ms. Lee-Anne Botha**
Additional assessor (1)	
Additional assessor (2)	
BAC2 Contact details of assessor (s)	
Lead assessor	Organisational affiliation: University of Pretoria, Department of Zoology and Entomology/ SANBI
	email: u18389164@tuks.co.za
	Phone: 072 833 7952
Additional assessor (1)	Organisational affiliation:
	email:
	Phone:
Additional assessor (2)	Organisational affiliation:
	email:
	Phone:
BAC3 Name(s) and contact details of expert(s) consulted	
Expert (1)	Name: Dr Tsungai Zengeya
	email: T.Zengeya@sanbi.org.za
	Phone: 021 799 8408
Expert (2)	Name:
	email:
	Phone:
Comments: Dr Tsungai Zengeya works for the South African National Biodiversity Institute (SANBI). His research interests are in freshwater ecology and biological invasions. He provided comments and inputs throughout the compilation of this risk analysis that improved its quality.	
BAC4 Scientific name of *Taxon* under assessment	
Taxon name: *Procambarus fallax* f. *virginalis*	Authority: (Hagen, 1870)
Comments:	
References: Feria TP, Faulkes Z. 2011. Forecasting the distribution of Marmorkrebs, a parthenogenetic crayfish with high invasive potential, in Madagascar, Europe, and North America. *Aquatic Invasions 6*: 55–67. Faulkes Z, Feria TP, Muñoz J. 2012. Do Marmorkrebs, *Procambarus fallax f. virginalis*, threaten freshwater Japanese ecosystems?. *Aquatic Biosystems* 8: 13.	
BAC5 Synonym(s) considered	
Synonyms:	
Comments:	

References:	
BAC6 Common name(s) considered	
Common names: Marbled crayfish/ Marmorkrebs	
Comments:	
References: Feria TP, Faulkes Z. 2011. Forecasting the distribution of Marmorkrebs, a parthenogenetic crayfish with high invasive potential, in Madagascar, Europe, and North America. *Aquatic Invasions 6*: 55–67. Faulkes Z, Feria TP, Muñoz J. 2012. Do Marmorkrebs, *Procambarus fallax f. virginalis*, threaten freshwater Japanese ecosystems?. *Aquatic Biosystems* 8: 13.	
BAC7 What is the native range of the *Taxon*? (add map in Appendix BAC7)	
Response: Unknown	Confidence: Low
Comments: It was first discovered in a pet shop in Germany in the mid-1990s and became a very popular pet species since then. "Most recently, Martin et al. (2010a) suggested that the Marmorkrebs is the parthenogenetic form of *Procambarus fallax* (Hagen, 1870) and proposed the tentative scientific name *Procambarus fallax* f. *virginalis*. *Procambarus fallax* occurs in southern Georgia and Florida and it is therefore reasonable to assume that the Marmorkrebs originates also from the southeastern United States, although an indigenous population has never been reported" (Churcholl and Pfeiffer, 2010).	
References: Chucholl C, Pfeiffer M. 2010. First evidence for an established Marmorkrebs (Decapoda, Astacida, Cambaridae) population in Southwestern Germany, in syntopic occurrence with *Orconectes limosus* (Rafinesque, 1817). *Aquatic invasions* 5**:** 405–412 Feria TP, Faulkes Z. 2011. Forecasting the distribution of Marmorkrebs, a parthenogenetic crayfish with high invasive potential, in Madagascar, Europe, and North America. *Aquatic Invasions* 6: 55-67. Soes M, Koese B. 2010. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis. https://www.cabi.org/isc/datasheet/110477	
BAC8 What is the global alien range of the *Taxon*? (add map in Appendix BAC8)	
Response: Madagascar, Europe, Japan, Netherlands, Italy	Confidence: Medium
Comments: Populations are increasing in Madagascar and there are also established populations in Europe and Germany.	
References: Chucholl C, Pfeiffer M. 2010. First evidence for an established Marmorkrebs (Decapoda, Astacida, Cambaridae) population in Southwestern Germany, in syntopic occurrence with *Orconectes limosus* (Rafinesque, 1817). *Aquatic invasions* 5: 405–412. Feria TP, Faulkes Z. 2011. Forecasting the distribution of Marmorkrebs, a parthenogenetic crayfish with high invasive potential, in Madagascar, Europe, and North America. *Aquatic Invasions* 6: 55–67. Soes M, Koese B. 2010. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis.	
BAC9 Geographic scope = the *Area* under consideration	
Area of assessment: South Africa	
Comments:	
BAC10 Is the *Taxon* present in the *Area*?	
Response: No	Confidence: Low

Comments: There are only records for the introduction of four freshwater crayfish into South Africa. Those species are *Cherax destructor*, *Cherax cainii/tenuimanus*, *Cherax quadricarinatus* and *Procrambarus clarkii*.
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.

BAC11 Availability of physical specimen	
Response:	Confidence in ID:
Herbarium or museum accession number:	
References:	

BAC12 Is the *Taxon* native to the *Area* or part of the *Area*?		
The *Taxon* is native to (part of) the *Area*.	No	Confidence: High
The *Taxon* is alien in (part of) the *Area*.	Yes	Confidence: High
Comments: Origin of marbles crayfish is unknown. There are no indigenous crayfish in South Africa.		
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.		

BAC13 What is the *Taxon*'s introduction status in the *Area*?		
The *Taxon* is in cultivation/containment.	Unknown	Confidence: Low
The *Taxon* is present in the wild.	No	Confidence: Low
The *Taxon* has established/naturalised.	No	Confidence: Low
The *Taxon* is invasive.	No	Confidence: Low
Comments: There are only records for the introduction of four freshwater crayfish into South Africa. Those species are *Cherax destructor*, *Cherax cainii/tenuimanus*, *Cherax quadricarinatus* and *Procrambarus clarkii*.		
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.		

BAC14 Primary (introduction) pathways		
Release	NA	Confidence:
Escape	Aquarium trade	Confidence: High
Contaminant	NA	Confidence:
Stowaway	NA	Confidence:
Corridor	NA	Confidence:
Unaided	NA	Confidence:

Comments:
Species was discovered in the pet trade in Germany, though the origin is unknown.
References: Chucholl C, Pfeiffer M. 2010. First evidence for an established Marmorkrebs (Decapoda, Astacida, Cambaridae) population in Southwestern Germany, in syntopic occurrence with *Orconectes limosus* (Rafinesque, 1817). *Aquatic invasions* 5: 405–412. Feria TP, Faulkes Z. 2011. Forecasting the distribution of Marmorkrebs, a parthenogenetic crayfish with high invasive potential, in Madagascar, Europe, and North America. *Aquatic Invasions* 6: 55–67. Faulkes Z. Feria TP, Muñoz J. 2012. Do Marmorkrebs, *Procambarus fallax f. virginalis*, threaten freshwater Japanese ecosystems?. *Aquatic Biosystems* 8: 13. Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92.

2. Likelihood

LIK1 Likelihood of entry via unaided primary pathways	
Response: Very unlikely	Confidence: Medium
Rationale: There are no wild populations in neighbouring countries that could act as source for unaided introductions (Nunes et al. 2017; Madzivanzira et al. 2020).	
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

LIK2 Likelihood of entry via human aided primary pathways	
Response: Probable	Confidence: Medium
Rationale: *Procambarus fallax f. virginalis* is a very popular aquarium pet species due to its size and also because of its pathogenesis abilities that makes it very easy to rear (Chucholl and Pfeiffer 2010; Faulkes 2015).	
References: Chucholl C, Pfeiffer M. 2010. First evidence for an established Marmorkrebs (Decapoda, Astacida, Cambaridae) population in Southwestern Germany, in syntopic occurrence with *Orconectes limosus* (Rafinesque, 1817). *Aquatic invasions* 5: 405–412 Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92.	

LIK3 Habitat suitability	
Response: Fairly probable	Confidence: Low
Rationale: Due to the uncertainty with regards to the native range of *Procambarus fallax f. virginalis* and no record of indigenous populations, nothing is known about its natural habitat. In areas of introduction it's found in both lotic and lentic freshwater habitats (Dorn and Volin 2009). However, in Germany, populations were only found in lentic habitats (Chucholl and Pfeiffer 2010). Populations from Madagascar occupy a variety of habitats from rivers, lakes, swamps, and drainage ditches and fish ponds (Feria and Faulkes 2011). Since *Procambarus fallax f. virginalis* is the parthogenic version of slough crayfish, *Procambarus fallax*, some of the habitat required could be inferred by using this species. *P. fallax* occurs in streams and rivers but seems to prefer lentic or slow flowing habitats and is found in marshes, wet prairies and sloughs with lightweight organic soils. *P. fallax* also inhabits temporary wetlands, which feature brief dry-downs during which crayfish retreat into refugia or simple burrows. It is considered as a tertiary burrowing species, i.e. it lives in open water during most of its life and burrows only under extreme conditions.	
References: Chucholl C, Pfeiffer M. 2010. First evidence for an established Marmorkrebs (Decapoda, Astacida, Cambaridae) population in Southwestern Germany, in syntopic occurrence with *Orconectes limosus* (Rafinesque, 1817). *Aquatic invasions* 5: 405–412 Dorn NJ, Volin JC. 2009. Resistance of crayfish (Procambarus spp.) populations to wetland drying depends	

on species and substrate. *Journal of the North American Benthological Society* 28: 766–777. Feria TP, Faulkes Z. 2011. Forecasting the distribution of Marmorkrebs, a parthenogenetic crayfish with high invasive potential, in Madagascar, Europe, and North America. *Aquatic Invasions* 6: 55–67. https://www.cabi.org/isc/datasheet/110477

LIK4 Climate suitability	
Response: Fairly probable	Confidence: Low
Rationale: There is contradicting information with regards to the climate requirements for this species. Results from a laboratory study suggest that it can tolerate low temperatures and even survive in direct ice cover. Overall, *Procambarus fallax f. virginalis* seem to be tolerant of a wide range of environmental conditions, including low oxygenation and temporary exposure to temperatures < 8°C and > 30°C.	
References: Feria, TP, Faulkes Z. 2011. Forecasting the distribution of Marmorkrebs, a parthenogenetic crayfish with high invasive potential, in Madagascar, Europe, and North America. *Aquatic Invasions* 6: 55–67. Seitz R, Vilpoux K, Hopp U, Harzsch S, Maier G. 2005. Ontogeny of the Marmorkrebs (marbled crayfish): a parthenogenetic crayfish with unknown origin and phylogenetic position.*Journal of Experimental Zoology Part A: Comparative Experimental Biology* 303: 393–405.	

LIK5 Unaided secondary (dispersal) pathways	
Response: Very unlikely	Confidence: Medium
Rationale: Currently this is very unlikely due to no known wild populations present in South Africa and neighbouring countries that could as a source for secondary dispersal (Nunes et al. 2017; Madzivanzira et al. 2020).	
References: Madzivanzira TC, South J, Wood LE, Nunes AL, Weyl OLF. 2020: A review of freshwater crayfish introductions in Africa. *Reviews in Fisheries Science & Aquaculture* 1–21. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	

LIK6 Human aided secondary (dispersal) pathways	
Response: Probable	Confidence: Medium
Rationale: Crayfish can be released into the wild by humans that have them as pets (Faulkes et al 2012; Faulkes 2015).	
References: Faulkes Z, Feria TP, Muñoz J. 2012. Do Marmorkrebs, *Procambarus fallax f. virginalis*, threaten freshwater Japanese ecosystems?. *Aquatic Biosystems 8*: 13. Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research* 44: 75–92.	

3. Consequences

CON1 Environmental impact	
CON1a: Competition	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON1b: Predation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1c: Hybridisation	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	

CON1d: Transmission of disease	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1e: Parasitism	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1f: Poisoning/toxicity	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1g: Bio-fouling or other direct physical disturbance	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1h: Grazing/herbivory/browsing	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1i: Chemical, physical or structural impact on ecosystem	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1k: Indirect impacts through interactions with other species	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data).	
CON1 Maximum environmental impact (Figure S3)	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact	
References: L. Botha (Unpublished data).	

CON2 Socio-economic impact	
CON2a: Safety	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data	
CON2b: Material and immaterial assets	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2c: Health	
Response: DD	Confidence: Low
Rationale: No documented information available to assess the level of impact.	
References: L. Botha (Unpublished data)	
CON2d: Social, spiritual and cultural relations	
Response: DD	Confidence: Low
Rationale:	
References: L. Botha (Unpublished data)	
CON2 Maximum socio-economic impact (Figure S3)	
Response: DD	Confidence: Low

Rationale: No documented information available to assess the level of impact.
References: L. Botha (Unpublished data).

<table>
<tr><th colspan="2">CON3 Closely related species' Environmental impact</th></tr>
<tr><th colspan="2">CON3a: Competition</th></tr>
<tr><td>Response: MR</td><td>Confidence: Medium</td></tr>
<tr><td colspan="2">Rationale:
Procambarus clarkii is very aggressive and usually out-competes native species for shelter and spawning sites, and these often lead to reproductive interference. In areas of introduction, some amphibian species (e.g., Bufo bufo, B. calamita, Rana sp., Taricha torosa and Triturus vulgaris) have been excluded or displaced from their natural habitats, resulting in local extinctions through either larval predation or amphibians spawning in areas that do not offer sufficient protection to avoid interaction with P.clarkii, resulting in low recruitment (Cruz et al. 2006, Lodge et al. 2012). In addition, as a result of direct competition, there has been a decrease in the distributional ranges and abundance of native crayfish populations (Astacus astacus, Austropotamobius pallipes and A. torrentium) in some areas in Europe and Japan (Cruz et al. 2006, Lodge et al. 2012). Furthermore, direct competition for food has caused dietary niche constriction and declines in populations of native crabs in some areas invaded by P. clarkia (Jackson et al. 2016).</td></tr>
<tr><td colspan="2">References:
Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, Procambarus clarkii, on the distribution of south-western Iberian amphibians in their breeding habitats. Ecography 29: 329–338.
Jackson MC, Grey J, Miller K, Britton, JR, Donohue, I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. Journal of Animal Ecology, 85:1098–1107.
Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. Annual Review of Ecology, Evolution and Systematics 43: 449–472.</td></tr>
<tr><th colspan="2">CON3b: Predation</th></tr>
<tr><td>Response: MR</td><td>Confidence: Medium</td></tr>
<tr><td colspan="2">Rationale:
In its invasive range, there is evidence that predation by P. clarkii can result in the local or population extinctions of at least one native species (Lodge et al. 2012, Souty-grosset et al. 2016). For example, P. clarkii has been implicated in causing population declines of several species of fish and amphibians by reducing their breeding success through predation on eggs and larval amphibians (Cruz et al. 2006, Francesco et al. 2011). Indirect effects of predation can also cause trophic cascades that can lead to changes in ecosystem structure and function. For example, predation on invertebrates can release algae from grazing pressure and lead to changes in the abundance and dominance of species in algal communities (Gherardi and Barbaresi 2008).</td></tr>
<tr><td colspan="2">References:
Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, Procambarus clarkii, on the distribution of south-western Iberian amphibians in their breeding habitats. Ecography 29: 329–338.
Ficetola GF, Siesa ME, Manenti R, Bottoni L, De Bernardi F, Padoa-Schioppa E. 2011. Early assessment of the impact of alien species: Differential consequences of an invasive crayfish on adult and larval amphibians. Diversity and Distributions 17:1141–1151.
Gherardi F, Barbaresi S. 2008. Feeding opportunism of the red swamp crayfish Procambarus clarkia, an invasive species. Freshwater crayfish 16: 77–85.
Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. Annual Review of Ecology, Evolution and Systematics 43: 449–472.
Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish Procambarus clarkii in Europe: Impacts on aquatic ecosystems and human well-being. Limnologica 58: 78–93.</td></tr>
<tr><th colspan="2">CON3c: Hybridisation</th></tr>
<tr><td>Response: MC</td><td>Confidence: Low</td></tr>
<tr><td colspan="2">Rationale:</td></tr>
</table>

This is unlikely in South Africa because there are no native crayfish species (de Moor 2002, Nunes et al. 2017b).	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323.	
CON3d: Transmission of disease	
Response: MR	Confidence: Medium
Rationale: *Procambarus clarkii* can harbour many pathogens, parasites, and diseases that can be transmitted to other congeneric species (Longshaw 2011, Lodge et al. 2012). There is evidence that transmission of diseases and parasites by *P. clarkii* to native species has caused local or population extinctions of at least one native species, leading to changes in community composition (Lodge et al. 2012). For example, *P. clarkii* is a vector of crayfish plague, a disease caused by the parasitic oomycete, *Aphanomyces astaci* (Longshaw 2011, Souty-grosset et al. 2016). In Europe, transmission of crayfish plague by *P. clarkii* to native crayfish species has been linked to a decline in populations of several native species of crayfish such as *Astacus astacus*, *Austropotamobius pallipes* and *A. torrentium* (Holdich et al. 2009, Longshaw 2011). *Procambarus clarkii* can also harbour white spot syndrome disease – a viral infections of crustaceans, and fungal pathogens such as *Batrachochytrium dendrobatids* that causes chytridiomycosis – a lethal skin infection in amphibians (Longshaw 2011, McMahon et al. 2013).	
References: Aquiloni L, Martín MP, Gherardi F, Diéguez-Uribeondo J. 2011. The North American crayfish *Procambarus clarkii* is the carrier of the oomycete *Aphanomyces astaci* in Italy. *Biological Invasions* 13: 359–367. Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449 –72. Longshaw M. 2011. Diseases of crayfish: A review. *Journal of Invertebrate Pathology* 106: 54–70. McMahon TA, Brannelly LA, Chatfield MW, Johnson PT, Joseph MB, McKenzie VJ, Richards-Zawacki CL, Venesky MD, Rohr JR. 2013. Chytrid fungus *Batrachochytrium dendrobatidis* has non-amphibian hosts and releases chemicals that cause pathology in the absence of infection. *Proceedings of the National Academy of Sciences of the United States of America* 110: 210–215. Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.	
CON3e: Parasitism	
Response: DD	Confidence: Low
Rationale: No information is available to assess the level of impact	
References: L. Botha (Unpublished data).	
CON3f: Poisoning/toxicity	
Response: MN	Confidence: Low
Rationale: **See CON4c**	
References: de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139. Gherardi F, Britton JR, Mavuti KM, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological* Conservation 144: 2585–2596. Putra MD, Bláha M, Wardiatno Y, Krisanti M, Bystřický PK, Kouba A, Kalous L, Petrusek A, Patoka J. 2017. *Procambarus clarkii* (Girard, 1852) and crayfish plague as new threats for biodiversity in Indonesia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 28: 1434–1440.	

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON3g: Bio-fouling or other direct physical disturbance

Response: DD	Confidence: Low

Rationale:

No information is available to assess the level of impact.

References:

L. Botha (Unpublished data).

CON3h: Grazing/herbivory/browsing

Response: MO	Confidence: Medium

Rationale:

Grazing by *P. clarkii* can lead to habitat loss and modification through the removal of macrophytes. Habitat loss can lead to a decline in populations of species that utilise the macrophyte stands as a food source, nesting sites, and as refugia from predation (Rosenthal et al 2005). *Procambarus clarkii* can also cause changes to community composition through trophic cascades (Gherardi and Aquistapace 2007, Souty-grosset et al. 2016). For example, in Lake Chozas (northwest Spain), grazing by *P. clarkii* caused a reduction in macrophyte communities and this impact cascaded up the food chain with declines in invertebrates, amphibians, and waterfowl (Rodriguez et al 2003). Grazing can also cause changes to community composition and structure, such as changing ecosystems from macrophyte-dominated areas with clear water, to turbid phytoplankton-dominated areas (Matsizaki et al. 2009). Excessive grazing can also lead to accelerated rates of important processes such as litter breakdown and decomposition.

References:

Gherardi F, Acquistapace P. 2007. Invasive crayfish in Europe: The impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. *Freshwater Biology* 52: 1249–59.

Matsuzaki SS, Usio N, Takamura N, Washitani I. 2009. Contrasting impacts of invasive engineers on freshwater ecosystems: An experiment and meta-analysis. *Oecologia* 158: 673–686.

Rodríguez CF, Bécares E, Fernández-Aláez M. 2003. Shift from clear to turbid phase in Lake Chozas (NW Spain) due to the introduction of American red swamp crayfish (*Procambarus clarkii*). *Hydrobiologia* 506: 421–26.

Rosenthal SK, Lodge DM, Mavuti KM, Muohi W, Ochieng P, Mungai BN, Mkoji GM. 2005. Comparing macrophyte herbivory by introduced Louisiana crayfish (*Procambarus clarkii*) (Crustacea: Cambaridea) and native Dytiscid beetles (*Cybister tripunctatus*) (Coleoptera: Dytiscidae), in Kenya. *African Journal of Aquatic Science* 30: 157–62.

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON3i: Chemical, physical or structural impact on ecosystem

Response: MO	Confidence: Medium

Rationale:

Water quality: *Procambarus clarkii* is often considered an ecosystem engineer due to its ability to change ecosystems through its burrowing activities (Souty-grosset et al. 2016). For example, its burrowing activities can cause a decrease in the water quality through bioturbation leading to increased turbidity and influx release of nutrients from sediments, often leading to algal blooms (Angeler et al. 2001, Yamamoto 2010). The impaired water quality also affects the quality of the habitats for other aquatic fauna (Angeler et al. 2001, Rodriguez et al. 2003). For example, increased turbidity can impede foraging and respiratory processes of fish (Rodriguez et al. 2003).

Erosion: Burrowing activities can cause structural damage to river banks and increase bank erosion, and also cause damage to water retention infrastructure such as dam walls and dykes (Souty-grosset et al. 2016).

References:

Angeler DG, Sánchez-Carrillo S, García G, Alvarez-Cobelas M. 2001. The influence of *Procambarus clarkii* (Cambaridae, Decapoda) on water quality and sediment characteristics in a Spanish floodplain wetland. *Hydrobiologia* 464: 89–98.

Rodríguez CF, Bécares E, Fernández-Aláez M. 2003. Shift from clear to turbid phase in Lake Chozas (NW Spain) due to the introduction of American red swamp crayfish (*Procambarus clarkii*). *Hydrobiologia*

506: 421–26.
Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.
Yamamoto Y. 2010. Contribution of bioturbation by the red swamp crayfish *Procambarus clarkii* to the recruitment of bloom-forming cyanobacteria from sediment. *Journal of Limnology* 69: 102– 111.

CON3k: Indirect impacts through interactions with other species

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data).

CON3 Maximum environmental impact (closely related taxa) (Figure S3)

Response: MR	Confidence: High

Rationale
Direct predation and competition for food, shelter, and spawning sites have led to local extinctions and a decrease in the abundance of native amphibians and crayfish species(Cruz et al. 2006, Gherardi & Acquistapace 2007). Impacts have been recorded in the Iberian Peninsula, Sweden, Italy (Gherardi and Acquistapace 2007), Japan, and U.S.A. (California) (Holdich et al. 2009, Lodge et al. 2012).

References:
Cruz MJ, Rebelo R, Crespo EG. 2006. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. *Ecography* 29: 329-338.
Gherardi F, Acquistapace P. 2007. Invasive crayfish in Europe: The impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. *Freshwater Biology* 52: 1249–59.
Jackson MC, Grey J, Miller K, Britton JR, Donohue, I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology* 85:1098–1107.
Longshaw M. 2011. Diseases of crayfish: A review. *Journal of Invertebrate Pathology* 106: 54–70.
Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON4 Closely related species' Socio-economic impact

CON4a: Safety

Response: DD	Confidence: Low

Rationale:
No information is available to assess the level of impact.

References:
L. Botha (Unpublished data).

CON4b: Material and immaterial assets

Response: MO	Confidence: Medium

Rationale:
Procambarus clarkii often inhabits agricultural fields and their burrowing activities can cause damage to infrastructure such as irrigation canals and dam walls (Lodge et al. 2012, Arce and Diéguez-Uribeondo 2015). Burrowing activities can also alter soil hydrology leading to water loss. Grazing causes crop damage and reduces yield (Anastácio et al. 2005). In Europe for example, *P. clarkii* affects rice production through field water loss, damage to rice field banks and ditches, direct consumption of rice seed and plants, and clogging of pipes (Souty-grosset et al. 2016).

References:
Anastácio PM. Correia AM, Menino JP. 2005. Processes and patterns of plant destruction by crayfish: effects of crayfish size and developmental stages of rice. *Archiv für Hydrobiologie* 162: 37–51.
Arce JA, Diéguez-Uribeondo J. 2015. Structural damage caused by the invasive crayfish *Procambarus clarkii* (Girard, 1852) in rice fields of the Iberian Peninsula: A study case. *Fundamental and Applied Limnology* 186: 259–269.
Lodge DM, Deines A, Gherardi F, Yeo DCJ, Arcella T, Baldridge AK, Branes MA, Chadderton WL, Feder

JL, Grantz CA, Howard GW, Jerdde CL, Peters JA, Sargent LW, Turner CR, Wittmann ME, Zeng Y. 2012. Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. *Annual Review of Ecology, Evolution and Systematics* 43: 449–72.

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON4c: Health

Response: MN	Confidence: Low

Rationale:

Procambarus clarkii can bio-accumulate toxins and metals from the environment (Gherardi et al. 2011, Souty-grosset et al. 2016). These pollutants are often harmful and can be transferred to higher food web levels through the consumption of affected crayfish by humans and predators such as otters, birds, and fish (Gherardi et al. 2011, Lodge et al. 2012).

Procambarus clarkii serves as vector for several parasites and diseases some of which are zoonotic, for example the parasitic fluke flatworms (*Paragonimus* spp.) that causes lung fluke disease in humans, tularemia-causing bacterium *Francisella tularensis*, rat lungworm *Angiostrongylus cantonensis* that causes meningitis, and the nematode *Gnathostoma spinigerum* that causes human gnathostomiasis (de Moor 2002, Souty-grosset et al. 2016, Putra et al. 2017).

References:

de Moor I. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125–139.

Gherardi F, Britton JR, Mavuti KM, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological* Conservation 144: 2585–2596.

Putra MD, Bláha M, Wardiatno Y, Krisanti M, Bystřický PK, Kouba A, Kalous L, Petrusek A, Patoka J. 2017. *Procambarus clarkii* (Girard, 1852) and crayfish plague as new threats for biodiversity in Indonesia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 28: 1434–1440.

Souty-Grosset C, Anastácio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E. 2016. The red swamp crayfish *Procambarus clarkii* in Europe: Impacts on aquatic ecosystems and human well-being. *Limnologica* 58: 78–93.

CON4d: Social, spiritual and cultural relations

Response: MO	Confidence: Low

Rationale:

Procambarus clarkii affects the fishing industry by damaging gill nets and spoiling the fish caught in the nets (Gherardi et al. 2011).

References:

Gherardi F, Robert FJ, Kenneth BB, Mavuti M, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological Conservation* 144: 2585–2596.

CON4 Maximum socio-economic impact (closely related taxa) (Figure S3)

Response: MO	Confidence: Medium

Rationale:

In its invaded range *P. clarkii* had caused harmful impacts in agricultural fields (Anastácio et al. 2005) and has disrupted some recreational activities leading to economic loss Gherardi et al. 2011).

References:

Anastácio PM. Correia AM, Menino JP. 2005. Processes and patterns of plant destruction by crayfish: effects of crayfish size and developmental stages of rice. Archiv für Hydrobiologie 162: 37–51.

Gherardi F, Robert FJ, Kenneth BB, Mavuti M, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological Conservation* 144: 2585–2596.

CON5 Potential impact

Response: MR	Confidence: High

Rationale: *Procambarus fallax f. virginalis*, is a highly sought after aquarium pet species, due to its small size reproduce via parthogenisis making it easy to rear. *Procambarus fallax f. virginalis* is in the same genus as *Procambarus clarkii*, it is therefore highly likely for it to have detrimental impacts in areas where it manages to establish populations. It is clear from the assessment that *P. clarkii* can becomes invasive in areas of introduction. It can tolerate a wide range of environmental conditions (Nunes et al. 2017b), and it is an aggressive competitor that can out-compete and displace native species in invaded ecosystems (Gherardi et al. 2011, Jackson et al. 2016). It is thereore highly likely that *Procambarus fallax f. virginalis* can have similar impacts in its invaded range.
References: Chucholl C, Pfeiffer, M. 2010. First evidence for an established Marmorkrebs (Decapoda, Astacida, Cambaridae) population in Southwestern Germany, in syntopic occurrence with *Orconectes limosus* (Rafinesque, 1817). *Aquatic invasions* 5: 405–412. Feria TP, Faulkes Z. 2011. Forecasting the distribution of Marmorkrebs, a parthenogenetic crayfish with high invasive potential, in Madagascar, Europe, and North America. *Aquatic Invasions* 6: 55–67. Gherardi F, Britton JR, Mavuti KM, Pacini N, Grey J, Tricarico E, Harper DM. 2011. A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological Conservation* 144: 258–2596. Jackson MC, Grey J, Miller K, Britton, JR, Donohue, I. 2016. Dietary niche constriction when invaders meet natives: Evidence from freshwater decapods. *Journal of Animal Ecology*, 85:1098–1107. Nunes AL, Zengeya TA, Measey GJ, Weyl OLF. 2017. Freshwater crayfish invasions in South Africa: Past, present and potential future. *African Journal of Aquatic Science* 42: 309–323. Soes M, Koese, B. 2010. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis. Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis

4. Management

MAN1 What is the feasibility to stop future immigration?	
Response: Medium	Confidence: Low
Rationale: There are no known populations in neighbouring countries, thus probability of species entering via unaided primary pathways is very low (Feria and Faulkes 211; Nunes et al 2017). *Procambarus fallax f. virginalis* is present the pet trade industry in the Czech Republic Germany, Ireland, Netherlands, Slovakia the U.S.A and the UK (Chucholl 2013, Faulkes 2015). Should the species be traded illegally as pets, it would be challenging to prevent future introductions, and P. fallax f virginalis might already be in South Africa. Thus, the trading of this species still needs to be assessed thoroughly.	
References: Chucholl C, Pfeiffer, M. 2010. First evidence for an established Marmorkrebs (Decapoda, Astacida, Cambaridae) population in Southwestern Germany, in syntopic occurrence with *Orconectes limosus* (Rafinesque, 1817). *Aquatic invasions* 5: 405–412 Feria TP, Faulkes Z. 2011. Forecasting the distribution of Marmorkrebs, a parthenogenetic crayfish with high invasive potential, in Madagascar, Europe, and North America.*Aquatic Invasions* 6: 55–67. Faulkes Z. 2015. The global trade in crayfish as pets. *Crustacean Research 44*: 75–92.	

MAN2 Benefits of the Taxon	
MAN2a Socio-economic benefits of the *Taxon*	
Response: None	Confidence: Low
Rationale:	
References:	
MAN2b Environmental benefits of the *Taxon*	
Response: None	Confidence: Low

Rationale:
References:

MAN3 Ease of management	
MAN3a How accessible are populations?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3b Is detectability critically time-dependent?	
Response: NA	Confidence:
Rationale:	
References:	
MAN3c Time to reproduction	
Response: NA	Confidence:
Rationale:	
References:	
MAN3d Propagule persistence	
Response: NA	Confidence:
Rationale:	
References:	
MAN3 Ease of management (Table 4)	
Response	Confidence:
References:	

MAN4 Has the feasibility of eradication been evaluated?	
Response: No	Confidence: low
Rationale: In areas of introduction, where it has managed to establish populations, there has been no successful eradication attempt. Generally, once crayfish species have established and become widespread, it is impossible to eradicate them (Gherardi et al 2011). They are very hardy and if chemical control is considered large quantities are needed to kill crayfish and biocides have been used to eradicate crayfish populations elsewhere (Gherardi et al. 2011). Furthermore, the chemicals used are not specific to crayfish and can also extirpate other freshwater species within the same freshwater ecosystem (Ghrardi et al. 2011). However, when species are restricted to dams, mechanical control via traps, electrofishing could still be feasible (Gherardi et al 2011).	
References: Gherardi F, Aquiloni L, Diéguez-Uribeondo J, Tricarico E. 2011. Managing invasive crayfish: is there a hope?. *Aquatic Sciences* 73: 185–200.	

MAN5 Control options and monitoring approaches available for the *Taxon*
Response: Not assessed
References:

MAN6 Any other management considerations to highlight? (if yes, fill in Appendix MAN6)	
Response	Yes / No

5. Calculations

Likelihood = Probable

Parameter	**Likelihood**	**Stages**	**Final assessment**
LIK1	0.0027	P(entry) = 1	P (invasion) = 0.5
LIK2	1		
LIK3	0.5	P(establishment) = 0.5	
LIK4	0.5		
LIK5	0.0027	P (spread) = 1	
LIK6	1		

Consequence = MR (Major)

Parameter	**Mechanism/sector**	**Response**
CON1	**Maximum environmental impact**	**DD**
CON2	**Maximum socio-economic impact**	**DD**
CON3a	Competition	MR
CON3b	Predation	MR
CON3c	Hybridisation	MC
CON3d	Disease transmission	MR
CON3e	Parasitism	DD
CON3f	Poisoning/toxicity	MN
CON3g	Bio-fouling or other direct physical disturbance	DD
CON3h	Grazing/herbivory/browsing	MO
CON3i	Chemical, physical, structural impact	MO
CON3k	Indirect impacts through interactions with other species	DD
CON3	**Maximum environmental impact (closely related taxa)**	**MR**
CON4a	Safety	DD
CON4b	Material and immaterial assets	MO
CON4c	Health	MN
CON4d	Social, spiritual and cultural relations	MO
CON4	**Maximum socio-economic impact (closely related taxa)**	**MO**
CON5	Potential impact based on traits, experiments, or models	**MO**

Table S3: Risk score

		Consequences				
		MC	MN	MO	MR	MV
Likelihood	Extremely unlikely	low	low	low	medium	medium
	Very unlikely	low	low	low	medium	high
	Unlikely	low	low	medium	high	high
	Fairly probable	medium	medium	high	high	high
	Probable	medium	high	high	high	high

Table S4: Ease of management

Parameter	Question	Response
MAN3a	How accessible are populations?	0
MAN3b	Is detectability critically time-dependent?	0
MAN3c	Time to reproduction	0
MAN3d	Propagule persistence	0
MAN3	**SUM**	0

Appendix BAC7: Global alien range of *Procambarus fallax* f. *virginalis.* Map from CABI: **https://www.gbif.org/species/2227309**