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EDITORIAL

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Frameworks used in invasion science: progress and prospects

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Abstract

Our understanding and management of biological invasions relies on our ability to classify and conceptualise the phenomenon. This need has stimulated the development of a plethora of frameworks, ranging in nature from conceptual to applied. However, most of these frameworks have not been widely tested and their general applicability is unknown. In order to critically evaluate frameworks in invasion science, we held a workshop on 'Frameworks used in Invasion Science' hosted by the DSI-NRF Centre of Excellence for Invasion Biology in Stellenbosch, South Africa, in November 2019, which led to this special issue. For the purpose of the workshop we defined a framework as "a way of organising things that can be easily communicated to allow for shared understanding or that can be implemented to allow for generalisations useful for research, policy or management". Further, we developed the Stellenbosch Challenge for Invasion Science: "Can invasion science develop and improve frameworks that are useful for research, policy or management, and that are clear as to the contexts in which the frameworks do and do not apply?". Particular considerations identified among meeting participants included the need to identify the limitations of a framework, specify how frameworks link to each other and broader issues, and to improve how frameworks can facilitate communication. We believe that the 24 papers in this special issue do much to meet this challenge. The papers apply existing frameworks to new data and contexts, review how the frameworks have been adopted and used, develop useable protocols and guidelines for applying frameworks to different contexts, refine the frameworks in light of experience, integrate frameworks for new purposes, identify gaps, and develop new frameworks to address issues that are currently not adequately dealt with. Frameworks in invasion science must continue to be developed, tested as broadly as possible, revised, and retired as contexts and needs change. However, frameworks dealing with pathways of introduction, progress along the introduction-naturalisation-invasion continuum, and the assessment of impacts are being increasingly formalised and set as standards. This, we argue, is an important step as invasion science starts to mature as a discipline.

Keywords
CBD introduction pathway classification framework, Environmental Impact Classification for Alien Taxa (EICAT), invasive alien species, invasive species, Socio-Economic Impact Classification of Alien Taxa (SEICAT), Unified Framework for Biological Invasions

The origins, purposes, and challenges facing frameworks in invasion science

The study of biological invasions has a rich history of developing and refining hypotheses, frameworks, theories, and other conceptual constructs with the aim of assisting with resolving particular problems and in some cases moving beyond case studies (observations of a small number of invasive taxa, invaded habitats or invasion events) to arrive at generalisations or principles that apply more widely. These conceptual constructs often link insights from fundamental research to policy and management responses. Frameworks, in particular, are an important way to communicate concepts and ideas between people. As humans, we like to structure the world around us; to some extent frameworks are scientific models of how we think the world works that allow us to test our ideas, debate edge cases, and build new hypotheses. Just like any scaffolding, frameworks are intended to be built upon. Reviewing developments in "implementation science", Nilsen (2015) posits that a framework usually denotes "a structure, overview, outline, system or plan consisting of various descriptive categories, e.g., concepts, constructs or variables, and the relations between them that are presumed to account for a phenomenon". In this typology, frameworks are not explanatory but "only describe empirical phenomena by fitting them into a set of categories". Frameworks are especially useful when they are used to collate, organise, combine, simplify, and synthesise a large volume of new information; to classify and integrate insights from various perspectives and disciplines; to bridge gaps between science and policy and between disciplines; and to provide roadmaps to guide further research inquiries. These endeavours all rely on frameworks to circumscribe and classify the problem.

However, as invasion science originates from various discipline-specific questions and problems, attempts at circumscription and classification have arisen from multiple different origins. These differences in origin largely align with traditional disciplinary boundaries (zoology, botany, marine biology) and debates (e.g., utilisation vs. protection or humans as a part of nature vs. humans as a threat to nature). In consequence, there are a plethora of terminologies, differences in emphasis, and similar ideas are expressed in slightly different formats. Taking the development of hypotheses as an analogy, many hypotheses used to explain aspects of biological invasions overlap, some are vague, and some can be collapsed to general ecological theories that need not be related to biological invasions at all (Catford et al. 2009; Enders et al. 2020). Furthermore, as only a few hypotheses in invasion science have attracted sustained attention, few hypotheses have consistent and strong evidentiary support (Jeschke et al. 2012; Ricciardi et al. 2013; Traveset and Richardson 2020). As such, it is difficult to differentiate between hypotheses that provide insights into the processes at play and those that should not be the basis for developing scientific models and management recommendations as they are misleading (Crystal-Ornelas and Lockwood 2020).

The challenge for those working on invasion frameworks is similar–that of demonstrating the utility of frameworks, being clear as to the contexts under which particular frameworks apply, and adapting (or abandoning) frameworks in response to new evidence or needs. Frameworks are needed both to address particular specific problems, to improve general understanding, and ideally to facilitate the transfer of lessons learnt from the general to specific and vice versa (Lawton 1996). This tension between generalisation and utility is crucial [cf. invasion syndromes for one practical approach of addressing it (Novoa et al. 2020)]. The context-dependency of the biological invasions phenomenon means there is substantial value in taking an idiographic approach, i.e., studying case by case to uncover mechanisms and consequences (Simberloff 2004); tailored frameworks can be very valuable in such cases. However, a major goal of some frameworks has been to facilitate generalisations and comparisons across scales, taxa, and biological realms, and more broadly to formalise frameworks as standards that are intended to be used by all stakeholders involved (Box 1). For example, the so called Unified Framework for Biological Invasions aimed to link frameworks developed by botanists and zoologists (Blackburn et al. 2011); the EICAT impact classification framework (Blackburn et al. 2014), which has been recently adopted as a standard of the IUCN, aims to facilitate the measurement and reporting of invasive species impacts in a consistent manner (IUCN 2020) (Box 2); and the CBD has proposed an introduction pathway classification framework that bridges decades of debate on how invasive species are transported out of their native range (CBD 2014) (Box 3). These frameworks have been proposed to be incorporated into biodiversity standards (Groom et al. 2019) with a view to developing a standardised system for monitoring and reporting on biological invasions that can be applied across scales from local to global, across habitats from coral reefs to mountain tops, across taxa from fungi to ferns to frogs, and across pathways from hitchhikers on plastic debris to seeds sent through e-commerce (McGeoch and Jetz 2020). There is thus some evidence that invasion science is coalescing around a few frameworks and formalising them as standards (Boxes 1–3). However, the frameworks are still rarely explicitly used in practice (Wilson et al. 2020, this issue), and our experience when applying the most commonly cited frameworks to real data and situations has been that they are very useful but that there are a number of practical challenges to be resolved, some of which are fundamental to the field (see the section on 'Putting frameworks to the test' below).

So, are current frameworks fit for purpose? How do they perform in practice? Can they be adapted to deal with new contexts? Do they need to be revised and adapted to deal with new information? Can frameworks be linked together to facilitate the transfer of lessons learnt from the general to the particular? What gaps are there that need addressing?

Box 1. Moving from frameworks to standards.

A framework, in the sense used here, provides a structure on which other ideas or applications are built. Frameworks can often be used flexibly, with details modified so they fit particular contexts (Wilson et al. 2020, this issue). However, for a framework to be a tool that is routinely used and shared, then definitions and terms need to be fixed, and, ideally, guidelines for use formalised. In such cases a framework becomes a standard. Adopting a standard has several advantages, notably that it facilitates the exchange of data within science, represents an agreed basis for the communication of the issue to a wider community, and provides an incontrovertible basis for policy. Data standards allow us to aggregate, compare, communicate, validate, and share data. They may include entity relationships, term definitions, controlled vocabularies, and formats. They have to be used precisely if data are to be readable by a machine.

Frameworks and standards are both abstractions of the real world. The confrontation of a framework or standard with real world data can lead to the realisation that the framework or standard needs to be revised, that it only applies to specific contexts or that it is fundamentally not fit for purpose. However, while a framework might be informally updated or adapted to particular contexts, any change to a standard needs to be formally documented and ideally reviewed and discussed by other users, i.e., there should be a clear process for consulting on, and implementing, changes. There is thus an interplay of frameworks, standards, and the stakeholders using them that leads to an evolution of ideas and data (see Boxes 2, 3).

A leading organisation in the development of biodiversity standards is the Biodiversity Information Standards (https://www.tdwg.org/). This organisation is a heterogeneous group of biodiversity data managers created in response to the need to manage biodiversity data. It liaises with a wide variety of international individuals and organisations, such as the Research Data Alliance (https://www.rd-alliance.org/), the International Union for Conservation of Nature (https://www.iucn.org/) and its Invasive Species Specialist Group (http://www.issg.org/), and the Global Biodiversity Information Facility (https://www.gbif.org/).

Box 2. The IUCN's Environment Impact Classification for Alien Taxa (EICAT)–a standard for categorising alien species impact.

The EICAT can be used to classify alien taxa according to the magnitude of their impacts on native taxa, with impact magnitude based on the organisational level in the affected community. Impact categories range from Minimal Concern to Massive (IUCN 2020). If only individual performance is affected, it is considered a Minor impact; if a native taxon is removed from the community (locally extinct or extirpated), it is considered Major or Massive, based on the reversibility of the change (IUCN 2020). For more details see IUCN (2020), Kumschick et al. (2020a, this issue), and Volery et al. (2020, this issue).

The IUCN EICAT Standard is the product of a long process of developing and adapting frameworks to quantify impacts. EICAT has its origins in the Generic Impact Scoring System (GISS) which was first published by Nentwig et al. (2010). The idea of GISS was to develop a system capturing all kinds of impacts from all alien taxa and classifying them according to their magnitude. As the impacts of an increasing variety of taxa were scored using GISS, several issues emerged, including that the description of impact magnitudes was not always clear (Strubbe et al. 2011) and that the way scores were summed across different types of impact did not always make logical sense (Game et al. 2013). Blackburn et al. (2014) designed a new framework to address these issues, specifically by providing consistent descriptions of impact magnitudes for different types of environmental impact and by classifying taxa based on the maximum impact seen for any one type of impact.

In parallel to the development of these impact classification frameworks, the Parties to the CBD invited the IUCN SSC Invasive Species Specialist Group (ISSG) in 2014 "to develop a system for classifying invasive alien species based on the nature and magnitude of their impacts" (COP XII Decision 17), Guidelines were then developed for the application of the framework by Hawkins et al. (2015), and the name EICAT was suggested. The IUCN then conducted a global consultation process, developed a standard, and revised the guidelines in response to the comments and suggestions received. EICAT was also revised in the light of the experiences of those using it (e.g., Kumschick et al. 2017; Evans et al. 2018; Volery et al. 2020, this issue). A final version of the standard was accepted by the IUCN Council in February 2020, and the standard was launched and published in September 2020 (IUCN 2020).

Circumscribing the problem–the workshop

In light of rapid developments in the field, we decided it was important to take stock and assess the current state of frameworks used in invasion science. We invited a wide range of researchers focussing on biological invasions to a workshop to discuss, develop, and revise ideas. In particular, we asked prospective attendees to develop draft manuscripts before the meeting with the aim of formalising their thoughts and sharing

Box 3. The CBD's pathway classification framework–a standard for classifying the pathways along which alien species are introduced.

Similar to classifying impact (Box 2), the need to classify introduction pathways into a small number of practical categories to better communicate pathway information and improve the monitoring and regulation of those pathways has long been recognised (Puth and Post 2005; Lodge et al. 2006). In 2008, Hulme and others published a framework of six broad introduction pathways that endeavoured to be globally applicable, suitable for terrestrial and aquatic organisms, and relevant for policy and management. Parallel to this, the need to focus research and management to identify, prioritise, and manage pathways of invasive alien species was set as part of the Aichi Biodiversity Target 9 adopted by the CBD in 2010. To help facilitate the achievement of this target, in 2014, the CBD proposed an introduction pathway classification framework that was developed based on extending the framework proposed by Hulme et al. (2008) to include sub-categories that could facilitate inclusion of data in other databases [in particular the Global Invasive Species Database, the Invasive Species Compendium (ISC) of CABI, Delivering Alien Invasive Species Inventories for Europe (DAISIE), and peer-reviewed literature (CBD 2014)]. A manual was produced in 2017 to assist users with interpreting the categories (Harrower et al. 2017).

The framework proposed by the CBD has been applied in numerous settings, not least to integrate pathway information across major alien species databases (Saul et al. 2017). However, to achieve this without manual intervention the vocabulary needs to be further formalised and incorporated into digital data standards, i.e., set as a formal standard rather than just a framework. As part of this, the Invasive Organism Information Task Group of the Biodiversity Information Standards organisation has proposed changes to the Darwin Core to incorporate pathway information (Groom et al. 2019) [the Darwin Core aims to provide a stable standard reference for sharing information on biological diversity (Wieczorek et al. 2012)].

This is not, however, the end of the story. New recommendations for changes will have to navigate the, often circuitous, route to ratification (Pergl et al. 2020, this issue), and several major issues have emerged—the pathway framework is arguably Euro-centric in origin and use (Faulkner et al. 2020, this issue; Wilson et al. 2020, this issue), and the sub-categories do not have many of the desirable properties that an introduction pathway classification framework should have (Faulkner et al. 2020, this issue). So even after more than a decade, a high degree of consultation, and the framework verging on being adopted in a formal data standard used by the whole biodiversity community, the CBD's introduction pathway classification framework is likely not appropriate to all contexts where it is intended to apply, and it might need a substantive overhaul if this were to be achieved.

them in advance of the discussions. The workshop itself, 'Frameworks used in Invasion Science', was held 11–13 November 2019 in Stellenbosch, South Africa, and was hosted by the DSI-NRF Centre of Excellence for Invasion Biology (for details of the workshop and how the special issue developed see Suppl. material 1).

One of the main areas of discussion at the workshop was to define what is meant by a framework and to clarify the overall aim of such a framework. It was felt that frameworks should be useful, and the broader, the better. However, generalisations are only worthwhile if they do not come at the cost of the utility of the framework for its original purpose. Frameworks are often used for purposes for which they were not initially intended and in some cases for which they are not suited (see examples in Wilson et al. 2020, this issue). Frameworks created in one context and naively used in other contexts might mean important details are missed by those applying the frameworks or that the problem is made much more complicated than it actually is. In other words, the sensitivity and specificity of frameworks are not always clear.

Over the course of the workshop, the question 'What is a framework?' was repeatedly debated, with such debate providing a valuable anchor for our discussions. We eventually settled on the following working definition:

A framework is a way of organising things that can be easily communicated to allow for shared understanding or that can be implemented to allow for generalisations useful for research, policy, or management.

Building on this, we developed an overall goal of the workshop, dubbed 'the Stellenbosch Challenge for Invasion Science':

Can invasion science develop and improve frameworks that are useful for research, policy or management, and that are clear as to the contexts in which the frameworks do and do not apply?

Putting frameworks to the test

A major goal of the workshop was for participants to formalise their thoughts in manuscripts, and to 'stress-test' the frameworks–indeed a survey conducted as part of this special issue found that while invasion scientists feel some of the major frameworks are very influential, the frameworks still lack serious critical examination (Wilson et al. 2020, this issue). The 24 papers in this special issue revisit many of the philosophical underpinnings and practical challenges associated with attempts to integrate, reconcile, and synthesise thoughts and concepts in invasion science (Appendix 1).

In achieving these aims, this special issue, we argue, addresses the Stellenbosch Challenge. The papers address the utility of frameworks for research, policy, and management; they clarify the contexts in which the frameworks do and do not apply; and they discuss how the frameworks need to be developed and improved to facilitate shared understanding. In particular, the special issue addresses all these above issues with respect to the rapidly developing field of impact assessment.

Can invasion science develop and improve frameworks that are useful for research…

Several of the papers show how frameworks can structure and guide research. Pyšek et al. (2020, this issue) build on a rich literature on the macroecology of introductions, naturalisations, and invasions, to explicitly outline the factors that must be considered when studying invasions, viz. species, location, event, and their interactions. This highlights that the required level of complexity has not often been adequately elucidated in previous macroecological analyses, leading to a high probability of spurious results. By contrast, Liebhold et al. (2020, this issue) propose a potential way to reduce complexity. They argue that the two basic processes of population growth and dispersal underlie several phases of the introduction-naturalisation-invasion continuum, which means that similar models can be used across scales and stages, thereby simplifying the problem. The value of rethinking biological invasions is also addressed by Hulme et al. (2020, this issue), who show how reconnecting invasion science to the rich theory in epidemiology can improve both understanding and management. They show how viewing habitats as hosts could potentially change the way we manage invasive species, and argue that concepts such as super-spreaders, herd immunity, ring vaccination, and cordon sanitaire are all promising areas for future applied research on biological invasions.

...policy...

Frameworks also provide valuable systematic means to phrase policy goals. At a broad level Essl et al. (2020b, this issue) show how frameworks can underpin global goals and targets, specifically the proposed revised CBD biodiversity targets, and to ensure that the indicators to track such targets are based on agreed standards and methods. At a more local scale, Kumschick et al. (2020b, this issue) present a novel risk analysis framework that combines existing frameworks on impact assessment, pathway classification, and scoring of introduction status to produce a method that integrates international best practice with local contexts to provide recommendations for South African regulations. Datta et al. (2020, this issue) explore another policy area in more detail– how regulations should deal with taxa at levels other than the species, and in particular what is needed to regulate 'safe' cultivars of invasive horticultural plants. They develop the foundation on which a new framework to address this issue can be built.

…[and] management…

Many of the papers go beyond the policy arena and explicitly use frameworks to address pressing on-the-ground management issues. Bertolino et al. (2020, this issue) and Ziller et al. (2020, this issue) develop approaches to prioritising management efforts (for mammals in Italy and for control efforts in protected areas in Brazil respectively). Such prioritisation efforts build on information from risk and impact assessments and ecological studies. In the same vein, Latombe et al. (2020, this issue) provide insights for the allocation of biosecurity resources across a network (e.g., of countries, islands or lakes) which is in the process of being invaded. They combine a framework considering categories of abundance and extent with a metapopulation model to show how the efficacy of management and synchronisation in management efforts together can reduce spread rates. Brock and Daehler (2020, this issue) tried to classify the whole alien flora of Hawai'i according to the Unified Framework for Biological Invasions (Blackburn et al. 2011). They found that while much of the framework is conceptually sound, in practice, and for management, some categories needed to be merged and new ones created. By combining the revised framework with information from risk assessments they propose a monitoring tool that is tailored to address the needs of managers in Hawai'i and likely other countries as well.

…and that are clear as to the contexts in which the frameworks do and do not apply?

The context dependency in invasions is not always well addressed by existing frameworks, but is an explicit focus of several papers in the special issue. Potgieter and Cadotte (2020, this issue) examine the 'urban effect' on invasions within the context of existing frameworks, both by demonstrating how different barriers to invasions tend to be weaker in cities and how the impacts differ. Paap et al. (2020, this issue) explore available frameworks in invasion science in the context of forest pathology. They found that most studies of forest pathogens have been undertaken without any connection with, or consideration of, the frameworks of invasion science. They argue that this is a consequence of the mechanistic approach required in forest pathology to investigate specific interactions between hosts and pathogens, the aim being to control resulting disease problems. In terms of pathways, Pergl et al. (2020, this issue) test the utility of the CBD pathway classification in Europe and demonstrate how recently published guidelines provide clarity and can improve the usefulness of the framework. However, Faulkner et al. (2020, this issue) found that while the main categories of the CBD pathway framework have many desirable features, the sub-categories are not useful; they note that the current framework performs poorly in some non-European settings. They propose a hybrid approach, using broad categories for global generalisations and reporting, and context-specific categories to serve local needs and purposes.

A framework is a way of organising things that can…allow for shared understanding

A notable emerging feature of this special issue is that while the papers cover a wide range of topics, taxa, habitats, and environments, there is some evidence of a growing consensus. Together, the 24 papers of the special issue cite well over a thousand different publications, but many of the papers cite the same handful of frameworks (Fig. 1, Appendix 1). The authors of this special issue are certainly not divided into distinct camps that use different frameworks. The leading frameworks are widely cited and highly influential (Wilson et al. 2020, this issue). Moving forward, we posit that it is critical to ensure frameworks in invasions' science are designed to also respond to the multitude of growing, changing, and interacting global change drivers under which biological invasions are playing out. For example, Robinson et al. (2020, this issue) highlight how climate change will have dramatic and varied impacts on biological invasions that will require new ways of thinking, emphasising the imperative of collecting foundational data and monitoring change. And, as outlined by Sinclair et al. (2020, this issue), frameworks should be explicit in how humans affect biological invasions, and how biological invasions affect humans.

A developing standard for impact assessments

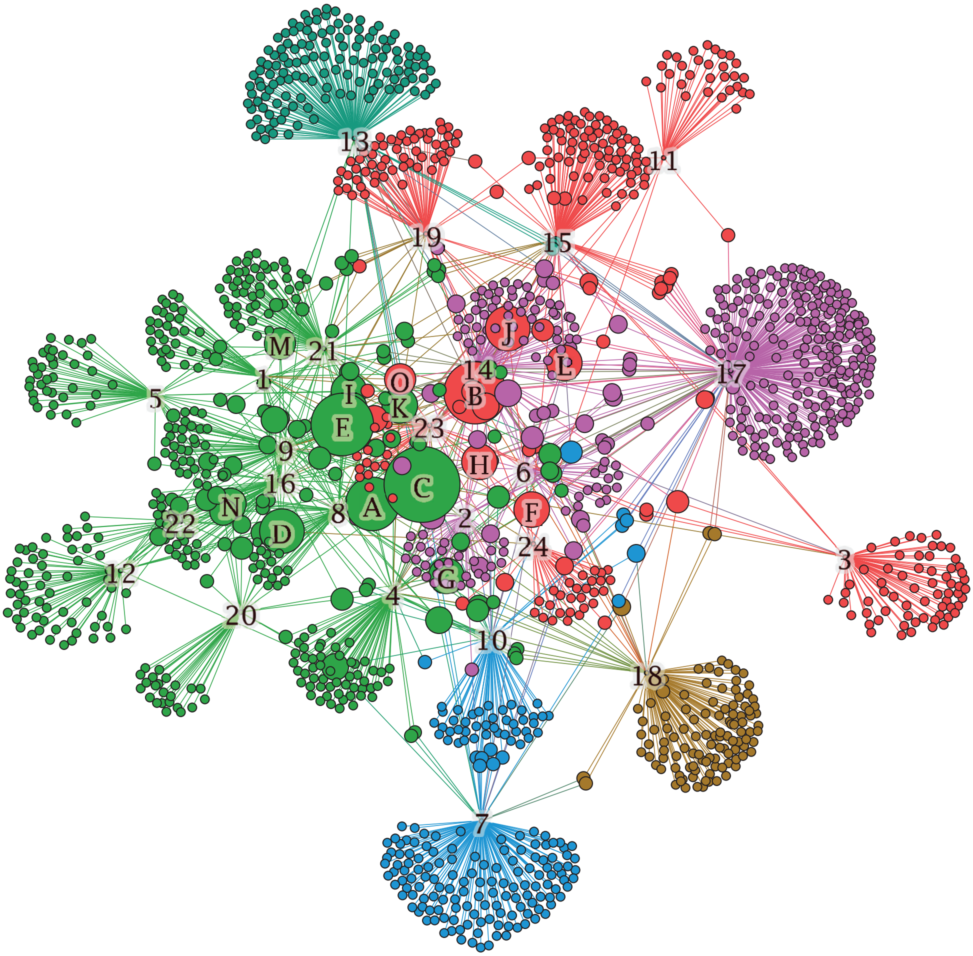
One of the major criticisms of invasion science has been that, at least historically, assessments of 'impact' magnitude have been subjective. However, recent developments in the field are explicitly addressing this (Simberloff et al. 2013; Blackburn et al. 2014; Bacher et al. 2018; Ireland et al. 2020). One of the main focus areas of the special issue, and one that cuts across the themes above, is the need to standardise impact assessments. Kumschick et al. (2020a, this issue) provide important insights on the dos and don'ts when using EICAT. Volery et al. (2020, this issue) build on the developing global experiences of applying EICAT and on feedback that emerged from an extensive IUCN consultation exercise to update guidelines for using EICAT. Probert et al. (2020, this issue) provide recommendations on how to categorise uncertainty in ICAT assessments (i.e., both EICAT and SEICAT). Invasion scientists appreciate the benefits alien species provide to society (Ewel et al. 1999). However, for practical purposes, most impact assessments focus on negative impacts. Vimercati et al. (2020, this issue) examine which frameworks in invasion science have considered positive impacts of alien taxa and argue that a systematic understanding of all types of impact is important for management and regulatory decisions. The test of such frameworks is, of course, when they are applied in practice. Van der Colff et al. (2020, this issue), using data on gastropods, demonstrate how EICAT assessments and Red List assessments provide complementary information valuable to evaluations of the impact of biological invasions on native biodiversity; they recommend that both should be used to inform policy and management decisions.

The more one looks, the more impacts are found

Evans et al. (2020, this issue) apply SEICAT to alien bird impacts and Measey et al. (2020, this issue) update EICAT and SEICAT assessments for amphibians providing the first detailed assessment of the cost of the research on which impact assessments are based. They both show that data on impact are limited and that varying levels of data availability have the potential to create biases–if an invasion is poorly studied (e.g., due to a lack of resources to conduct a detailed investigation of impact) the current recorded impact will likely be considered to be lower than it actually is. However, both studies agree that a major benefit of the ICAT frameworks is that they make data needs explicit; they also show that these frameworks serve an important function in directing and guiding research. On this point, Kumschick et al. (2020a, this issue) recommend that decision makers should use EICAT in conjunction with information on how likely it is that current recorded impact is underreported or the likelihood of significant increases in negative impacts in future.

A hierarchy of frameworks

While each paper in the special issue tackles specific parts of the Stellenbosch Challenge and draws from particular frameworks (Appendix 1), the frameworks themselves are not explicitly linked. At the workshop there was substantial discussion on whether the Stellenbosch Challenge could be satisfied by the creation of a single all-encompassing framework. However, there was general consensus that the frameworks do not always align, nor should they be forced to do so (cf. the comparison of EICAT and the Red List by Van der Colff et al. 2020, this issue). There was agreement that it is more realistic to aim for a hierarchy of frameworks where important contextual detail is nested within the overarching ideas, rather than aiming for an 'über-framework' that tries to embrace all contexts. The analogy with hypotheses in invasion science is again pertinent. Jeschke and Heger (2018) very elegantly demonstrate the value of the hierarchy of hypotheses approach to organise ideas within invasion science. A similar approach to frameworks in invasion science would help clarify how frameworks constructed to re-



spond to particular needs or contexts are related to each other, how they can share ideas and approaches, and to identify gaps where new frameworks might be valuable. We present a tentative sketch of the inter-connection of existing frameworks in Figure 2.

At a broad scale (Fig. 2A), frameworks in invasion science should link to other drivers of global change (Robinson et al. 2020, this issue, #18 on Fig. 2A), other areas of biological research (7. Hulme et al. 2020, this issue; 13. Paap et al. 2020, this issue), and to societal issues more generally (15. Potgieter and Cadotte 2020, this issue). These linkages can be made within the understanding that biological invasions can be viewed through the prism of pathways, species or sites (4. Essl et al. 2020b, this issue). These linkages can also be made recognising that the phenomenon involves bio-geographical and ecological processes (e.g., the introduction-naturalisation-invasion continuum), that there are environmental and societal impacts (e.g., the ICAT frameworks), and

Figure 1. A citation network of papers within this special issue. Each node represents an article, with the node radius proportional to the number of citations. Citations between papers within the special issue have been excluded, and this editorial was not included at all. Numbered nodes are papers in the special issue (Appendix 1) and lettered nodes are the 15 articles that were cited six or more times in the network. The colours represent different modularity classes of the network (the light green one appears to be related to impact assessments). Of the 1520 papers cited 87.2% were only cited by one paper in special issue, and less than 1% were cited by four papers. This network can thus be seen as indicative of a wide-ranging field linked by a few key frameworks, though the nature of the special issue and the authors involved means there are some significant biases and self-selections occurring (which, we expected, would have biased the network towards being more connected than it would otherwise be). The network was built in Gephi (0.9.2). **A** Bacher et al. (2018), Socio-economic impact classification of alien taxa (SEICAT); https://doi.org/10.1111/2041-210X.12844 **B** Blackburn et al. (2011); A proposed unified framework for biological invasions; https://doi.org/10.1016/j.tree.2011.03.023 **C** Blackburn et al. (2014); A Unified Classification of Alien Species Based on the Magnitude of their Environmental Impacts; https://doi.org/10.1371/journal.pbio.1001850 **D** Evans et al. (2016); Application of the Environmental Impact Classification for Alien Taxa (EICAT) to a global assessment of alien bird impacts; https://doi.org/10.1111/ddi.12464 ental Impact Classification for Alien Taxa (EICAT); https://doi.org/10.1111/ddi.12379 **F** Hulme et al. (2008); Grasping at the routes of biological invasions: a framework for integrating pathways into policy; https://doi.org/10.1111/j.1365-2664.2007.01442.x **G** Latombe et al. (2017); A vision for global monitoring of biological invasions; https://doi.org/10.1016/j.biocon.2016.06.013 **H** McGeoch et al. (2016); Prioritizing species, pathways, and sites to achieve conservation targets for biological invasion; https://doi.org/10.1007/s10530-015-1013-1 **I** Nentwig et al. (2016); The generic impact scoring system (GISS): a standardized tool to quantify the impacts of alien species; https://doi.org/10.1007/s10661-016-5321-4 **J** Richardson et al. (2000); Naturalization and invasion of alien plants: concepts and definitions; https://doi.org/10.1046/j.1472-4642.2000.00083.x **K** Seebens et al. (2017); No saturation in the accumulation of alien species worldwide; https://doi.org/10.1038/ncomms14435 **L** Wilson et al. (2009); Something in the way you move: dispersal pathways affect invasion success; https://doi.org/10.1016/j.tree.2008.10.007 **M** Pyšek et al. (2008); Geographical and taxonomic biases in invasion ecology; https://doi.org/10.1016/j.tree.2008.02.002 **N** Kesner and Kumschick (2018); Gastropods alien to South Africa cause severe environmental harm in their global alien ranges across habitats; https://doi.org/10.1002/ece3.4385 **O** Harrower et al. (2017); Guidance for interpretation of CBD categories on introduction pathways.

that biological invasions pose societal challenges that require political and management responses. These three issues (biogeography, impacts, and interventions) arguably form the core of invasion science (Fig. 2B). However, these issues are not always congruent. For example, while impact, abundance, and geographical distribution are often correlated, alien species can have massive negative impacts without forming a naturalised or invasive population (Ricciardi et al. 2013), and widespread, abundant invaders ['successful' as per 10. Latombe et al. (2020, this issue)] might have negative impacts scored as *Minor* or *Minimal Concern* under the ICAT frameworks (Ricciardi and Cohen 2007). Also, while pathways of introduction represent an important elucidation of the first stage of the invasion process, they do not necessarily map neatly on to pathways of spread within a region (6. Faulkner et al. 2020, this issue; 14. Pergl et al. 2020, this issue, 11. Liebhold et al. 2020, this issue). It is important, therefore, to ensure that the domain of applicability and relevance of each framework is clear, and that if linkages are made these are done without compromising the original purpose for which the framework was constructed. As an example, a recent effort to link interventions to the introduction-naturalisation-invasion continuum forces management terms on to invasion stages and barriers, conflates activities, goals, and objectives, and in so doing neglects the primary purposes of the framework, which is to facilitate interventions (Robertson et al. 2020).

Finally, it is important to zoom into on-the-ground management needs to ensure that there are frameworks that can be used to improve our understanding and management of particular issues (one example is shown in Fig. 2C). Context-specific frameworks are needed: for management prioritisation in Italy and Brazil (1. Bertolino et al. 2020, this issue; 24. Ziller et al. 2020, this issue); to support decisions regarding the listing of alien species under South African regulations (9. Kumschick et al. 2020b, this issue); to provide clarity regarding the risks and appropriateness of regulating horticultural cultivars (3. Datta et al. 2020, this issue); and to ensure that the monitoring of alien plant species in Hawai'i is relevant to management (2. Brock and Daehler 2020, this issue). It might be possible to extend such frameworks to similar contexts, but ultimately if those frameworks are not well suited to the problem they were designed to address, then they need to be adapted or abandoned.

The need to zoom in and out to different spatial or thematic scales is currently being developed further by workshop participants with a view to producing a hierarchy of frameworks. Parallel to this work, workshop participants are reviewing the history of frameworks in invasion science and developing a typology to classify them. Finally, participants felt a natural conclusion of the workshop would be to refine and recast some existing frameworks. Specifically, participants suggested that the frameworks used to classify populations according to their stage along the introduction-naturalisation-invasion continuum (Blackburn et al. 2011) and the CBD's introduction pathway classification framework (Box 3) deserved renewed attention. We believe that this special issue provides a necessary precursor to these important products.

Gaps

We could, of course, not address all issues related to invasion frameworks at the workshop or in this special issue. There are notable gaps in the implementation of existing frameworks that deserve much more attention, for example the need for: frameworks to be modified so that they are relevant to different ecological contexts (e.g., freshwater, marine, micro-organisms); a way to incorporate expert opinion in transparent and standardised ways; and methods to apply frameworks when biogeographic and administrative boundaries do not align. There is also a need to consider if existing frameworks can be applied to address broader issues such as invasions at the gene level and range shifts resulting from climate change or other human modifications of the environment (e.g., managed relocation, assisted migrations). These gaps in the ability of frameworks to deal with different contexts impact our ability to monitor and report on invasions [e.g., see Zengeya and Wilson (in press) for South Africa].

Biological invasions are a central factor in global environmental change as they impact, and are impacted by, climate, ecosystem functions and services, and species extinction (Vitousek et al. 1997; Ricciardi et al. 2017). One potential avenue for further work is to try to link frameworks in

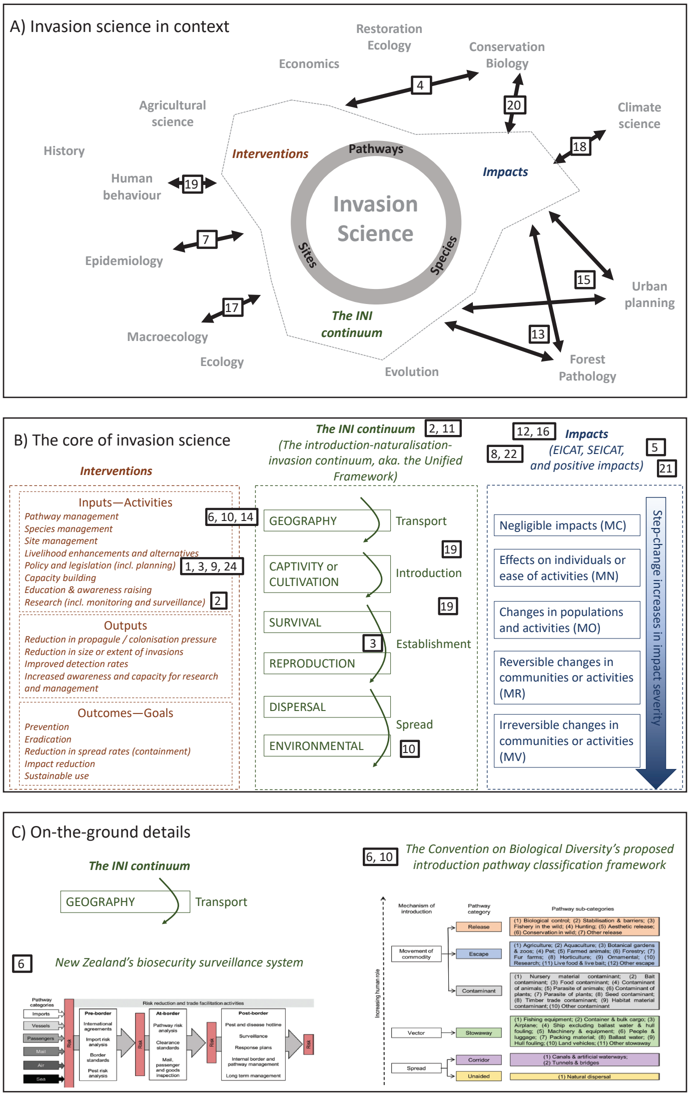


Figure 2. A tentative hierarchical structure linking frameworks in invasion science. Three levels are proposed here, though details at the finest level are only shown for one component—the part of the Unified Framework that addresses transport across the geographic barrier. Numbers represent papers in the special issue as per Appendix 1 and are placed according to how they fit in with the existing frameworks. Papers touch on multiple aspects and different hierarchical levels. However, each paper is only indicated once on the diagram at the place we feel it contributes the most; except for 19. Sinclair et al., which, to highlight how some studies are cross-cutting, is plotted on levels A and B, and, as the paper also discusses how the transport process should be viewed as a coupled-human natural system (CHANS), it could arguably have been plotted on level C as presented here as well. At level B (the core of invasion science), there are well established frameworks for the impacts of species and the introduction-naturalisation-invasion continuum, but there are no equivalent well recognised frameworks for interventions (or the impacts on sites). The intervention activities shown are based on the categories used by the Cambridge Conservation Forum framework for evaluating projects with the addition of a pathway management activity (Kapos et al. 2008).

invasion science more clearly to broader issues within conservation biology, community ecology, evolutionary biology, and global environmental change. Similarly, alien species are now regularly incorporated into foundational ecological and evolutionary science as ‘probes’ that can effectively test core tenets in these fields (e.g, Strauss et al. 2006; Vellend et al. 2007; Guisan et al. 2014) and ‘biological assays’ to test dominant paradigms in biogeography (Rouget et al. 2015). If invasion frameworks are to facilitate interdisciplinarity they must be clearly articulated by invasion scientists in collaboration with researchers in other fields to ensure that the definitions and processes that these frameworks capture can be understood and adopted across the various disciplines. However, of the ~110 authors of this special issue, we estimate around 70% would describe themselves as having biological invasions as a main interest or responsibility and about two-thirds are primarily based at a university. All but a handful are ecologists, highlighting the ongoing need for better integration with other disciplines and the social sciences in particular. When invasion frameworks do not successfully bridge disciplines and provide a link between research and implementation, then it seems inevitable that there will be points of confusion and tension (Richardson and Ricciardi 2013), leading to the reinvention or 'creative' use of terminology within allied fields (Essl et al. 2020a; Wilson 2020), and lost opportunities for reciprocal advancement in knowledge (Hulme 2014). We see this articulation between disciplines using invasion frameworks as particularly pertinent given the expected massive shift in species ranges due to climate change and the increasing frequency with which we are confronted with emerging infectious diseases in human and non-human populations (Ogden et al. 2019; Nunez et al. 2020).

Finally, if, as per our working definition, a framework should “…be easily communicated to allow for shared understanding…” then at least some frameworks should also be valuable aids for communicating between invasion scientists and the people and industries that are impacted (negatively and positively) by alien species. Arguably, one of the most effective communication tools in invasion science is the invasion curve [The invasion curve is a roughly logistic shaped curve of ‘area infested’ or something similar plotted against time. It is split into different stages with different management actions highlighted. It is perhaps best exemplified by the version of the Department of Primary Industries (2010)]. However, this simplifies the issue and so is not useful as a framework in practice. Similarly, the impact equation of Parker et al. (1999) captures the essence of the problem—impact is the product of the range size of a species, its abundance per unit area, and the effect per individual or per biomass unit——but is also not easy to implement in practice (Blanchard et al. 2011). Many frameworks within the field of invasion science might be primarily about facilitating communication between invasion scientists, however it will be valuable to also have frameworks that clarify key aspects of biological invasions in a way that links the ‘nuts and bolts’ of invasions with societal priorities, and to create or modify frameworks in invasion science so they are easily understood not just by scientists, policy makers, and managers, but also by broader stakeholders.

Conclusion

It appears from the set of articles in this special issue that invasion science is maturing as a distinct discipline. The process of developing, refining, and increasingly implementing frameworks suggests the field is moving from ‘storming’ to ‘norming’ [to paraphrase a framework from psychology (Tuckman 1965)]. If we assume that trends in globalisation will continue, as seems almost certain, there is now strong evidence that the taxonomic variety and number of species that have the opportunity to establish as aliens somewhere on Earth will continue to rise (Seebens et al. in press). In this context, frameworks in invasion science should be viewed as tools that are worthwhile only if they are used and are useful. It is important that frameworks are increasingly tested (be it within policy, research or management settings) and any limitations clearly shared with others in and outside the field. We suspect that the overriding importance of context in invasion science will continue to be the rule rather than the exception, and that frameworks will need to adapt to these contingencies to remain useful. We consider this approach to be encompassed by the 'Stellenbosch Challenge for Invasion Science'. We believe the articles within this special issue (Appendix 1) show how responding to this challenge can improve our understanding of, and responses to, biological invasions.

Postscript

The urgent need to reduce carbon emissions meant that several people decided not to attend the workshop in person. Moreover, the review and revision of the articles published in this special issue happened against the backdrop of the COVID-19 pandemic (Nunez et al. 2020). While face-to-face workshops like the one described here might be less common in future, we hope that they will soon be possible again. A beautiful venue, good food, and stimulating company will not resolve biological invasions, but they make the process that bit more enjoyable (Figure 3).

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Figure 3. Workshop attendees benefitting from the shade of an alien *Eucalyptus* sp. on a transformed lawn.

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Supplementary material 1

Details of the workshop, the invitation, list of attendees, the programme, ground rules, form for highlighting case-studies, and the process for compiling the special issue

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Data type: explanatory text

Explanation note: additional information regarding the workshop 'Frameworks used in Invasion Science' held 11–13 November 2019 in Stellenbosch, South Africa, hosted by the DSI-NRF Centre of Excellence for Invasion Biology, and the special issue of NeoBiota on frameworks in invasion science that emerged from it.

Link: https://doi.org/10.3897/neobiota.62.58738.suppl1

Appendix 1

Table A1. The papers in this special issue on 'Frameworks in Invasion Science' with the details of the frameworks they consider, which aims of the special issue they address, and a summary of key findings or recommendations.

	Paper	Frameworks considered[1]	Aims[2]	Findings / Recommendations
1	Bertolino et al. (2020) A framework for prioritising present and potentially invasive mammal species for a national list. https://doi.org/10.3897/neobiota.62.52934	• *CBD pathway classification* • *EICAT* • *SEICAT*	5, 7	• "We developed a prioritisation process for alien mammals already established in Italy…(n = 6 species) and a systematic horizon-scanning procedure to obtain ranked lists for those species that are already introduced worldwide or traded in Italy (n = 213) and which are likely to establish, spread and impact on biodiversity and human well-being." • "…the procedure developed in this study could be used as a blueprint for similar prioritisation initiatives…according to different priorities established by country regulations or policies."
2	Brock and Daehler (2020) Applying an invasion and risk framework to track non-native island floras: a case study of challenges and solutions in Hawai'i. https://doi.org/10.3897/neobiota.62.52764	• *Hawai'i–Pacific Weed Risk Assessment* • *Unified Framework*	1, 4, 5	• The unified framework has limitations as a tracking system for entire alien floras—both too detailed for practical use, and the category 'naturalised but not invasive' can indicate both low and high priority for management. • Propose a revised system for tracking status along the introduction-naturalisation-invasion continuum. • Incorporating information from weed risk assessment frameworks can provide insights for management.
3	Datta et al. (2020) Identifying safe cultivars of invasive plants: six questions for risk assessment, management, and communication. https://doi.org/10.3897/neobiota.62.51635	• None (though follows the generic process of a risk analysis as one composed of risk identification, assessment, management, and communication)	7	• "…clarify the issue of distinguishing 'safe' cultivars from 'risky' relatives by recasting the problem as a set of six questions that align with the risk analysis process" o Has an infra- or inter-specific entity of an invasive entity been proposed as 'safe to use'? o Which traits are different between the non-invasive and invasive entities? o Do the trait differences lead to a significant difference in invasion risk? o Are the differences spatially and temporally stable? o Can the entities be distinguished in practice? o How can the risks and the management of them be best communicated?
4	Essl et al. (2020) The Convention on Biological Diversity (CBD)'s Post-2020 target on invasive alien species – what should it include and how should it be monitored? https://doi.org/10.3897/neobiota.62.53972	• *CBD pathway classification* • *EICAT* • *SEICAT* • *Red List* • *Indicator frameworks*	1, 3, 5, 6	• A target on biological invasions should "…explicitly consider[s] the three main components of the phenomenon of biological invasions, i.e. (i) pathways, (ii) species, and (iii) sites…; (iv) is quantitative…; (v) is supplemented by a set of indicators that can be applied to track progress; and that it (vi) can be evaluated at medium- (2030) and long-term (2050) time horizons". • Proposes the following target: "Halting the loss of biodiversity caused by invasive alien species by 2030, by preventing their impacts in [100% of] the most vulnerable areas, regulating [50% of] the most harmful invasive alien species, and effectively managing [50% of] the most significant pathways of introduction, such that their impacts are reversed through restoration and recovery by 2050." • Provides recommendations for proposed indicators to track progress towards meeting the target.
5	Evans et al. (2020) Application of the Socio-Economic Impact Classification for Alien Taxa (SEICAT) to a global assessment of alien bird impacts. https://doi.org/10.3897/neobiota.62.51150	• *SEICAT*	1, 6	• "…SEICAT can be used effectively to quantify and categorise the impacts of alien species on human well-being." • "The most significant problem… was a lack of impact data." • Most significant threat to human well-being is impacts on aviation safety; most data described agricultural impacts. "No data were found describing disease transmission impacts on humans." Suggests the availability of impact data is biased to developed countries. • Notes that SEICAT is important for stimulating and directing research.

	Paper	Frameworks considered[1]	Aims[2]	Findings / Recommendations
6	Faulkner et al. (2020) Classifying the introduction pathways of alien species: are we moving in the right direction? https://doi.org/10.3897/neobiota.62.53543	• *CBD pathway classification* (main and sub categories) • *New Zealand biosecurity surveillance system*	2, 3, 6	• Identifies five desirable properties for the categories used in an introduction pathway classification framework 'Compatible', 'Actionable', 'General', 'Equivalent', and 'Distinct'. • "…the main categories of the CBD framework have all of the desirable properties…but the sub-categories have few". • Proposes scenarios for improving existing frameworks and recommends "a hybrid model—a few general categories at the global scale and context-specific sub-categories driven by local needs at a regional level".
7	Hulme et al. (2020) The Epidemiological Framework for Biological Invasions (EFBI): an interdisciplinary foundation for the assessment of biosecurity threats. https://doi.org/10.3897/neobiota.62.52463	• *SIR models* • *State-and-Transition model*	7	• "The EFBI approach presents a new biosecurity perspective that takes account of ecosystem status and complements demographic models to deliver clearer insights into the dynamics of biological invasions at the landscape scale." • "The basic epidemiological compartment model can…provide insights… for the monitoring, mapping and management of non-native species."
8	Kumschick et al. (2020) Appropriate uses of EICAT protocol, data and classifications. https://doi.org/10.3897/neobiota.62.51574	• *EICAT*	2, 3, 6	• "Standardising and globalising the process of impact assessment within a framework, such as EICAT, can aid countries…to develop policies and priorities for tackling biological invasions". • "…present guidelines designed to clarify and facilitate the appropriate use of EICAT…as well as to guide research and communication more generally". • "…deviations from the standard process should be adequately described and acknowledged to avoid confusion with the official, standardised process."
9	Kumschick et al. (2020) A framework to support alien species regulation: the Risk Analysis for Alien Taxa (RAAT). https://doi.org/10.3897/neobiota.62.51031	• *EICAT* • *SEICAT* • *CBD pathway classification* • *Unified framework* • *Confidence rating* • *Eradication feasibility*	3, 5, 7	• Proposes a new risk analysis framework for alien taxa: "1) given major recent developments in international frameworks dealing with biological invasions (including the scoring of impacts); 2) so that decisions can be made consistently across taxa, regions, and realms; 3) to explicitly set out uncertainties; and 4) to provide decision-makers with information both on the risks posed and on what can be done to mitigate or prevent impacts." • Outlines how the framework has been tested and applied to support decisions regarding the listing of alien taxa under South Africa's regulations on biological invasions.
10	Latombe et al. (2020) The effect of cross-boundary management on the trajectory to commonness in biological invasions. https://doi.org/10.3897/neobiota.62.52708	• *Categories of commonness*	1, 4	• Proposes an additional two categories to the existing eight categories of commonness: 'dispersed + abundant somewhere' and 'sparse + abundant somewhere'. • Compares the value of improving the efficacy of biosecurity vs. how quickly countries implement biosecurity against a particular threat. • "... [under certain conditions] synchronisation across spatial units will improve the efficacy of management". • "...time lags in population growth…[should] be considered explicitly for management, as they can amplify the efficacy of such measures."
11	Liebhold (2020) Scale invariance in the spatial-dynamics of biological invasions. https://doi.org/10.3897/neobiota.62.53213	• *"stratified diffusion"* • *"bridgehead effect"* • *Unified framework*	7	• "...all [invasion] stages biologically ensue from just two demographic processes—dispersal and population growth" • "...different invasion stages [arrival, establishment, and spread] can be considered manifestations of similar processes operating at different spatial scales". • "...future frameworks may be able to incorporate these similarities in a simpler structure."

	Paper	Frameworks considered[1]	Aims[2]	Findings / Recommendations
12	Measey (2020) The cost and complexity of assessing impact. https://doi.org/10.3897/neobiota.62.52261	• *EICAT* • *SEICAT* • *study designs* (e.g. BACI, randomised control trials)	1, 6	• "…studies that resulted in higher impact scores were more costly…we need to carefully consider whether species with low scores represent true impact, or require more research investment and time." • Suggests the availability of impact data is biased to developed countries. • "…a relatively short period of time (less than four years) is enough to make considerable changes to the global list of EICAT and SEICAT amphibian scores."
13	Paap et al. (2020) Harmonising the fields of invasion science and forest pathology. https://doi.org/10.3897/neobiota.62.52991	• *Unified framework* [cf. Wingfield et al. (2017)] • *CBD pathway framework* • *EID frameworks* • *EICAT*	2, 6	• Invasion frameworks are not widely applied in the study of forest pathology as historically the focus of the field has been on controlling the resulting disease problems rather than understanding how invasions arise. • Advances in molecular technologies increase the "visibility" of microorganisms, and will facilitate productive collaborations between pathologists and other invasion scientists.
14	Pergl et al. (2020) Applying the Convention on Biological Diversity Pathway Classification to alien species in Europe. https://doi.org/10.3897/neobiota.62.53796	• *CBD pathway classification*	1, 4	• "...the CBD Pathway Classification framework offers a robust, hierarchical system suitable for the classification of alien species introduction and spread…However, simple modifications could improve interpretation of the pathway categories ensuring consistent application across databases and information systems at local, national, regional, continental and global scales…[and] in the development of pathway action plans." • The CBD Pathway Classification framework should be used jointly with the guidance of Harrower et al. (2017). • Several specific recommendations, e.g., "…if the contaminated substratum is itself a commodity and a vector, then the assigned pathway should fall in the Contaminant category. However, if the contaminated substratum is only a vector (physical or biological), then the assigned pathway should fall in the Stowaway category".
15	Potgieter and Cadotte (2020) The application of selected invasion frameworks to urban ecosystems. https://doi.org/10.3897/neobiota.62.50661	• *EICAT* • *SEICAT* • *Unified Framework*	1, 6	• "In urban areas, the relative effectiveness of the barriers to invasion is diminished (to varying degrees) allowing a greater proportion of species to move through each subsequent invasion stage, i.e. 'the urban effect' on invasion." • "Impact classification schemes inadequately circumscribe the full suite of impacts (negative and positive) associated with invasions in urban areas." • "We suggest ways of modifying these frameworks to improve their applicability to understanding and managing urban invasions."
16	Probert et al. (2020) Understanding uncertainty in the Impact Classification for Alien Taxa (ICAT) assessments. https://doi.org/10.3897/neobiota.62.52010	• *EICAT* • *SEICAT* • *Uncertainty classification*	2, 4	• "We identify three types of biases…not captured by the confidence score…biases in the existing data, data collection, and data assessment." • "Clarifying uncertainty concepts relevant to [the ICAT frameworks] will lead to more consistent impact assessments and more robust intra- and inter-specific comparison of impact magnitudes".
17	Pyšek et al. (2020) MAcroecological Framework for Invasive Aliens (MAFIA): disentangling large-scale context dependence in biological invasions. https://doi.org/10.3897/neobiota.62.52787	• None though various frameworks are discussed and have elements of MAFIA (e.g., *TEASI* and *PAB*)	3, 6, 7	• Note that as invasion are a result of "Alien species traits, Location characteristics, and Event-related factors", then "For a successful invasion, all factor classes and their interactions need to be favourable (Species × Location × Event)." • Recommend that all these factors and their interactions must be explicitly considered in macroecological analyses of invasions, otherwise spurious conclusions will be reached.

	Paper	Frameworks considered[1]	Aims[2]	Findings / Recommendations
18	Robinson et al. (2020) Double trouble: the implications of climate change for biological invasions. https://doi.org/10.3897/neobiota.62.55729	• *CBD pathway classification* • *Invasion syndromes* • *Unified framework*	6	• Climate change will have varied, and in some cases unpredictable, effects on biological invasions across the introduction-naturalisation-invasion continuum. • Our understanding of the implications of climate change for biological invasions would be improved by: o more foundational research (including on taxonomy); o a greater appreciation of context-dependency and tools to address it explicitly; o data and analytical tools at the appropriate resolution; and o more inter-disciplinary work.
19	Sinclair et al. (2020) Reciprocal human-natural system feedback loops within the invasion process. https://doi.org/10.3897/neobiota.62.52664	• *Propagule pressure as a null model* • *Human Adaptation to Invasive species*	1, 6, 7	• "…invasion frameworks generally do not consider reciprocal interactions between non-native species and people… [but] 'coupled human and natural system' (CHANS) could…play a key role in mitigating…or exacerbating…ongoing and future invasions". • People in source regions (the supply-side) influence which taxa are introduced and how. • The way people interact with non-native species changes over time and can lead to unexpected emergent effects. • The study of CHANS in the context of biological invasions is in its infancy, but CHANS can have important implications for policy and management.
20	Van der Colff et al. (2020) Comparing the IUCN's EICAT and Red List to improve assessments of the impact of biological invasions. https://doi.org/10.3897/neobiota.62.52623	• *EICAT* • *Red List*	1, 2, 5	• "The EICAT and Red List schemes will benefit each other if information underpinning their assessments is made available and shared." • The EICAT and Red List statuses are only closely correlated in special circumstances. In most cases the two frameworks are complementary rather than equivalent, and both should be used to assess impacts.
21	Vimercati et al. (2020) The importance of assessing positive and beneficial impacts of alien species. https://doi.org/10.3897/neobiota.62.52793	• *EICAT* • *Biopollution assessment scheme* • *EICAT* • *GISS* • *impacts of invasive marine species* • *InSEAT* • *Invasive species assessment protocol* • *A prioritisation tool for IAS management* • *SEICAT*	2, 6	• Provides a summary of frameworks assessing beneficial impacts. • Reviews papers arguing for greater inclusion of positive impacts (both from value-free and value-laden perspectives). • Existing frameworks should be extended to include positive impacts.
22	Volery et al. (2020) Improving the Environmental Impact Classification for Alien Taxa (EICAT): a summary of revisions to the framework and guidelines. https://doi.org/10.3897/neobiota.62.52723	• *EICAT*	3, 4	• Details changes made to the EICAT framework and guidelines in response to the IUCN's consultation process in terms of: o definitions (performance rather than fitness; defining population, sub-population, and local population); o impact categories (distinguishing between Major and Massive impacts); o impact mechanisms (to deal with indirect impacts, transmission of disease, and hybridisation); o presentation of overall impact (spatial and geographic scales of assessments, and using maximum ever recorded impact rather than current impact); and o dealing with uncertainty (confounding effects, study design, and temporal scale).

	Paper	Frameworks considered[1]	Aims[2]	Findings / Recommendations
23	Wilson et al. (2020) Is invasion science moving towards agreed standards? The influence of selected frameworks. https://doi.org/10.3897/neobiota.62.53243	• *Hulme et al (2008)* • *CBD pathway classification* (main categories) • *Unified Framework* • *EICAT*	2	• The frameworks are cited by researchers from across the world working on different taxa and in different habitats, and they are increasingly being taken up into invasion policy and management. However, roughly half of all citations might be viewed as frivolous or 'citation fluff'. • A survey of those who cited the frameworks found that while the frameworks are highly regarded, many respondents felt the frameworks have not been rigorously tested yet. • To increase uptake, the frameworks need to be revised or adapted to particular contexts, guidelines for their usage developed, and there should be incentives for their usage.
24	Ziller et al. (2020) A priority-setting scheme for the management of invasive non-native species in protected areas. https://doi.org/10.3897/neobiota.62.52633	• None, though various other prioritisation frameworks are discussed; the definitions used align with those of the *Unified Framework*; and *EICAT* is proposed as a data source	7	• Presents a management prioritisation system for biological invasions that is being applied by managers of protected areas in Brazil. • "Priorities are calculated from…species risk of invasion (R), invasion stage (S), and species frequency for each occurrence (F)". • "As per the prioritisation scheme, the highest priorities for control were attributed to species of high invasion risk in early stages of invasion restricted to one location"

[1]The frameworks / concepts used as cited in the papers are: *Biopollution assessment scheme* (Olenin et al. 2007); *Bridgehead effect* (Lombaert et al. 2010); *Categories of commonness* (McGeoch and Latombe 2016); *CBD pathway classification* (CBD 2014; Harrower et al. 2017), and also *Hulme et al. (2008)*; *Confidence rating* (as cited by Hawkins et al. 2015); *EICAT* (the Environmental Impact Classification for Alien Taxa) (Blackburn et al. 2014; Hawkins et al. 2015; IUCN 2020); *eradication feasibility* (Panetta and Timmins 2004; Wilson et al. 2017); *the Hawai'i–Pacific Weed Risk Assessment* (Daehler et al. 2004) *the Human Adaptation to Invasive Species framework* (Howard 2019); *indicator frameworks for biological invasions* (McGeoch et al. 2010; Latombe et al. 2017; Wilson et al. 2018) see also sTWIST – Theory and Workflows for Alien and Invasive Species Tracking (https://www.idiv.de/en/stwist.html); *invasion syndromes* (Novoa et al. 2020); *Invasive species assessment protocol* (Morse et al. 2004); *INvasive Species Effects Assessment Tool (InSEAT)* (Martinez-Cillero et al. 2019); *impacts of invasive marine species* (Katsanevakis et al. 2014); *the New Zealand biosecurity surveillance system* (Ministry of Agriculture and Forestry (MAF) Biosecurity New Zealand 2008); *a prioritization tool for IAS management* (Kumschick et al. 2012); *propagule pressure as a null model* (Colautti et al. 2006); the *TEASI* (Transport, Establishment, Abundance, Spread, Impact) framework (Leung et al. 2012); the *PAB* (Propagule pressure, Abiotic characteristics, and Biotic characteristics) framework (Catford et al. 2009); *the IUCN Red List* (IUCN Standards and Petitions Committee 2019); *SEICAT* (the Socio-economic Impact Classification of Alien Taxa) (Bacher et al. 2018); *state-and-transition models* (Bestelmeyer et al. 2017); *stratified diffusion models* (Hengeveld 1989); *study designs* (Christie et al. 2019); *SIR models* (Susceptible-Infectious-Resistant compartment model) (Blackwood and Childs 2018); a *classification of uncertainty framework* (Regan et al. 2002); and the *Unified Framework* (for Biological Invasions) (Blackburn et al. 2011).

[2]The aims were adapted and expanded from those of the original advert for the meeting (see Suppl. material 1). As listed here they are: 1) apply the frameworks to new data or contexts; 2) review how the frameworks have been adopted and used; 3) develop useable protocols or guidelines for applying frameworks to different contexts; 4) refine the frameworks; 5) integrate frameworks; 6) identify gaps; and 7) develop new frameworks. Several of the papers addressed multiple aims, but the special issue as a whole addressed all of them fairly evenly (each aim is addressed by between five and eleven papers).