Human-predator conflict in the South African fly-fishing industry: fish survival probabilities and stakeholder perceptions

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Submitted in fulfilment of the requirements for the degree Master of Science (Zoology)

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DECLARATION

I, Marié de Vos, declare that the dissertation, which I hereby submit for the degree MSc 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………………………………………………………….

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by

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ABSTRACT

The aquaculture and fishing industries have a long history of human-wildlife conflict (HWC), involving a miscellany species ranging from birds to mammals, and fishes to reptiles. Effectively mitigating HWC requires research to focus on both wildlife management as well as the human-side of the conflict, for despite the variety of species and circumstance involved, human opinions and actions will ultimately decide the outcome of conflicts.

South Africa has a well-established fly-fishing industry, mainly based on non-native fishes such as brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*). Some stakeholders in the industry have expressed their concerns that piscivorous predators, such as otters (*Aonyx capensis* and *Hydrictis maculicollis*) and cormorants (mostly *Phalacrocorax carbo lucidus*) are detrimentally impacting fish stocks. In order to obtain a more complete view on HWC in the South African fly-fishing industry my research consisted of two components. Firstly, I investigated countrywide stakeholder perceptions of HWC in the fly-fishing industry. Secondly, I studied the survival of fish stocks at a fly-fishing property near Dullstroom in Mpumalanga Province, and assessed predator preference of water bodies at this study site.

A questionnaire indicated that an overlap of human- and wildlife interests certainly occurs in the South African fly-fishing industry, with all respondents (n = 22) reporting that they experience stock losses to predators. However, the perceived extent of predator-induced losses varied greatly between individual respondents. Otters, cormorants, African fish eagles, and herons were commonly reported piscivorous predators on fly-fishing

properties. Cormorants and otters are the predators most likely to be involved in conflicts as they are seen to pose the highest threat and are most often targeted by mitigation measures. Respondents reported to employ mitigation measures in 55 % of responses with shooting (both lethal and non-lethal) being the most common measure. Catch-and-release angling was reported to be highly prevalent at fly-fishing properties in South Africa.

Using a mark-recapture approach, I investigated the survival probabilities of rainbow trout stocked in a comparatively large water body, as well as trout stocked in two smaller water bodies. I found high short-term (weekly) apparent survival probability (Phi) of fish stocked in both large (Phi = 0.97) and smaller water bodies (Phi = 0.93), while annual survival probability was low for both sites. This likely indicates that C&R has limited effects on fish survival at this study site, as most mortalities attributable to C&R have been found to occur within 48 h post-release. Low long-term survival is likely due to factors including predation, water quality, food availability, temperature and rainfall. Fish stocked in the larger water body had nearly nine times the annual survival probability (Phi = 0.18) of fish stocked in the smaller water bodies (Phi = 0.02). Otters were most prevalent at the smaller water bodies and are potentially capitalizing on the easy foraging opportunity provided by high fish numbers in relatively small confines. In contrast, avian predators were most prevalent at the large water body, possibly due the location being more distant to areas of high human disturbance.

Despite the negative impacts of trout introduced for fly-fishing purposes, the habitat that these properties provide to many indigenous species should be considered when environmental regulations pertaining to the fly-fishing industry are made. However, for these properties to provide a continuous habitat for piscivorous predators, ways of mitigating HWC that are both beneficial for fish predator conservation as well as the economics of the fishing property are needed.

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CHAPTER ONE: GENERAL INTRODUCTION

Human-Wildlife Conflict in the Aquaculture and Fishing Industries

Human-wildlife conflict is as old as humanity itself – in Africa, San rock art provide record of humans fleeing from large animals, and historical records from Egypt, dating back to 2000BC, reveal that hippopotamuses pillaged crops while crocodiles predated on livestock in the Nile Delta (Lamarque *et al.* 2009). Today, human-wildlife conflict is considered one of the most extensive and troublesome obstacles facing conservation efforts (Dickman 2010). The rapidly expanding human population is leading to continuing increases of conflict, as human needs for food, habitat and other resources progressively overlap with those of wildlife (Browne-Nuñez & Jonker 2008).

Conflicts between humans and wildlife are prevalent in both developed and developing countries and include a miscellany of species and circumstances, ranging from birds eating crops (e.g. Bruggers 1980) to lions predating on livestock and sometimes even people (Packer *et al.* 2005; Kissui 2008). The diversity of cultures, circumstances, and social views and beliefs further complicates the human-side of these conflicts (White & Ward 2010; Young *et al.* 2010; Marzano *et al.* 2013). In many cases what were once cases of conflict between humans and wildlife have progressed into conflicts between people harbouring different views (reviews by Madden 2004; Marzano *et al.* 2013). Counter-intuitively, conservation efforts can sometimes exacerbate human-wildlife conflicts or generate negative attitudes towards conservation (e.g. Mishra 1982; McGregor 2005; Heinen & Shrestha 2006). A key example is the case of great cormorants (*Phalacrocorax carbo*) in Europe. In the early 20th century, human persecution drove populations of the continental subspecies of great cormorant (*P.c. sinensis*) to near extinction, with fewer than 5,000 known breeding pairs left in the whole of Netherlands, Germany, Sweden, Denmark and Poland during the early 1970's (Bregnballe 1996; Frederiksen *et al.* 2001). Protection for the species was established in the 1970's and 1980's and their population in Europe expanded to at least 285,000 pairs by 2006 (Bregnballe *et al.* 2011). This remarkable population increase is considered by many to be a nature conservation success, however stakeholders from the fisheries and angling sectors are continually emphasising the negative impacts of cormorants on their livelihoods or lifestyles (van Eerden *et al.* 2003). There is increasing acknowledgement that research towards solving conflicts between wildlife and humans (and between people of different views), need to not only focus on wildlife management, but also on the human-side of the conflict (Baruch-Mordo *et al.* 2009).

The aquaculture and fishing industries have a long history of human-wildlife conflict, with piscivorous species considered either an active threat or at least a nuisance with regards to fish stocks (e.g. Mills 1967; Adamék *et al.* 1997; Kloskowski 2011). Avian predators, in particular, have been a recognized economic threat to fisheries for over 300 years (Mills 1967). Although the cormorant has become the poster-child of human-wildlife conflict in aquaculture, numerous species spanning a range of taxa are involved in aquaculture related conflicts. In Africa, human conflicts with crocodiles (mainly *Crocodylus niloticus*) are not restricted to livestock losses or the loss of human life - crocodiles also do considerable damage to fishing nets, and are often seen as competitors to subsistence fisheries (e.g. McGregor 2005; Aust *et al.* 2009). American white pelicans (*Pelecanus erythrorhynchos*) pose a threat to catfish farms in the United States, both by active predation on fish stocks as well as transmission of trematode infections and other diseases (overview by King 2005). Seals are frequently involved in conflicts with fisheries around the globe, and cause problems at fish farms as well as in the line- and net fishing industries (e.g. Wickens *et al.* 1992; Bjørge *et al.* 2002; Northridge *et al.* 2013; Cosgrove *et al.* 2013).

South Africa has a well-established and widespread inland fly-fishing industry that provides jobs and income to some of the poorest and most rural regions of the country (du Preez & Lee 2010). Fly-fishing has also been identified as having potential for pro-poor local economic development initiatives (du Preez & Lee 2010). Several small towns situated at high altitudes, have developed tourism-based economies centred around fly-fishing that is based mainly on introduced fishes such as rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) – Dullstroom in the Province of Mpumalanga, and Rhodes in the Eastern Cape Province are prime examples. The popularity of rainbow trout and brown trout as sport-fish have seen their introduction to at least 82 countries across the globe (Welcomme 1988), and these species were introduced to South Africa in the 1890's (Pike 1980; Cambray 2003). According to a survey conducted by du Preez & lee (2010) rainbow trout followed by brown trout where the species most sought after by anglers visiting Rhodes. The fly-fishing industry supports a vast array of economic endeavours including tackle manufacturers and retailers, travel agents and specialised accommodation, as well as professional fishing guides and instructors (du Preez & Lee 2010). There are concerns that government legislation which calls for the eradication of trout from certain ecosystems as well as increased regulation of trout stocking (to curb the environmental impacts on native species), could damage the tourism potential of many South African catchments (du Preez & lee 2010).

The miscellany of negative environmental effects pertaining to the introduction of non-native fishes for recreational purposes are well known (trout reviewed in Cambray 2003), however it should be recognized that the fly-fishing industry does hold certain environmental benefits that other land-use practices such as crop farming, mining, plantations or residential development might not. For example, the industry is dependent on water quality to ensure the survival of fish stocks, and therefore strives towards pollution-free waters on fishing properties. In contrast, the negative effects of pesticides and fertilizers, often used in crop farming, on groundwater and surface water are well-documented. Similarly, fly-fishing and nature-based tourism in Dullstroom, Mpumalanga is ecologically far more sustainable than the proposed coal mining operations, which jeopardizes both the environmental integrity of the region as well as tourism-based jobs (Leonard 2016; Conesa 2010). Other forms of land use such as tree plantations are, similarly to fly-fishing, often associated with areas of high rainfall and high altitudes, but which can lead to reductions in streamflow, particularly in the dry season (Scott et al. 1998; Dye & Versfeld 2007).

In the Dullstroom, Mpumalanga area, some stakeholders in the fly-fishing industry have expressed concerns that fish predators are damaging their fish stocks. Dullstroom, only about two-and-a-half hours' drive from South Africa's capital, Pretoria, is a prime fly-fishing and tourism location with fly-fishing mostly focused on stocked rainbow trout and brown trout (discussed in more detail in chapter three, under 'study site'). Concerns are seemingly mostly about cormorants and otters, and a 2015 pilot study on a trout-fishing estate near Dullstroom, Mpumalanga, indicated that African clawless otters (*Aonyx capensis*) were indeed consuming more trout than expected based on previous studies (de Vos 2015, unpublished, Appendix B). Stocking trout is a large expense of fishing-properties, and also the basis of their profits, and it is therefore understandable that predator-induced losses (both perceived and actual) is an urgent management concern. The management of the fly-fishing property used as my study site in chapter three, were especially concerned about apparent decreases in the number of fish angled over the past few years, despite increased stocking. Based on these concerns and the evidential lack of literature on HWC in the South African fly-fishing industry my research encompassed the following aims:

- Assess the perceptions of stakeholders in the South African fly-fishing industry towards fish predators.
    - Based on the concerns voiced by fly-fishing property managers, which spurred this research, and the near universality of HWC in the fishing industry, I predicted wide-spread reports of predator-induced losses to fish stocks with fish predators perceived as an extensive threat to fish stocks.
- Estimate the survival and recapture probabilities of rainbow trout (*O. mykiss*) in selected still waters on a fly-fishing estate.
    - Given the reports of decreasing numbers of fish landed over the past few years at the study site, as well as the potential impacts of catch-and-release angling on fish health, I predicted low recapture and survival probabilities for rainbow trout at the study site.
- Investigate daytime visitation rates of fish predators to selected still waters on a fly-fishing estate.
    - I predicted daytime visitation rates of predators to be negatively correlated with angling effort due to the disturbance posed by human presence. Similarly I predicted that waters closer to sources of human-disturbance will have lower predator visitation rates.

Specific research questions and predictions relating to above mentioned aims are included in the relevant chapters. Qualitative data on the perceptions of fly-fishing industry stakeholders towards fish predators were collected by means of a questionnaire that was made available online, or, if the stakeholder preferred, was conducted telephonically. A mark-recapture approach was taken to obtain information on fish survival and recapture probabilities on a fly-fishing estate near Dullstroom, Mpumalanga, and was employed over two fieldwork sessions of nine and seven weeks respectively. During these fieldwork sessions I also collected observational data on the daytime visitation rates of potential fish predators to the study sites.

Dissertation Structure

The research for this study is presented over four chapters; chapter one provides a brief literature review on the background information pertaining to this study and serves as a general introduction to my dissertation. Chapter one broadly summarizes the main aims of my research and the methodology followed. The research conducted on the perceptions of fly-fishing industry stakeholders towards fish predators is presented in chapter two, while chapter three encompasses the research done on fish survival and recapture estimates, as well as on predator visitation rates. A summary and conclusion is provided in chapter four and this is followed by the reference list and appendices.

CHAPTER TWO: STAKEHOLDER PERCEPTIONS OF FISH PREDATORS IN THE SOUTH AFRICAN FLY-FISHING INDUSTRY

Abstract

In order to effectively resolve human-wildlife conflicts (HWC) research incorporating both wildlife management and the human-side of HWC is needed. Literature on HWC in the South African fly-fishing industry is extremely sparse, yet managers of several fly-fishing properties in Mpumalanga, South Africa, have expressed concerns about otter and cormorant damage to fish stocks. This study aimed to investigate the perceptions of stakeholders in the South African fly-fishing industry towards fish predators and some of the management strategies utilised. A questionnaire indicated that an overlap of human- and wildlife interests certainly occurs in the South African fly-fishing industry, with all respondents (n = 22) reporting that they experience stock losses to predators. However, the perceived extent of predator-induced losses varied greatly between individual respondents. Otters, cormorants, African fish eagles, and herons were commonly reported piscivorous predators on fly-fishing properties. Cormorants and otters are the predators most likely to be involved in conflicts as they are seen to pose the highest threat and are most often targeted by mitigation measures. Respondents reported to employ mitigation measures in 55 % of responses with shooting (both lethal and non-lethal) being the most common measure. Catch-and-release angling was reported to be highly prevalent at fly-fishing properties in South Africa. Concerns about government legislation pertaining to the invasion status of trout likely contributed to the low response rate, indicating a need to reconcile legislation and science with stakeholder views.

Introduction

A miscellany of species and circumstances are entangled in human-wildlife conflict (HWC), but one factor is common to all – human opinion and action will, in the end, dictate the path and outcome of the conflict (Manfredo & Dayer 2004). Research efforts endeavouring to solve human-wildlife conflicts have often been centred on wildlife management, but there is increasing recognition of the need to incorporate research on the human-side of HWC in order to effectively resolve conflicts (Baruch-Mordo *et al.* 2009). Human-wildlife conflict endangers human lives and livelihoods, increases management costs, and deleteriously impact conservation efforts (Woodroffe *et al.* 2005). The understanding of standpoints and beliefs underlying HWC can provide valuable insights that can be implemented to formulate alternative management options (Baruch-Mordo *et al.* 2009).

Aquaculture has seen HWC arising between fisheries and marine and semi-aquatic carnivores (Baker *et al.* 2008), and recreational anglers often view piscivorous predators as competition for sport fish (e.g. Čech & Vejřík 2011; *et al.*Almeida *et al.* 2012). For example, in Poland otters (*Lutra lutra*), cormorants (*Phalacrocorax carbo*), and grey heron (*Ardea cinerea*) are among the fish predators perceived to cause substantial damage to pond fisheries (Kloskowski 2011). However, opinions regarding fish predators can vary greatly, sometimes regardless of actual losses (e.g. Kloskowski 2005a), and owners' and managers' perception of the threat posed by wildlife to fish stocks is likely to be biased based on economic interest and conspicuousness of the damage (Conover 2001a; Kloskowski 2005a). Despite the possible inaccuracy of owners' views on the economic threats posed by wildlife (Freitas *et al.* 2007), knowledge of the perceived threats is nonetheless essential as these perceptions may play a crucial role when methods to reduce predator-related losses are chosen (West & Parkhurst 2002). Lethal methods are often perceived as the best measure to reduce damage caused by otters and cormorants (e.g. Kloskowski 2011; Poledníková *et al.* 2013), and Kloskowski (2011) found that fisheries who perceived predator damage to be extensive were more likely to deploy lethal measures.

Methods to mitigate predation losses can be categorized into three broad strategies: physically preventing predator access to the resource, managing predator populations, and managing the resource targeted by predators (Glahn *et al.* 2000). Despite the assortment of damage prevention methods that exist, the feasibility and success of mitigation attempts are greatly dependent on the physical properties of the fisheries and water bodies involved (e.g. Quick *et al.* 2004). Non-lethal methods, such as frightening and physical exclusion, are often considered ineffective or economically unfeasible (e.g. Littauer *et al.* 1997; Kloskowski 2005) and opinions regarding the efficacy of a method can vary greatly (e.g. the use of seal scarers at salmon farms; Quick *et al.* 2004).

While literature on conflicts between inland fishing interests (commercial, subsistence and recreational) and piscivorous predators in Africa is noticeably sparse compared to many other parts of the world, there are some reports available in the literature. For example, conflict between local fishermen and spotted-necked otters (*Hydrictis maculicollis*) have been reported in Benin, where otters prey on fish caught in nets and also damage fishing equipment (Akpona *et al.* 2015). Butler (1994) reported that African clawless otters (*Aonyx capensis*) were suspected of being responsible for declining trout catches in a stocked river in Zimbabwe, however a faecal dietary analysis showed this to be unlikely. A study on white-breasted cormorants (*P. c. lucidus*) at Lake Malawi reported some overlap in fish taken by cormorants and fishermen, but concluded that cormorants had no significant impact on commercial or traditional fisheries at the time (Linn & Campbell 1992).

Managers of several fly-fishing properties in Mpumalanga, South Africa, have expressed concerns about otter and cormorant damage to fish stocks. Both species of otters native to South Africa are facing conservation threats - spotted-necked otters are listed as Near Threatened on the IUCN Red List of Threatened Species (Reed-Smith *et al.* 2015), and are regionally listed as Vulnerable on the Mammal Red List of South Africa, Lesotho and Swaziland (Ponsonby *et al.* 2016), while African clawless otters are listed as Near Threatened both globally (Jacques *et al.* 2015) and regionally (Okes *et al.* 2016). The IUCN lists habitat loss and especially the degradation of freshwater ecosystems as major threats to both otter species (Jacques *et al.* 2015; Reed-Smith *et al.* 2015). Fly-fishing properties likely provide valuable (albeit not always natural) habitats for otters and other piscivorous species, but their utilisation of these habitats could be in jeopardy if otters are perceived as serious threats to stocked fish. Information on the prevalence of fish predators at fly-fishing properties can serve as a first step towards determining the importance of these properties in terms of habitat provisioning. Furthermore, knowledge on the perceptions of stakeholders toward fish predators in the fly-fishing industry is important to inform appropriate mitigation action and, if needed, to ensure the continued availability of these habitats to wildlife such as otters.

In their review on co-managing human-wildlife conflicts, Treves *et al.* (2006) presented a step-by-step process for traversing the social, political and strategic aspects of managing HWC. The process is based on three main steps, and includes the objectives and critical components of each step (Treves *et al.* 2006). Step one focusses on baseline research (locations and timing of conflicts, different human participants, and participant perceptions), step two entails participatory planning (identifying shared objectives and deciding on interventions to implement), and finally monitoring and assessing the success of interventions makes up step three (Treves *et al.* 2006).

This particular section of my research draws on step one of the Treves *et al.* (2006) process for managing HWC – namely identifying the spread (in terms of both geography and species involved) of HWC in the South African fly-fishing industry and investigating the perceptions of fly-fishing property owners and managers. I constructed a questionnaire to investigate this, and the questionnaire was made available online, or, if the stakeholder so preferred, was conducted telephonically. By the inclusion of this section in my study I aimed to achieve a more complete assessment of HWC in the fly-fishing industry of South Africa. Specifically the questionnaire was aimed at achieving the following:

- Assess the perception and attitude of fly-fishing estate managers and/ or owners towards fish predators (e.g. otters, cormorants, fish eagles).
    - Given the concerns voiced by managers of fly-fishing properties in Mpumalanga, I postulated that the questionnaire will result in reports of wide-spread predator-induced stock losses and that fish predators are seen as an extensive threat to fish stocks. I furthermore expected cormorants and otters to be seen as the predators posing the highest threat to fish stocks, as concerns voiced to date has mainly centred on these animals.
- Investigate which control or mitigation measures are being implemented to reduce predation on fish stocks.
    - In light of the findings of Kloskowski (2011), who investigated human-wildlife conflict at pond-fisheries, I expected lethal methods to be the most commonly used measures to reduce predation of fish stocks.
- Investigate management strategies pertaining to fish stocks (e.g. stocking practices and catch-and-release (C&R) angling).
    - Catch-and-release angling is an increasingly common practice world-wide (Cooke & Cowx 2004; ICES 2013; Gargan *et al.* 2015) and I therefore postulated that it is also widely practiced at South African fly-fishing properties.

Methods and Materials

The questionnaire was arranged into three sections, the first section related to demographic and geographic elements, the second section investigated fish predators, mitigation measures, and the respondent's perception of these, and section three contained questions on catch-and-release practices. In total, 33 questions made up the questionnaire, and completion time was roughly 10 – 15 minutes for both the telephonic and online versions (see Appendix A for questionnaire or https://goo.gl/ooYugu). Fly-fishing properties were identified by means of internet searches as well as referrals. Properties were contacted via e-mail and asked to participate in the survey by either completing the online version of the questionnaire or, if so preferred, by means of telephonic interview. The option of telephonic interviews was included as telephone surveys are believed to be superior to visiting interviewees or to postal surveys when it comes to obtaining information on potentially sensitive issues (i.e. such as predator control methods) (Sellitz *et al.* 1965; Brace 2004). E-mails were followed up with phone calls in an effort to increase participant numbers, and also to reduce the nonresponse bias where people more interested in the matters included in the questionnaire are more likely to respond (McKinstry & Anderson 1999; Conover 2001b).

A total of 103 fly-fishing properties were identified by these means. E-mails were sent to 98 properties for which email addresses were available. Emails were sent in batches, with each batch incorporating 20-30 properties in no particular order (randomly picked from a list of properties) and all within three days of the first round of emails being sent. This process was followed to avoid bias pertaining to the order in which the questionnaires were distributed to properties. As only 98 contactable properties were discovered in my search, I did not apply any method of random selection or additional filters to reduce the number of properties to a smaller sample, and instead contacted all properties. From the initial round of emails, 11 responses relevant to the study were obtained. A further round of emails containing a link to an online version of the questionnaire resulted in 3 further responses. By telephoning fly-fishing properties I was able to obtain 8 additional responses, bringing the total number of respondents to 22.

Telephone interviews and interpretation of answers from the online questionnaire was done only by myself, to ensure consistency in interpretation. Ethical clearance was obtained to engage human participants from the Faculty of Natural and Agricultural Sciences Ethics Committee (Reference number: EC 160721-060; Appendix A).

Data Analyses

Descriptive statistics were used to provide a summary of the information gained from the questionnaire responses. Differences in the perceptions of respondents belonging to different age groups, different levels of experience, and respondents from different provinces, were investigated by means of chi-square tests. When the expected values of contingency cells were smaller than 5, a Fisher's exact test was used. I similarly used chi-square tests (or Fischer's exact tests) to investigate whether there were differences in the reported presence/absence of individual predator species between the different provinces and between properties with or without rivers/streams. Google forms were used to capture responses while Microsoft Excel 2013 and SPSS version 24.0 (IBM Corp, 2017) were used to sort and analyse the data.

Results

Demographics

The majority of responses were made by stakeholders who have been involved in the fly-fishing industry for 10 years or more (64 %) (hereafter 'experienced respondents'), while 36 % of respondents have been involved for less than 10 years (hereafter 'less experienced respondents'). Respondents were predominantly male (n = 19), and I obtained only three responses from females. No respondents were younger than 25 years of age, and the majority of respondents were older than 40 years of age (77 %, Fig. 1). The provinces of Mpumalanga (MP) and KwaZulu-Natal (KZN) were both represented by seven responses each, while three responses each came from the Western Cape (WC) and Gauteng (GP), and one response each was obtained from the Eastern Cape (EC) and Free State (FS) provinces respectively. The provinces other than KZN and MP, where amalgamated for analysis purposes and are henceforth referred to as "Other Provinces". The sizes of the fishing properties represented by respondents varied greatly – the smallest property was 9ha and the largest 4000 ha, and mean property size was 1059.8 ha (SE 293.46). A river or a stream was present on 68 % of the properties represented. The number of dams per property varied greatly, as did the sizes of the dams (Appendix A, Table A1)

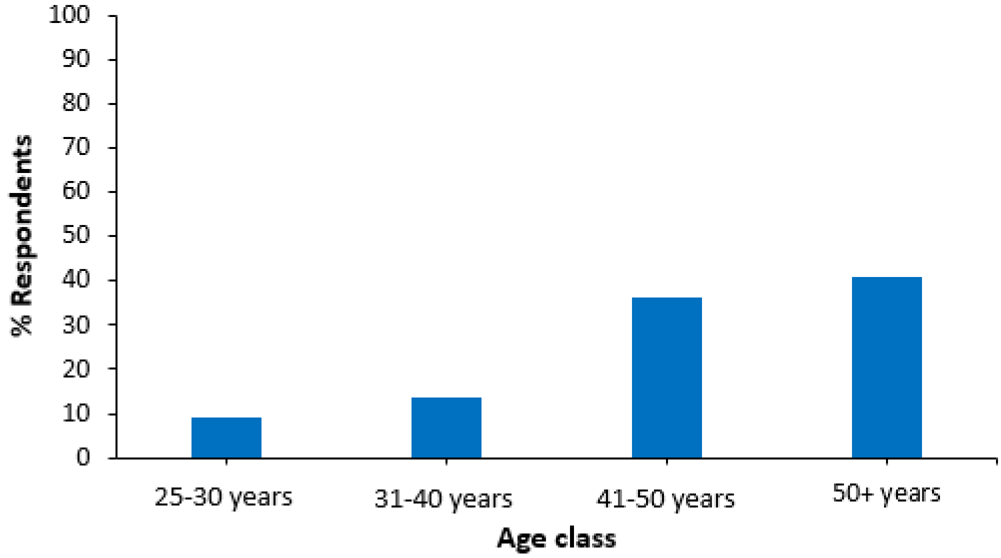

Figure 1: Age class distribution of respondents.

<u>Stakeholder Perceptions</u>

All respondents reported to be experiencing fish losses to predators. Respondents had varying perceptions as to the extent of predator-induced fish losses – 33 % of respondents perceived losses to be small, 38 % as medium, and 29 % perceived losses as extensive in relation to other sources of fish losses such as disease or angling induced mortality. KwaZulu-Natal had the most respondents who perceived fish losses to be extensive (43 %) followed by the Other Provinces (38 %) and lastly MP (33 %) (Fig. 2). However, there were no significant differences in the overall perceived levels of losses between respondents from different provinces (Fischer's exact test, $p = 0.68$).

Experienced respondents rated fish losses as extensive in 43 % of responses, while none of the less experienced respondents perceived losses as being extensive (Fig. 3). A Fischer's exact test showed that there was no significant difference overall in the level of predator-induced fish losses perceived by more experienced respondents compared to less experienced respondents (Fischer's exact test, $p = 0.48$), nor between properties that did or did not have a stream or a river (Fischer's exact test, $p = 0.84$).

Predator prevalence (in terms of all predator categories) was highest for KZN respondents, followed by respondents from MP and then the Other Provinces (Fig. 4). However, Fischer's exact tests revealed no statistically significant differences in the absence or presence of different predators between provinces (Table 1, $p > 0.05$).

Otters (*A. capensis* and *H. maculicollis*), cormorants (mostly *P. c. lucidus*), African fish eagles (*Haliaeetus vocifer*), and herons (mostly *Ardea cinerea*) were commonly reported piscivorous predators on properties (Fig. 5). Respondents rated the perceived threat level of the respective predators on a level of 1-5, with 1 constituting no threat, while 5 constituted a very high threat to fish stocks. Otters obtained a mean perceived threat level of 3.12 (SE 0.25), cormorants 3.33 (SE 0.29), fish eagles 1.74 (SE 0.23), and herons 2.00 (SE 0.27).

Respondents believed that fish predators attract guests or contribute to guest experience in 59 % of the responses, while 23 % felt that predators did not attract guests, and 18 % of the respondents were unsure of the attractive value of predators. However, of the respondents that believed fish predators to have attractive value, only 23 % felt that this attraction compensated for predator-induced fish losses Twenty-three percent felt that this compensated for losses to some extent, while 54 % felt that it did not compensate for fish losses. Of the experienced respondents, 64 % felt that predators have attractive value, while 50 % of less experienced respondents believed that fish predators attract guests. A Fischer's test found no significant difference between more experienced and less experienced respondents' views on the overall attractive value of predators (Fischer's exact test, $p = 0.72$). Similarly, no significant difference was found in the views of respondents from different provinces (Fisher's exact test, $p = 0.43$).

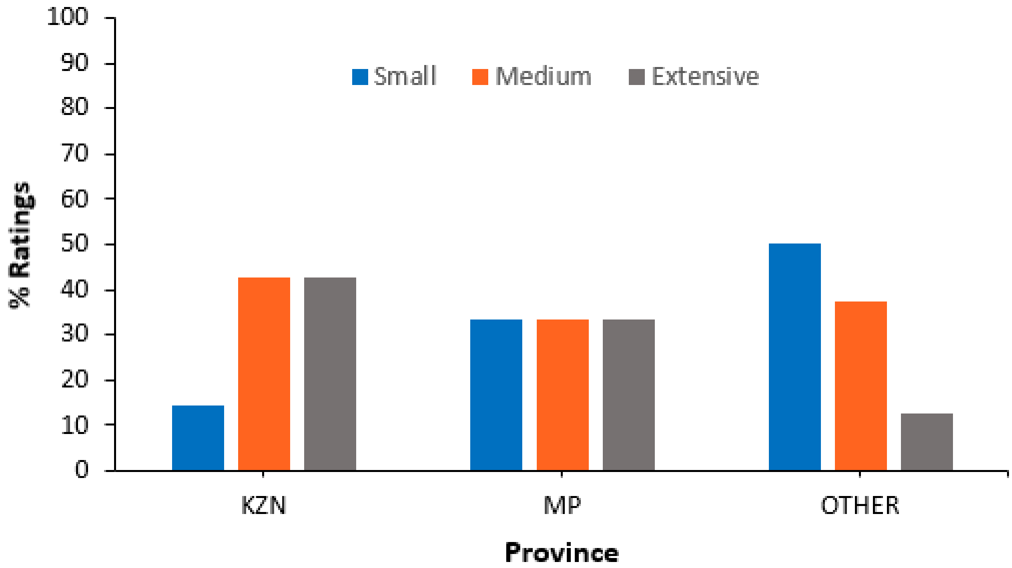

Figure 2: The percentage of small, medium, and extensive predator damage ratings given by respondents from KwaZulu Natal (KZN), Mpumalanga (MP) or 'other' provinces (Free State, Western Cape, Gauteng and Eastern Cape).

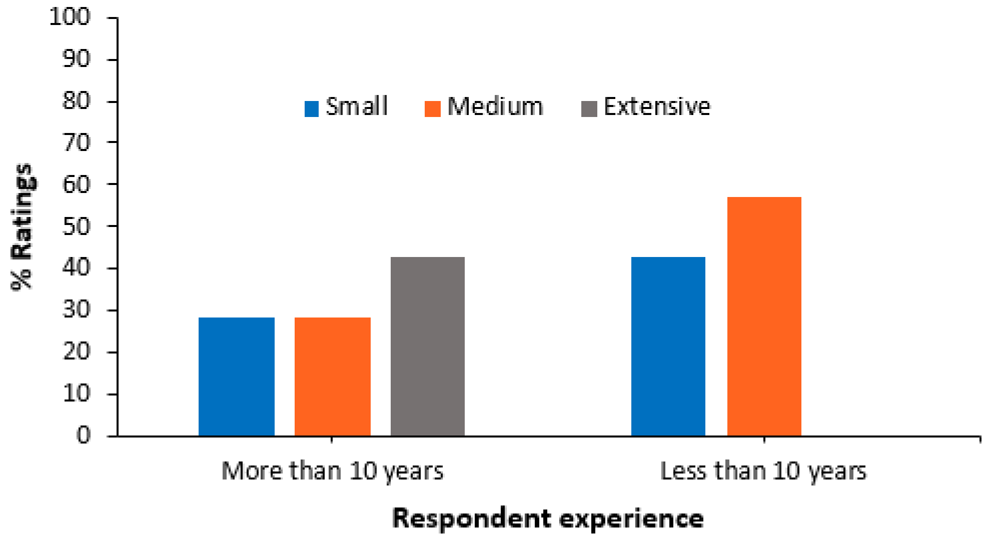

Figure 3: The percentage of small, medium, and extensive predator damage ratings given by experienced (10 or more years' experience) and less experienced respondents respectively.

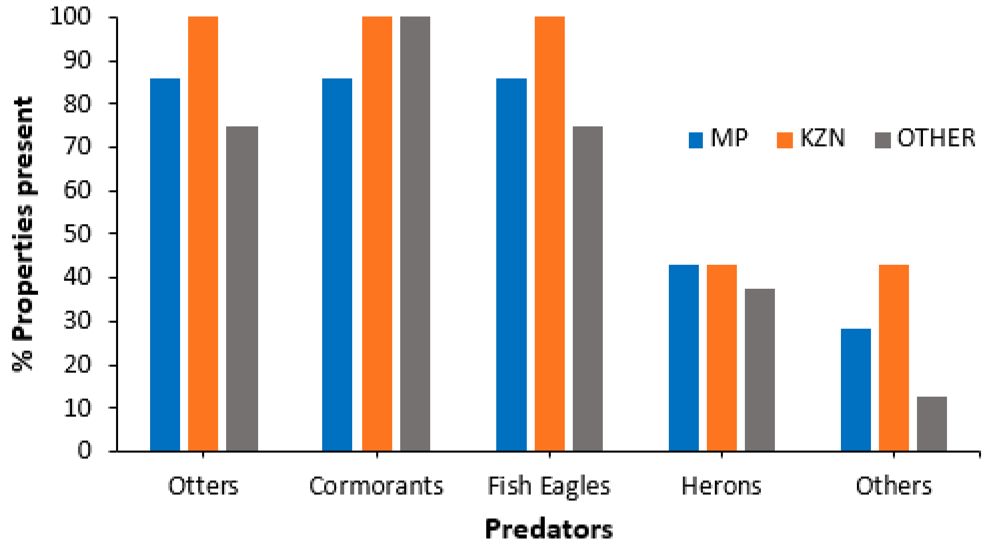

Figure 4: Percentage of represented properties who reported the presence of various predators on the property. KwaZulu Natal (KZN), Mpumalanga (MP) and 'other' provinces (Free State, Western Cape, Gauteng and Eastern Cape).

Table 1: Results of comparing reported presence of various predators between different provinces using Fischer's exact tests.

	TEST	**Asymptotic Significance (2-sided)**
Otter presence/absence	Fischer's exact	0.75
Cormorant presence/absence	Fischer's exact	0.64
Fish eagle presence/absence	Fischer's exact	0.75
Heron presence/absence	Fischer's exact	1.00
Other predators presence/absence	Fischer's exact	0.43

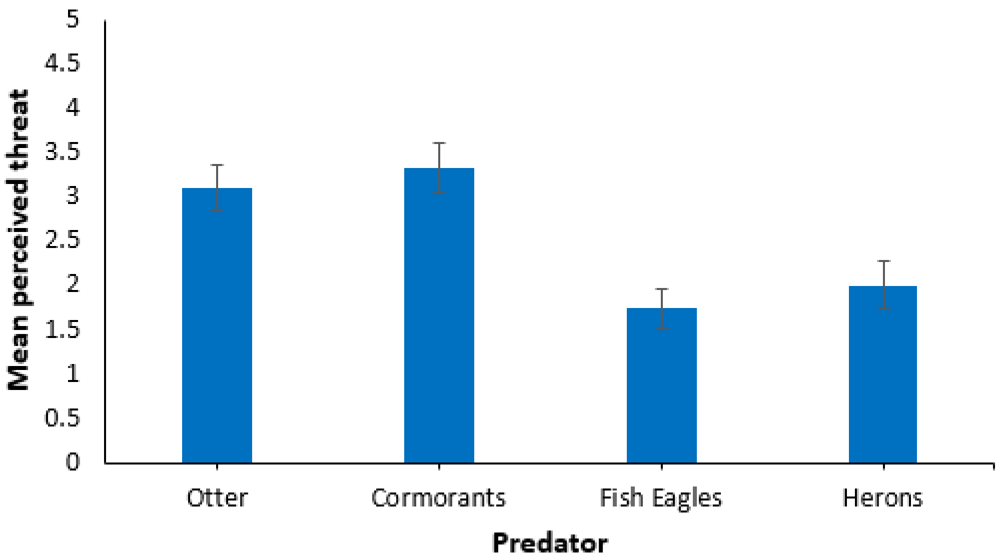

Figure 5: Mean perceived threat of various predators to fish stocks. Threat was rated on a scale of 1-5, one being no threat and 5 being a very large threat. Error bars represent standard error.

Mitigation Measures

Fifty-five percent of the respondents reported to employ mitigation measures to reduce predation, and 45 % of respondents reported not to employ mitigation measures (n = 22). Conserving nature was the most frequent reason given for not employing mitigation measures (Appendix A, Table A 2). Proportionately more respondents from KZN (86 %) employed mitigation measures than respondents from MP (57 %), and Other Provinces (25 %) (Fig. 6). There was no significant difference between respondents from different provinces with regards to whether or not they employ mitigation measures (Fisher's exact test, p = 0.08). Likewise, there was no significant difference in the employment of mitigation measures between experienced and less experienced respondents (Fisher's exact test, p = 1).

Respondents who did not perceive predators to have attractive value or who were unsure of the attractive values of predators, were not more likely to employ mitigation measures when compared to respondents who perceived predators to attract guests (Fisher's exact test, $p = 0.51$). Neither were there differences between these groups in terms of reported levels of predator-induced fish losses (Fisher's exact test, $p = 0.87$).

Mitigation measures varied greatly – of the 11 respondents that reportedly employ preventative measures, 50 % used shooting to kill as a mitigation measure, 33 % used shooting to scare away predators, 33 % employed human patrols to chase off predators, 25 % used physical barriers (such as fencing) to deter predators, one respondent employed trapping of problem animals but did so many years ago, and one respondent employed scaring devices to discourage predators. Cormorants were reported as targets by all respondents who said they employ mitigation measures, while only 36 % reported to target otters, and 36 % reported to target other piscivorous predators (e.g. herons, fish eagles, water mongoose, hamerkop). Lethal action (i.e. shooting to kill) (employed by 6 respondents) was mainly aimed at cormorants (83 % of responses) and to a lesser extent otters (33 %).

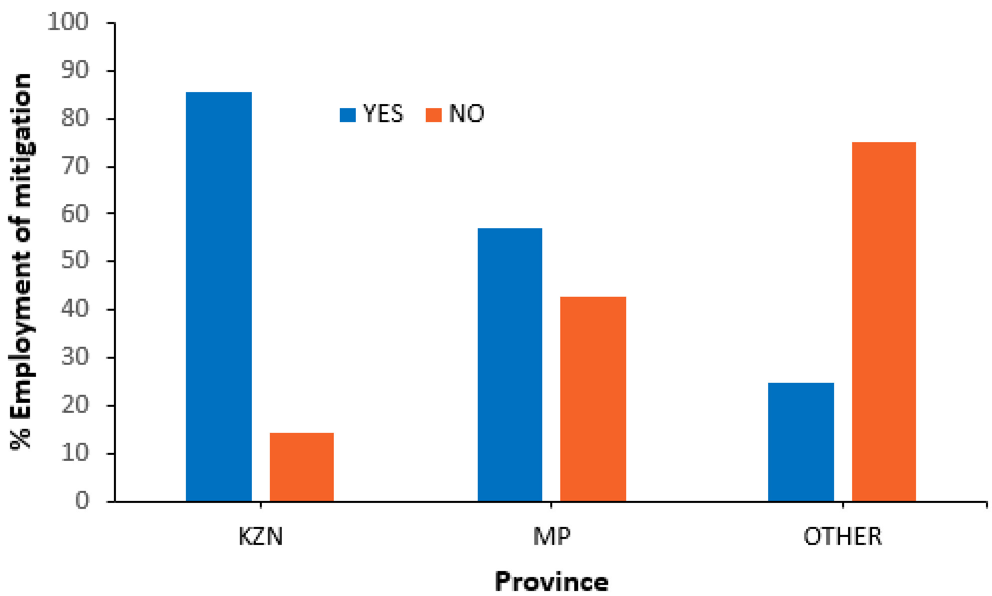

Figure 6: The proportion of respondents from different provinces who reportedly do (YES) or do not (NO) employ mitigation measures to reduce depredation of fish stocks.

Management Strategies

The reported frequency of fish stocking varied widely between responses from different properties - some properties did not stock at all as fish numbers were kept up by fish breeding in their waters; other properties stocked on a weekly basis and yet others had not stocked for the last two years or only stocked fish every two- to three years. Stocking practices were categorized as either less than (or equal to) twice a year, or more than twice a year, when possible (n = 19). There were no significant differences in stocking frequency (either more or less than twice a year) between provinces (Fisher's exact test, p = 0.61). Mitigation measures were employed proportionately more by properties that stocked more than twice a year (64 %), compared to properties that stocked less frequently (38 %) (Fig. 7). However, no overall statistically significant difference was found between properties that did or did not employ mitigation measures (Fisher's exact test, p = 0.37).

Properties that stocked less than twice a year reported proportionally more losses of small extent (57 %) than properties that stocked more than twice a year (18 %), while properties that stocked more than twice a year reported proportionally more medium level losses (Fig. 8). However, a Fischer's exact test indicated that there was overall no significant difference in the reported level of fish losses between properties that stocked more than twice a year and those that stocked less than twice a year (Fisher's exact test, p = 0.10).

Catch-and-release angling (C&R) was practiced by all but one property manager who felt that trout are too sensitive to survive C&R if done by inexperienced anglers. One respondent stated that they did not allow C&R of trout on the property, but that C&R was allowed for all other fish species (bass, carp, yellowfish, and bream). Various reasons were given for practicing C&R, but protecting fish stocks and ethical reasons, were the most common responses (Appendix A, Table A 3).

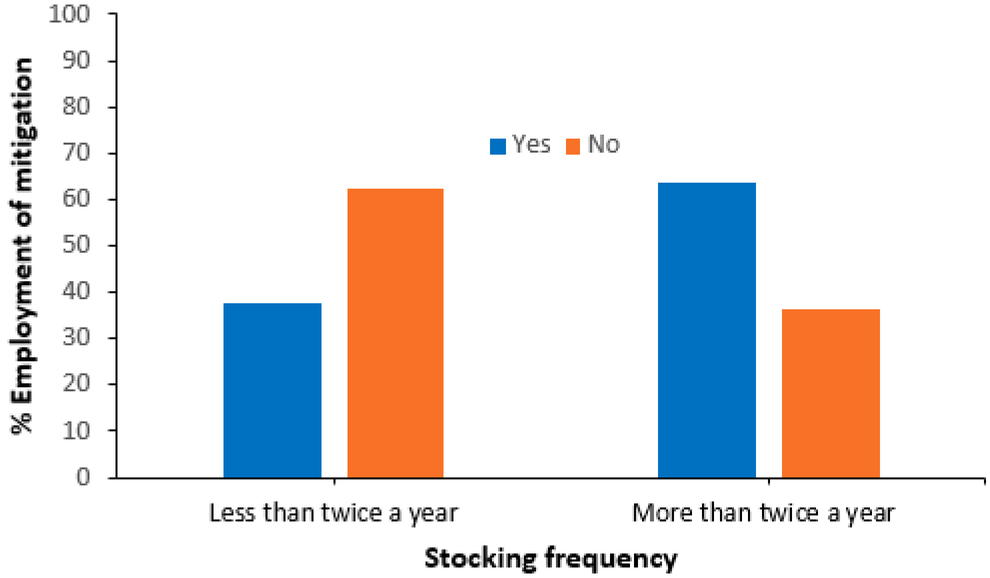

Figure 7: Proportions of represented properties stocking less frequently than (or equal to) twice a year, or more frequently than twice a year who reportedly do (Yes) or do not (No) employ mitigation strategies to reduce depredation.

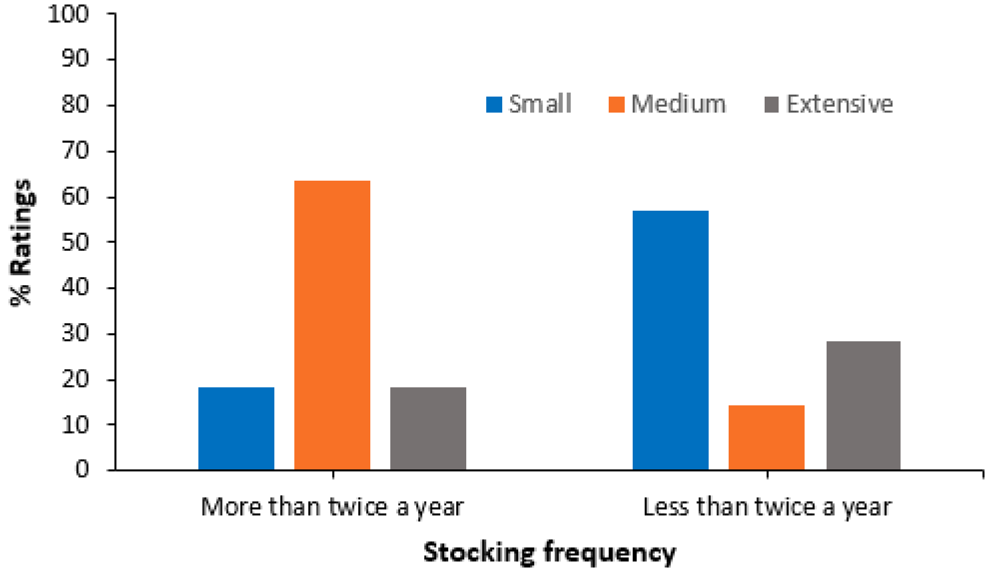

Figure 8: Percentage of different levels of losses perceived by respondents representing properties that stock less frequently than (or equal to) twice a year, or more frequently than twice a year.

Discussion

In line with my prediction of wide-spread reports of predator-induced losses, the questionnaire revealed that all respondents believed they were incurring predator-induced fish losses, and that piscivorous predators, especially otters and cormorants, are highly prevalent at fishing properties (Fig. 4). Human-wildlife conflict can occur whenever human interests overlap with those of wildlife (Distefano 2005), and the results obtained through this study indicate that this overlap of interests certainly occurs in the South African fly-fishing industry. However, in contrast to my expectations of perceived losses to be extensive, the perceived extent of predator-induced losses varied greatly between individual respondents and not consistently between: respondents from different provinces; respondents that were experienced or less experienced with respect to the fly-fishing industry; respondents that did or did not employ mitigation measures; or between respondents that stocked more regularly as opposed to those who stocked less than twice a year. In a study conducted in Poland on Eurasian otter (*Lutra lutra*) damage at fisheries, Kloskowski (2005) reported that two adjacent fish-farms had vastly different perceptions as to the level of otter induced damage, despite the analysis of otter spraints showing similar proportions of fish in the diet of otters on both farms. Similar to my findings, Kloskowski (2005) found no significant differences in perceived damage between fish farms in different locations, or between enterprises of different sizes.

Interestingly, predators were reported to be most prevalent on KZN properties (Fig. 4), and KZN respondents also proportionately reported the most cases of extensive predator-induced damage (Fig. 2). This may indicate a link between predator prevalence and the perception of predator-induced damage. Whether increased prevalence of predators in fact leads to more extensive damage to fish stocks, or whether their presence merely inflates respondents' perception of potential stock damage, was beyond the scope of this study but could be a potentially useful avenue of research. Kloskowski (2005) mentioned how incidents of conspicuous damage to fish stocks likely influences the attitudes of fish farmers – it may be worth investigating how the conspicuousness of fish predators at properties influence stakeholders attitudes towards predators and whether or not predator prevalence do in fact correlate with stock losses.

Mitigation measures were employed by half of the respondents, with lethal shooting being the most common action taken. Cormorants were by far the most targeted predator followed by otters and then other fish predators (e.g. herons and African fish eagles). As predicted, cormorants and otters also received the highest average perceived threat rating, while herons and fish eagles were seen to pose only a small threat (Fig. 5) - cormorants and otters where likewise the only predators against which lethal action were reported. These findings are in line with those of Kloskowski (2011), who correspondingly reported cormorants (*Phalacrocorax carbo*) to be the most widely persecuted species at Polish pond fisheries, with lethal controls being the most popular mitigation measure. Kloskowski (2011), also found that most damage to pond fisheries were attributed to otters (*L. lutra*) and cormorants (*Phalacrocorax carbo*), but in contrast to this study, Kloskowski (2011) found that otters were more often considered a problem than cormorants. Most respondents who reported not to employ mitigation measures, did so for conservation reasons (Appendix A, Table A 2). In line with my postulations, lethal action was the most commonly used mitigation measure – specifically my findings indicated that shooting to kill was the most commonly employed mitigation measure reported by respondents.

Human-wildlife conflict involving otters have been reported on all continents where otters occur (e.g. Miller 1977; Freitas *et al.* 2007; Lima *et al.* 2014; Akpona *et al.* 2015), while cormorants are similarly notorious for their conflicts with the fish industry (review by Madden 2004; Marzano *et al.* 2013). Cormorants are known to forage either singly or communally in groups (Linn & Campbell 1992), and foraging in a flock likely increase both the perceived and actual damage done by these birds. Reasons for the generally small threat posed by herons include their mostly solitary foraging behaviour and reported tendency to drive away other birds that could compete with them for resources (Cook 1978). Similarly, African fish eagles are highly territorial and resident pairs will actively defend their territories against other fish eagles (Brown 1980; Simmons & Mendelsohn 1993), making it unlikely that fish eagle numbers will be high enough on fly-fishing properties to present a serious threat to fish stocks. Fish eagles are further iconic and well-loved birds and therefore less likely to be persecuted.

Stocking practices differed greatly between respondents, ranging from fish being stocked on a weekly basis to stocking taking place only every two to three years. One respondent noted that cormorants were a particular nuisance during stocking. C&R appears to be a common practice in the South African fly-fishing industry with all but one of the represented properties allowing C&R, and one property allowing C&R of fish species other than trout. C&R is an increasingly common practice world-wide (Cooke & Cowx 2004; ICES

2013; Gargan *et al.* 2015), and seen as a possible way in which to maintain the benefits of recreational angling, while limiting the effects on fish populations (e.g. Gargan *et al.* 2015). Respondents in this study mostly employed C&R to protect fish stocks, but also for ethical reasons (Appendix A, Table A 3), with one respondent stating that many anglers expect them to practice C&R. Although most properties practiced a C&R policy, they generally also allowed anglers to keep the occasional fish (sometimes at a fee), especially if the fish was considered a trophy or if it was a novice angler's first fish.

The low response rate to the questionnaire suggests some caution in the interpretability of my results. However, despite the relatively small sample size, novel views on predators and fish stocks were limited after the first 10 responses. The point at which data collection no longer yields any novel or relevant information is defined by many as “saturation” (reviewed in Dworkin 2012), a concept used by many scholars to determine sample size when conducting qualitative research (Mason 2010). Therefore, the results reported are likely to provide a reasonable representation of the perceptions of, and mitigation measures employed by, fly-fishing estate managers with regard to piscivorous predators. Nonetheless, to account for possible biases that may have occurred from respondents with particularly strong views on the topic being more likely to respond to the questionnaire, I believe that further attempts to conduct a more inclusive study along similar lines as this one, are warranted. However, in order for such an endeavour to be successful one must first address the potential underlying causes of the low response rate incurred by this questionnaire. Changing government legislation pertaining to the invasive status of trout in South Africa is a contentious issue (e.g. du Preez & Lee 2010; Hoogendoorn 2014), and likely contributed to the low participation obtained. A number of potential respondents expressed their concerns on the matter and were reluctant to participate in fear of the information collected being used against the fly-fishing industry.

The environmental benefits of the fly-fishing industry must be considered when legislative decisions are made. This study revealed that fly-fishing properties provide a habitat to many indigenous piscivorous species, of which some, like the Near Threatened African clawless otter and the Vulnerable spotted-necked otter (Okes *et al.* 2016; Ponsonby *et al.* 2016), are threatened by habitat loss (Jacques *et al*. 2015; Reed-Smith *et al*. 2015)). The value and extent of habitat provided by fly-fishing properties to indigenous species are not known, and should be determined before actions are taken that could potentially harm the fly-fishing industry. Alternative land-use options such as crop and livestock farming or residential development are unlikely to provide suitable habitat for many indigenous species that presently utilize fly-fishing properties. In turn, stakeholders in the fly-fishing sector must strive to promote the environmental health of the land in their custody and mitigation measures should be employed and tested to resolve conflicts with piscivorous predators when they arise.

In summary, although no consistent trends were found as to which factors underlie the perceptions of respondents towards fish predators, a few broad inferences can be made: Human-wildlife conflict is wide-spread in the South African fly-fishing industry but the seriousness of the perceived conflict varies greatly between properties; Piscivorous predators are prevalent on fly-fishing properties and these properties likely provide valuable habitat to predators; Otters and cormorants are the most likely predators to be involved in such conflicts as they are seen to pose the highest threat and are targeted most often by mitigation measures; Lethal action is taken against some predators, but overall many properties are tolerant towards predators and wish to conserve nature; C&R is highly prevalent although not strictly enforced. A larger study, along similar lines, would likely provide better insights, especially at the finer-scale, on the perceptions of fly-fishing industry stakeholders towards fish predators. Efforts are needed to gain the trust of the fly-fishing sector in order to further research efforts beneficial to the industry as well as nature conservation. Field-based studies to evaluate the utilization of fly-fishing properties by indigenous species, especially piscivorous predators, are needed to determine the importance of these habitats to indigenous fauna.

CHAPTER THREE: RAINBOW TROUT SURVIVAL AND DIURNAL PREDATOR VISITATION RATES ON A FLY-FISHING ESTATE

Abstract

The impacts of cormorants and other predators on fisheries are notoriously difficult to measure. A shortage of informative fisheries data is seen to most often impede quantification of predator-induced fish losses. Stocked trout face many challenges to their survival including competition with conspecifics, injury or mortality from piscivorous predators, and angling – both catch-and-keep, as well as catch-and-release (C&R) angling. In response to concerns about fish predators as expressed by managers of fly-fishing properties in Mpumalanga, South Africa, I investigated the probabilities of rainbow trout (*Oncorhynchus mykiss*) stocked on a fly-fishing property and recorded predator visits to the study site during daytime.

Using a mark-recapture approach, I investigated the survival probabilities of rainbow trout stocked in a comparatively large water body, as well as trout stocked in two smaller water bodies. I found high short-term (weekly) apparent survival probability (Phi) of fish stocked in both large (Phi = 0.97) and smaller water bodies (Phi = 0.93), while annual survival probability was low for both sites. This likely indicates that C&R has limited effects on fish survival at this study site, as most mortalities attributable to C&R have been found to occur within 48 h post-release. Low long-term survival is likely due to factors including predation, water quality, food availability, temperature and rainfall. Fish stocked in the larger water body had nearly nine times the annual survival probability (Phi = 0.18) of fish stocked in the smaller water bodies (Phi = 0.02). Otters were most prevalent at the smaller water bodies and are potentially capitalizing on the easy foraging opportunity provided by high fish numbers in relatively small confines. In contrast, avian predators were most prevalent at the large water body, possibly due the location being more distant to areas of high human disturbance.

Introduction

Accurately quantifying stock losses to predators is key to effective mitigation and management of resulting human-wildlife conflicts (e.g. Palmeira *et al.* 2008; Yirga & Bauer 2010). The impacts of cormorants and other predators on fisheries are notoriously difficult to measure (Wires *et al.* 2003; Marzano *et al.* 2013), and the challenges in measuring these impacts can exacerbate conflicts involving piscivorous predators (Marzano *et al.* 2013). For example, stakeholders that believe cormorants are threatening fisheries may feel that scientists are doing nothing to address the matter and express astonishment at the apparent inability of science to prove cormorant impacts (Marzano *et al.* 2013). A shortage of informative fisheries data is seen to most often impede quantification of predator-induced fish losses (Marzano *et al.* 2013).

Management practices can influence the scale of predator impacts on fisheries. For example, stocking density, fish size, harvesting systems and proximity to roost sites are all factors that are known to impact cormorant induced stock losses at catfish farms in the United States (Mott *et al.* 1992; King *et al.* 1995). Double-crested cormorants (*Phalacrocorax auritus*) preferentially feed on ponds with high fish densities (Werner & Dorr 2006), and it has been suggested that otters may be incited to increase predation in situations where prey are enclosed in small areas at high densities (Poledník *et al.* 2004).

Stocked trout face many challenges to their survival including competition with conspecifics, injury or mortality from piscivorous predators, and angling – both catch-and-keep, as well as catch-and-release (C&R) angling. Catch-and-release takes place under the assumption of fish survival post-release and with negligible fitness consequences (Wydoski 1977; Broadhurst *et al.* 2005; Cooke & Schramm 2007; Pollock & Pine 2007; Hall *et al.* 2009). However, there is increasing evidence that this is often not the case, and literature suggests that substantial post-release mortality can occur, even though fish appear to be in good condition at the time of release (reviewed in Muoneke & Childress 1994; Bartholomew & Bohnsack 2005; Arlinghaus *et al.* 2007).

Catch-and-release is an increasingly common practice (Cooke *et al.* 2013), and this is also true for my study site, Millstream Farm. Here the proportion of angled fish that are released have shown a significant increasing trend over the years (Appendix B, Figure B 1, 2000 – 2016 data). However, as the survival of released fish is not guaranteed and stocked fish endure multiple challenges, resorting to C&R does not necessarily ensure high survival rates of fish. Knowledge of the survival of fish stocks is a crucial tool in effective management, and the recapture probability of released fish has implications on the angling success of visitors to fishing properties. Importantly, information relating to fish populations is needed to assess the potential impact of piscivorous predators on fish stocks - Marzano *et al.* (2013)

identified the lack of useful fish population data as a complication of accurately quantifying cormorant impacts on fisheries.

Aquaculture is particularly attractive to piscivorous animals – relatively shallow water, high densities of fish and individual prey that are similar in size, all make for a ready source of food (Littauer 1990; Curtis *et al.* 1996; Manikowska-Ślepowrońska *et al.* 2015). Predators have further been shown to take advantage of fish that are released/discarded after capture (Stevens *et al.* 2000; Ryer 2002), making post-release predation (PRP) a further challenge faced by C&R fish. Specifically, animals released in a weakened state are at a heightened risk to predation until they have recuperated from capture-induced exhaustion (Cooke & Philipp 2004). Hatchery-reared fish are sometimes considered to have underdeveloped anti-predator behaviour as they tend to dawdle in the shallow waters near the bank where they were released, becoming easy targets for predators (Olla *et al.* 1998). A study by Biro *et al.* (2004) showed that domestic trout took greater risks when foraging and, under conditions of high predation risk, had lower survival rates than fish of wild strains.

Piscivorous predators threatening fish stocks naturally lead to conflict between these predators and stakeholders in the fish industry. The subtleties underlying HWC can be affected by behavioural characteristics of involved species, such as predation behaviour, wariness, fondness for certain foods, and migratory routes and routines (Lamarque *et al.* 2009). Furthermore, information on the effect of fishery practices combined with the food and habitat predilections of predators may contribute to the advancement of effective mitigation measures (Werner & Dorr 2006). It is for this reason that we included an observational section in our research to investigate differential visitation rates of predators to the study sites.

In this section of my study I aimed to assess the apparent survival and recapture probabilities of rainbow trout at selected still waters on Millstream Farm, Mpumalanga, using a mark-recapture approach. I estimated survival probabilities between sampling intervals (each a week in length), then adjusted these estimates to reflect monthly and yearly survival probabilities respectively – information essential for informing management decisions. As mentioned before, we also included an observational component to the study in an aim to quantify daytime visitation rates of predators to the study sites.

I predicted the following outcomes:

- Fish survival to be higher in a larger dam, compared to smaller weirs. This expectation is based on the likelihood that the larger dam likely makes it harder for predators (and anglers) to catch fish as there is simply more space for fish to escape and hide.
- C&R will result in low short term survival of fish. Here I clumped recapture data into weeks to give weekly estimates of survival as it is unlikely that mortality later than a week after capture can directly be attributed to C&R.
- Predators will be more prevalent in the larger dam, which is characterized by less human disturbance.

Methods and Materials

Fish Survival and Recapture Probabilities

Study species

Rainbow trout (*Oncorhynchus mykiss,* Walbaum 1792) is a salmonid species with a native range extending from California in the eastern Pacific to the Kamchatkan Peninsula in eastern Siberia (Gall & Crandell 1992). Rainbow trout has both a freshwater (simply referred to as rainbow trout) and anadromous form (referred to as steelhead trout). A variety of terrestrial and aquatic invertebrates, as well as small fishes, are consumed (Kottelat & Freyhof 2007), and at sea cephalopods and fish are the major prey items (Page & Burr 1991). The species are adapted to cold waters and prefer temperatures between 10 °C and 24°C (Eaton *et al.* 1995), although they are known not to breed if water temperatures do not fall below 13°C (Kottelat & Freyhof 2007). The species is cultured in many countries, often for stocking of waterbodies to attract recreational anglers (Frimodt 1995), and was first introduced into South Africa in 1897 (Cambray 2003).

Study site

The study took place on Millstream Farm, a fly-fishing estate near Dullstroom, Mpumalanga, South Africa. The area forms part of the Dullstroom Plateau Grassland ecosystem, and grasses and forbs make up the bulk of the vegetation (Ferrar & Lötter 2007). It is a summer rainfall area with average yearly rainfall of 664mm. Ambient temperatures in summer range between a night-time average of 10.5°C and a midday average of 21.3°C. In winter, temperatures regularly fall below freezing with average ambient temperatures ranging between 3°C and

13.9°C. A series of weirs (12 in total) of varying sizes are fed by the Witpoort River and terminates in Lake Millstream. A further eight bodies of water (five dams and three ponds) are present on the property (Table 2, Fig. 10). Lake Crystabel and Solitary Reaper are strictly C&R only, while anglers are allowed to either keep or release fish angled in other waters, but are restricted to a bag limit of 15 fish per cottage per week. Stocking takes place on a bi-monthly basis in all waterbodies, except the C&R only dams which are stocked less often but with larger fish. Fish stocked vary in size from approximately 250g to 1500g (however larger individuals are occasionally stocked in the C&R only dams), with smaller waters being stocked largely with smaller-sized fish and larger waters with larger fish.

Lake Coleridge (water surface area of approximately 29,493 m²) was used as my specific study site during the 2016 fieldwork session (Fig. 9). The vegetation surrounding Coleridge consists mainly of open grasslands, and a reed bed flanks the one end of the dam. A few small trees grow along the banks. There are no cottages near the dams, and the dirt road passing by the dam is closed to visitor vehicles. Five jetties are positioned on the banks from where anglers can cast. Angling also takes place directly from the banks as well as from float tubes. Lake Coleridge is generally frequented by more advanced anglers than some of the smaller waters on Millstream Farm (Kemp pers. comm., Fishing Manager, Millstream Farm).

The 2017 fieldwork session used two of the weirs as specific study sites. The weirs used, named My Beauty and Evening Rise, have a water surface area of approximately 2,246 m² and 1,495 m² respectively (Fig. 9). Multiple cottages are in close proximity to the weirs, and a parking area for anglers is situated less than 100m from Evening Rise. Reeds and small shrubs partly flank both weirs. Established trees grow next to the weirs and include willows (*Salix sp*.), conifers (Order Pinales) and white stinkwoods (*Celtis africana*). Flowing water connects all the weirs, but fish movement upstream is not possible due to steep embankments between weirs, and fish movement downstream is limited due to the inherent nature of trout to swim upstream (Kemp pers. comm.).

Figure 9: Top right - Evening Rise, a weir of approximately 1,495 m² (surface area) in size; Top left - My Beauty, a weir of approximately 2,246 m² in size; Bottom - Lake Coleridge, approximately 29,493 m² in size.

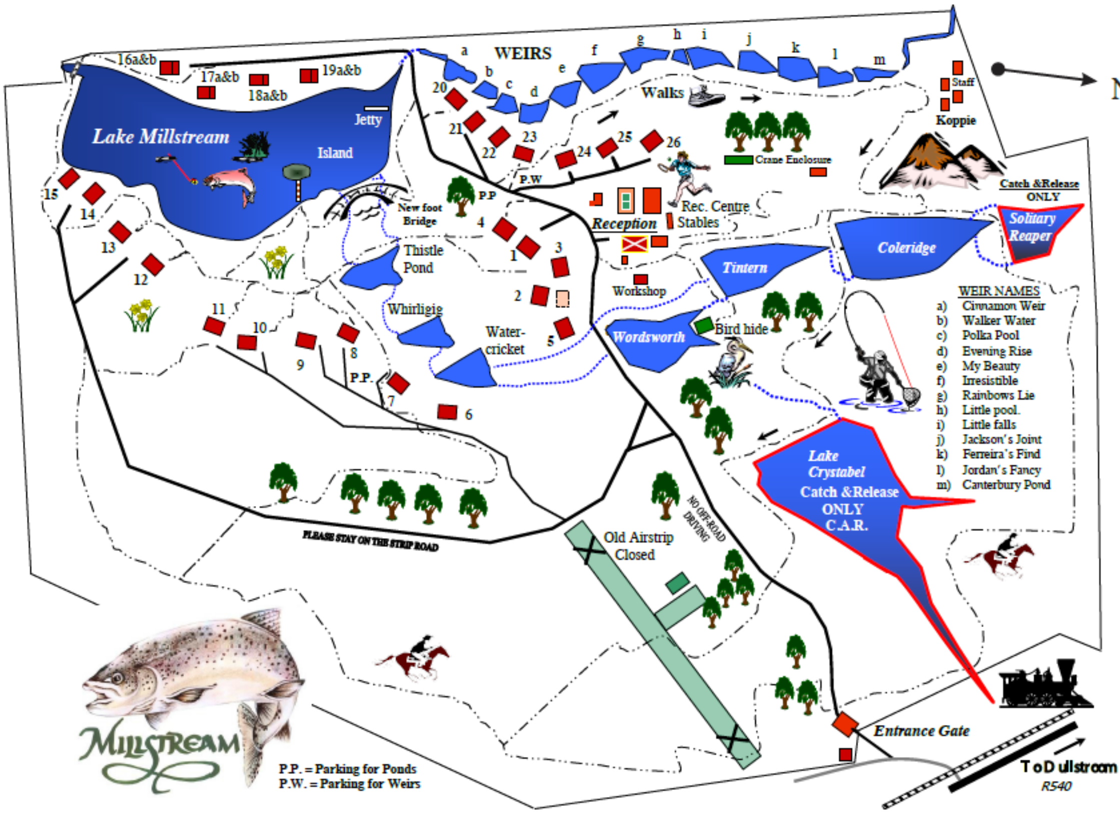

Figure 10: Map of Millstream Farm depicting the locations of the different water bodies, buildings and roads (paved roads indicated as solid lines, with dirt roads and footpaths shown as broken lines).

Table 2: Names of the different water bodies of Millstream and their approximate water surface areas.

Waters	**Size**
Lake Millstream	107,613 m^2
Watercricket pond	3,429 m^2
Whirlygig pond	4,306 m^2
Thistle pond	5,637 m^2
Lake Crystabel	52,528 m^2
Wordsworth	12,583 m^2
Tintern	16,340 m^2
Lake Coleridge	29,493 m^2
Solitary Reaper	20,368 m^2
Average weir size	865 m^2

Methodology

The study comprised two fieldwork sessions of nine and seven weeks respectively. The first session occurred during late winter to early spring of 2016, and the second session during mid to late winter of 2017. During the first session, tagged rainbow trout (n = 300) were stocked at the study site in batches of 100 fish at the start of the first, second and fifth weeks of the study, so as to stay at pace with the usual stocking rate of the farm (stocking takes place approximately twice a month). Tagged rainbow trout (n = 120) were stocked in batches of 60 fish during the second fieldwork session, and stocking took place at the start of the first and third weeks of the study. The reason for the smaller sample size during the second session lies in the fact that the specific study site (two weirs as described under 'study site') was much smaller than the specific study site used during the first session (Lake Coleridge), and stocking the same numbers would lead to bias in the findings resulting from greatly higher stocking densities.

I tagged all fish used in this study at the fish supplier (Lunsklip Fisheries (Pty) Ltd, Lydenburg, Mpumalanga, South Africa), one day prior to their release at Millstream Farm. Trout were tagged with 12 mm HDX+ PIT Tags (Oregon RFID, Portland, Oregon, USA http://www.oregonrfid.com), using a syringe injector fitted with a needle with Luer lock connector (Oregon RFID, Portland, Oregon, USA http://www.oregonrfid.com). Tags were injected into the dorsal muscle near the dorsal fin, as this site has been found optimal for tag retention in trout (Dieterman & Hoxmeier 2009). Tagging of suitably sized fish has little to no adverse effects on fish (e.g. Feldhaus *et al.* 2008; Tatara 2009; Richard *et al.* 2013). The needles used in the procedure were disinfected before use and between individual fish with a 70-80 % ethanol: water dilution. All fish were handled with wet hands, so as to prevent damage to the mucus layer of fish and reduce the chances of infections. Tagged fish were weighed to the nearest 50 g. After tagging, fish were placed in a holding pen with flowing fresh water and allowed to recover overnight before being transported to Millstream and stocked in the specific waterbodies used as study sites. Ethical clearance for the study was obtained from the University of Pretoria's Animal ethics committee (Project number EC028-16; Appendix B).

Fish stocked during the first fieldwork season ranged in size from 150 g to 1100 g, with fish in the first batch being larger than 500 g (hereafter referred to as 'large fish'), with a mean weight of 811.50 g (SE 12.77 g). Fish in the second batch were equal to or smaller than 500 g (hereafter referred to as 'small fish') and had a mean weight of 351.98 g (SE 7.03 g). The third batch of fish comprised both large (57 individuals) and small fish (43 individuals) and mean fish weight was 524.5 g (SE 21.53 g).

The second fieldwork season involved fish ranging in size from 150g to 700g, with a mean weight of 408.33 (SE 8.50 g) and 484.583 (SE 8.06 g) for fish in the first and second batches respectively. In general, smaller fish were used during the second fieldwork season in order to reflect the normal stocking practices at the farm, where the weirs and smaller waterbodies are mostly stocked with smaller fish compared to the larger waterbodies.

Following stocking, fishing activity at the study sites was monitored during daylight hours for the duration of the study (approximately 10-12 hours per day). Angling effort was recorded on a daily basis, with multiple anglers cumulatively contributing to the effort – i.e. if two anglers angled for three hours each (regardless if simultaneously or not) angling effort for the day would be six hours (2 x 3 = 6). All fish caught by anglers were scanned upon landing using a tag reader (EasyTracer FDX/HDX Reader; Oregon RFID, Portland, Oregon, USA http://www.oregonrfid.com), and if the fish was a tagged individual the tag number was recorded and the angler asked to release the fish. Caught untagged fish were also recorded as well as how C&R fish were handled (e.g. hooked removed in or out of water, whether a net was used, etc.). Removal of untagged fish by anglers were noted, as well as cases of direct angling-related mortality of tagged fish. Daily water temperatures along with minimum and maximum ambient temperatures were obtained from Millstream Farm's records for the duration of the study periods.

Data analysis

Fish recapture data were analysed on a mark-recapture basis using Programme Mark version 8.2. A Cormack Jolly-Seber (CJS) model for live-recaptures was used to analyse the data. A binary format was used to indicate whether a fish was captured and released (1), killed upon capture (-1), or not captured (0) during the sampling period. Due to comparatively low recapture rates data were clumped into weeks, and one sampling occasion therefore constituted one week. A candidate set of 9 models was created, in which the apparent survival probability (Phi) and the recapture probability (p) was held constant (.), allowed to vary with time (t), constrained to be a function of angling effort (effort), or fitted with a linear trend for time (T). Akaike's Information Criterion (AIC) was used to compare models with the most parsimonious model scoring the lowest AIC value. AIC weights were used to evaluate the relative fit of the models. The starting model (Phi(t) p(t)) was tested for goodness of fit using the bootstrap method. The random seed number was generated using the computer clock and 100 bootstrap simulations were run. In the event of lack of fit, a variance inflation factor ($\hat{c}$) was applied and models compared using the quasi-Akaike's Information Criterion (QAIC) (Lebreton *et al.* 1992). The variance inflation factor was calculated by dividing the observed $\hat{c}$ of the original data by the mean of the simulated values of $\hat{c}$ from the bootstraps. The observed $\hat{c}$ was obtained by dividing the model deviance with the deviance degrees of freedom. Data from Coleridge and the weirs were analysed separately.

Descriptive statistics, including frequencies, averages (mean ± standard error), weekly totals and collective totals, were calculated for angling effort and fish landings. Angling success was expressed as number of landings per hour of angling effort. Pearson's correlation was used to test for a relationship between number of fish landings and angling effort. Data from Coleridge and the weirs were treated separately.

Observed Daytime Predator Visitation Rates

Study species

White-breasted cormorants (*Phalacrocorax carbo lucidus)*, African fish eagle (*Haliaeetus vocifer*), Spotted-necked otters (*Hydrictis maculicollis*), and African clawless otters (*Aonyx capensis*) were the fish predators that I focused on during the observational section of the study. Reed cormorants (*Microcarbo africanus*) were also regularly observed, but are not considered to pose a serious threat to fish stocks at Millstream due to fish being too large for these birds to target (Kemp pers. comm.).

White-breasted cormorant (WBC)

The white-breasted cormorant (*Phalacrocorax carbo lucidus,* Linnaeus 1758) is a subspecies of the great cormorant, although some authorities recognize it as its own species (*Phalacrocorax lucidus*) (Hockey *et al.* 2005). The great cormorant (together with its subspecies) has an extremely wide distribution, occurring on all continents except South America and Antarctica, and both marine and freshwater habitats are utilised (Birdlife International 2017). The African subspecies occur widely in Africa, and can be found wintering off the northern coast and along the Nile, and also breeding year-round on the north-west coast, as well as in parts of central-east Africa and South Africa (Birdlife International 2017). Great cormorants are predominantly piscivorous (Gremillet *et al.* 2003a) and also feed on crustaceans, amphibians (del Hoyo *et al.* 1992) molluscs and nestling birds (Brown *et al.* 1982). They are highly mobile birds and are known to fly between 20 and 25 km between feeding and roosting sites (Birdlife International 2018).

In Europe, the great cormorant is a source of intensive debates and conflict- not only between humans and the species, but also between conservationists and fisheries stakeholders (Marzano *et al.* 2013). There is little literature from Africa suggesting damage to fish stocks from white-breasted cormorants on the scale of their European counterparts, however some concerns have been reported regarding the impact of white breasted cormorants on fisheries (Linn & Campbell 1992).

The species is listed as Least Concern by the IUCN Red List for Threatened Species, and believed to have an increasing population trend (Birdlife International 2017). Persecution from the aquaculture industry (Carss 1994), disturbance from coastal windfarms (Bradbury *et al.* 2014), and outbreaks of Avian influenza and Newcastle disease (Kuiken 1999, Melville &

Shortridge 2006), are among the threats to this species. Great cormorants are also vulnerable to bycatch in gillnets (Zydellis *et al.* 2013), purse seines (Oliveira *et al.* 2015), and longlines (Zydellis *et al.* 2009), while sea-based recreational activities may lead to displacement from crucial habitat (Birdlife International 2017).

African fish eagle (FE)

The African fish eagle (*Haliaeetus vocifer,* Daudin 1800) is a widely distributed afrotropical species that is common to abundant in its range with the exception of waterless areas (Birdlife International 2018). The species is known to be nomadic in reaction to resource scarcities, but is considered to be mostly sedentary (Ferguson- Lees & Christie 2001). It utilizes terrestrial, freshwater and marine habitats, and is predominantly piscivorous but will also feed on other available taxa and even carrion when prey is scare (this is especially so in the case of juveniles) (Ferguson- Lees & Christie 2001, Birdlife International 208).

In southern Africa, fish eagles breed from April to October. These birds have been shown to be sensitive to human disturbance when breeding and likely to abandon nests within a 100 m proximity to high levels of human disturbance (Chomba & M'Simuko 2013). The species is listed as Least Concern by the IUCN Red List for Threatened Species, and believed to have a stable population trend (Birdlife International 2016). Although African fish eagles are very abundant and likely in direct competition with humans for fish, the species is not known to be persecuted by people (Birdlife International 2018). The species is not presently particularly affected by habitat loss (Birdlife International 2018), but a build-up of organochlorine pesticides in fish prey (accumulated from the water bodies they inhabit) results in eggshell thinning in some areas (del Hoyo *et al.* 1994; Ferguson-Lees & Christie 2001).

African clawless otter

African clawless otters (*Aonyx capensis*, Schinz 1821) are endemic to Africa and are widely distributed throughout the continent south of the Sahara (Rowe-Rowe & Somers 1998). They occur in most aquatic habitats, ranging from freshwater lakes to sporadic rivers in arid environments and even rocky marine shores (Nel & Somers 2007). However, the availability of freshwater sources and sufficient food are considered essential (Nel & Somers 2007). The African clawless otter is the world's third largest otter with an average body mass of 11 - 16kg, although larger specimens have been recorded (Skinner & Smithers 1990). They are generally solitary, although it is not unusual to see pairs or family groups (Rowe-Rowe 1978). African clawless otters are considered to be mainly nocturnal or crepuscular (Rowe-Rowe 1975; Arden-Clarke 1983).

Dietary studies have repeatedly shown that freshwater crabs (*Potamonautes* spp.) are the most important prey items in the diet of African clawless otters inhabiting freshwater habitats (e.g. Rowe-Rowe 1977a; Somers & Purves 1996; Purves *et al.* 1994). However, both rainbow trout and brown trout (*Salmo trutta*) have been recorded to form part of African clawless otter diet in some areas (e.g. Rowe-Rowe 1977b; Butler 1994). In these cases the reported relative contribution of trout to their diet varied across studies. In a pilot study conducted on a fly-fishing estate outside Dullstroom, MP, I found that African clawless otter were consuming more trout than expected based on previous studies (de Vos 2015, unpublished –Appendix B, Fig. B2 and B3).

The species is listed as Near Threatened with a declining population trend by the IUCN Red List of Threatened Species (Jacques *et al.* 2015). The declining state of freshwater habitats throughout Africa is considered the main threat to the species (Jacques *et al.* 2015). Humans sometimes persecute African clawless otters in areas where they are seen as direct competition for food, especially in areas where fishing is an important income source, or where otters are blamed for poultry losses (Rowe-Rowe 1995). Otters are also hunted for their skins and other body parts in some parts of their range (e.g., Cunningham & Zondi 1991, De Luca & Mpunga 2005).

Spotted-necked otter

The spotted-necked otter (*Hydrictis maculicollis,* Lichtenstein 1835) is another otter species endemic to the African continent (Nel & Somers 2007), and occurs in lakes and large rivers throughout much of Africa south of 10°N (Reed-Smith *et al*. 2015). The species prefers freshwater habitats with un-silted, unpolluted waters rich in small to medium sized fishes (Reed-Smith 2010, d'Inzillo Carranza &Rowe-Rowe 2013). Suitable terrestrial habitat in terms of dense shoreline/ bank vegetation and piled-boulders appears to influence their abundance (Reed-Smith 2010). Unlike the African clawless otter, this species does not utilize estuarine or marine habitats (Reed-Smith *et al*. 2015).

Spotted-necked otters are considered to be more piscivorous than African clawless otters (Rowe-Rowe 1975). A study conducted in Kwazulu-Natal by Rowe-Rowe (1977b), reported that brown trout had a 10 times higher relative frequency of occurrence in spotted-necked otter spraints than in African clawless otters spraints. Conflicts between spotted-necked otters and fishermen have also been reported in Benin, where the species is listed as endangered (Akpona *et al.* 2015). Spotted-necked otters are mainly crepuscular (Proctor 1963; Rowe-Rowe 1978b), but both diurnal and nocturnal activities have been recorded (Proctor 1963; Perrin *et al.* 1999). Early studies of the species reported group sizes of up to approximately 20 individuals in large East African lakes and South African riverine systems (Rowe-Rowe & Somers 1998, Reed-Smith unpublished data), but more recent informant interviews from East Africa reveals that groups of more than five otters are now rarely encountered (Reed-Smith *et al.* 2010 and unpublished data).

The IUCN Red List of threatened species lists Spotted-necked otters as Near Threatened, with a decreasing population trend (Reed-Smith *et al*. 2015). The deterioration of freshwater habitats and riparian vegetation, exacerbated by unsustainable agricultural and fishing activities, is considered the main threat to the species (Rowe-Rowe 1990, 1992, 1995, mason 2008). The bioaccumulation of organochlorines and other bio-contaminants from polluted waters is another threat (Mason & Rowe-Rowe 1992). Habitat loss with accompanying increased conflict with humans are impacting all populations (Reed-Smith *et al*. 2015), and as with African clawless otters, spotted-necked otters are killed in areas where they are seen to compete with humans for fish or where they are believed to threaten poultry (Rowe-Rowe 1990; Akpona *et al.* 2011, 2015; Reed-Smith *et al.* 2010).

Study site

The observational part of my research took place during the same time periods and at the same localities as the research on fish survival and recapture probabilities. Details pertaining to the study site as a whole (Millstream Farm, Dullstroom, MP) and the specific localities used (Lake Coleridge and the weirs) can be found under “Fish Survival and Recapture Probabilities – Study site” earlier in this chapter.

Methodology

I collected daytime observational data on predator visitations to the study sites. Predators were identified visually with the aid of binoculars (Tasco Sonoma 10X24). Avian predators were all identified to species level, however because of their elusive nature it was not always possible to distinguish between the two otter species and as such data on the two species were combined under the general term 'otters'. As I had no means to identify individual animals, counts of individuals of a species visiting the study sites were not made. Instead the daily absence or presence (based on the observational data) at the study sites were noted for each predatory species observed. Furthermore, the intent was not to record activity levels of predators as such, nor to quantify predator impact, but simply to establish a baseline record of which predators visited the study sites and how often, and also to look at potential differences in predator visits to sites.

Data analysis

The number of days per week, as well as in total, that otters (both African clawless and spotted-necked otters), white-breasted cormorants, and African fish eagles were respectively seen was calculated (denoted as predator observation days, e.g. otter observation days). Basic descriptive statistics were used, including mean number of weekly predator observation days (with standard error [SE]), maximum and minimum number of predator observation days, as well as the percentage of days on which the respective predators were seen during the study period. Pearson's correlation was used to test for linear trends between weekly angling effort and weekly number of observation days for the various predators. Data obtained from the weirs were analysed separately from data obtained from Coleridge. Microsoft Excel 2013 and IBM SPSS version 4 were used to sort and analyse the data.

Results

Fish Survival and Recapture Probabilities – Coleridge

Goodness of fit testing was performed on the starting model Phi(t)p(t) using the bootstrap method. The starting model's observed deviance (191.9875) was higher than any of the simulated deviances, indicating some lack of fit ($p < 0.01$). The lack of fit was corrected for by applying a $\hat{c}$-value of 1.8472 (see "Data analyses" pp. 33-34 for calculation).

The model that best fit the data had constant probability of survival (Phi(.)) and time-variant probability of recapture (p(t)) (Model $A_{Coleridge}$, Table 3). The best model (Model $A_{Coleridge}$) was 15 times better supported than the next best model (Model $B_{Coleridge}$) based on the AIC weights (Table 3). Weekly probability of survival (Phi) was estimated at 0.97 (95 % confidence interval [CI] 0.82- 0.99), with the highest weekly recapture probability estimated at 0.34 (95 % CI 0.25-0.44) and the lowest at 0.03 (95 % CI 0.02-0.07) (Table 4). The survival estimate was rescaled using the delta method to obtain monthly and annual survival probabilities respectively. Monthly survival was estimated at 0.88 (SE 0.18) and annual survival at 0.18 (SE 0.48).

Table 3: Summary of models ran on fish recapture data collected at Lake Coleridge during winter to early spring of 2016.

Model Identification	Model	QAICc	Δ QAICc	AICc Weights	Number of Parameters
$A_{Coleridge}$	{Phi(.) p(t)}	717.88	0	0.91	10
$B_{Coleridge}$	{Phi(.) p(T)}	723.3	5.41	0.06	3
$C_{Coleridge}$	{Phi(T) p(T)}	724.93	7.048	0.03	4
$D_{Coleridge}$	{Phi(t) p(t)}	730.66	12.78	0.00	17
$E_{Coleridge}$	{Phi(.) p(effort)}	738.07	20.18	0.00	3
$F_{Coleridge}$	{Phi(effort) p(effort)}	740	22.11	0.00	4
$G_{Coleridge}$	{Phi(T) p(.)}	740.65	22.76	0.00	3
$H_{Coleridge}$	{Phi(effort) p(.)}	741.84	23.95	0.00	3
$I_{Coleridge}$	{Phi(.) p(.)}	744.24	26.36	0.00	2

Table 4: Specific outputs for the best supported model {Phi(.) p(t)} for fish recapture data collected from Lake Coleridge during winter and early spring of 2016. Phi refers to weekly survival probability and p_i to recapture probability for the respective weeks of the study.

Parameter	Estimate	Standard Error	Lower 95% CI	Upper 95% CI
Phi	0.9674	0.0302	0.8197	0.9949
p_1	0.3414	0.0496	0.2516	0.4441
p_2	0.2428	0.0331	0.1839	0.3133
p_3	0.1109	0.0249	0.0707	0.1698
p_4	0.132	0.0294	0.0842	0.2009
p_5	0.1632	0.028	0.1154	0.2256
p_6	0.0317	0.0118	0.0152	0.0651
p_7	0.0576	0.0177	0.0313	0.1037
p_8	0.0553	0.0184	0.0285	0.1046
p_9	0.0839	0.0265	0.0445	0.1527

Fish Survival and Recapture Probabilities – Weirs

The starting model (Phi(t) p(t)) was tested for goodness of fit using the bootstrap method. The starting model's observed deviance (61.98) fell between the 51st (61.32) and 52nd (62.05) simulated deviances, showing that the observed deviance was reasonably likely to be observed ($p > 0.48$) and the model fitted the data adequately.

The model that best fit the data had constant probability of survival (Phi(.)) and time-variant probability of recapture (p(t)) (Model A_{weirs}, Table 5). The best model (Model A_{weirs}) was 11.5 times better supported than the next best model (Model B_{weirs}) based on the AIC weights (Table 5). Weekly probability of survival (Phi) was estimated at 0.93 (95 % confidence interval [CI] 0.80-0.98) per week, with the highest weekly recapture probability estimated at 0.44 (95 % CI 0.31-0.58) per week and the lowest at 0.04 (95 % CI 0.01-0.11) (Table 6). The survival estimate was rescaled using the delta method to obtain monthly and annual survival probabilities respectively. Monthly survival was estimated at 0.74 (SE 0.16) and annual survival at 0.02 (SE 0.06).

Table 5: Summary of models ran on fish recapture data collected at the weirs during the winter of 2017.

Model Identification	Model	AIC_c	Δ AIC_c	AIC_c Weights	Number of Parameters
A_{weirs}	{Phi(.) p(t)}	598.55	0	0.90	8
B_{weirs}	{Phi(effort) p(effort)}	603.44	4.89	0.08	4
C_{weirs}	{Phi(.) p(effort)}	606.92	8.37	0.01	3
D_{weirs}	{Phi(t) p(t)}	607.23	8.68	0.01	13
E_{weirs}	{Phi(T) p(T)}	613.17	14.62	0.00	4
F_{weirs}	{Phi(.) p(T)}	613.76	15.21	0.00	3
G_{weirs}	{Phi(.) p(.)}	620.11	21.56	0.00	2
H_{weirs}	{Phi(effort) p(.)}	620.79	22.24	0.00	3
I_{weirs}	{Phi(T) p(.)}	622.03	23.48	0.00	3

Table 6: Specific outputs for the best supported model {Phi(.) p(t)} for fish recapture data collected from the weirs during the winter of 2017. Phi refers to weekly survival probability and p_i to recapture probability for the respective weeks of the study.

Parameter	Estimate	Standard Error	Lower 95% CI	Upper 95% CI
Phi	0.9289	0.0393	0.8027	0.9767
p_1	0.4356	0.0707	0.3052	0.5756
p_2	0.1993	0.0592	0.1074	0.3400
p_3	0.2247	0.0450	0.1486	0.3248
p_4	0.1674	0.0429	0.0990	0.2689
p_5	0.2361	0.0584	0.1408	0.3683
p_6	0.0367	0.0221	0.0111	0.1146
p_7	0.2371	0.0757	0.1204	0.4136

Angling Effort and Success – Coleridge

A total of 814 hours of angling effort were recorded for Coleridge. Angling effort varied greatly between weeks - mean weekly angling effort was 90.44 h (SE 14.77 h), with the lowest angling effort recorded during week 9 at 43.75 h and the highest during week 2 at 161.48 h (Appendix B, Fig. B 4). A total of 482 fish landings were recorded, on 399 occasions (83 %) the fish was released and on 83 occasions (17 %) the landed fish was kept (Table 7). On 229 occasions (48 %) the landed fish was a tagged individual and on 11 of these occasions (2 %) the tagged fish suffered angling related mortality (Table 7). Mean number of fish landed per week was 53.56 (SE 10.277) with the highest number of fish landed during week 2 (117 fish) and the lowest number during week 7 and week 8 (26 fish respectively) (Appendix B, Fig. B 5). Overall angling success at Coleridge was 0.59 fish landed per hour spent angling. Number of fish landed correlated moderately with angling effort and this correlation was statistically significant ($r = 0.66$, $p < 0.00$; Fig. 11). Angling effort explained 44 % of the variation in number of fish landed ($R^2 = 0.44$).

Table 7: Summary of landing occasions of tagged and untagged fish and fish fate upon capture (K = kept, C&R = Caught and released) during the 2016 study period in Lake Coleridge.

Event	Count
Landing occasions	**482**
C+R Tagged	*218*
K Tagged	*11*
C+R Untagged	*181*
K Untagged	*72*
Individual tagged fish landed	**166**
Landed once	*57*
Landed twice	*31*
Landed three times	*13*
Landed four times	*2*

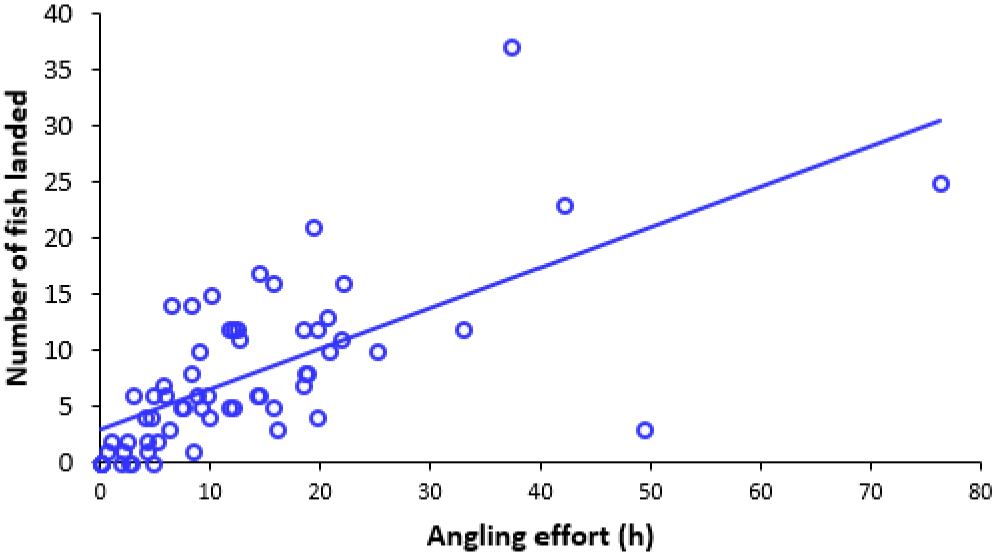

Figure 11: The relationship between angling effort in hours and the number of fish captured at Lake Coleridge. A Pearson's correlation revealed a moderate positive correlation between angling effort and number of fish captured (r = 0.66, p< 0.00). Angling effort explained 44 % of the variance observed in number of fish landed (R^2= 0.44).

<u>Angling Effort and Success – Weirs</u>

Angling effort of approximately 446.78 hours was recorded for the weirs. Mean weekly angling effort was 63.83 h (SE 6.61 h), with the lowest effort logged during week 6 (31.52 h) and the highest effort logged during week 2 (87.78 h) (Appendix B, Fig. B 6). Record was made of 295 fish landings in total, with the fish being released on 265 occasions (90 %) and kept on 30 occasions (10 %) (Table 8). On 122 occasions (41 %) the landed fish had a tag, on 2 of these occasions the tagged fish was kept due to angling injuries (1 %) and on one occasion a tagged fish died in the water after release (Table 8). Mean number of fish landed per week was 42.14 (SE 5.21), with the lowest number landed in week 6 (18 fish), and the highest number landed in week 1 and week 5 (54 fish respectively) (Appendix B, Fig. B 7). Overall angling success for the weirs was 0.66 fish per hour spent angling. Number of fish landed correlated moderately with angling effort and this correlation was statistically significant (r = 0.62, p < 0.00; Fig. 12). Angling effort explained 38 % of the variation in number of fish landed (R^2 = 0.38).

Table 8: Summary of landing occasions of tagged and untagged fish and fish fate upon capture (K = kept, C&R = Caught and released) during the 2016 study period in Lake Coleridge.

Event	Count
Landing occasions	**295**
C+R Tagged	120
K Tagged	3
C+R Untagged	145
K Untagged	27
Individual tagged fish landed	**76**
Landed once	*37*
Landed twice	*33*
Landed three times	*5*
Landed four times	*1*

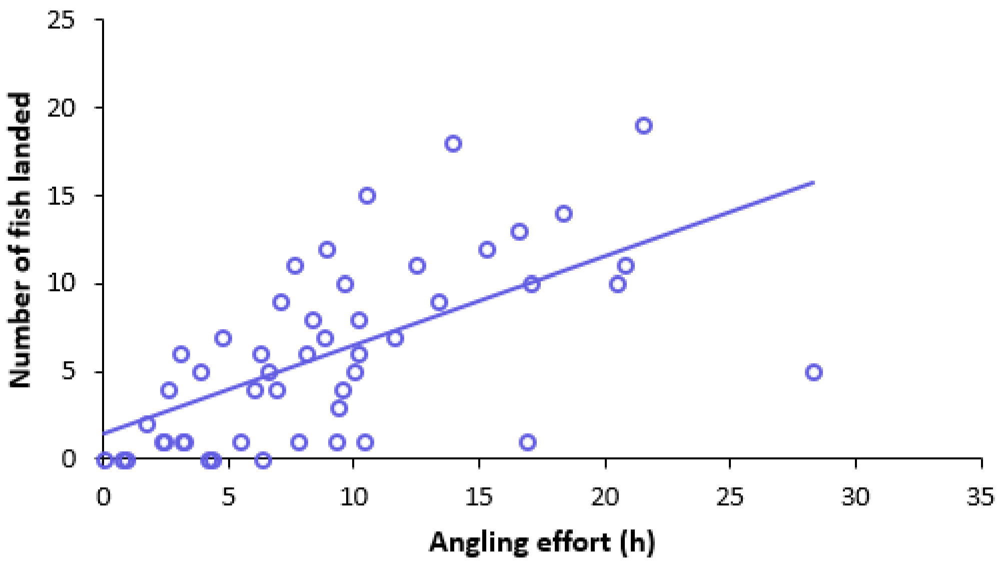

Figure 12: The relationship between angling effort in hours and the number of fish captured at the weirs. A Pearson's correlation revealed a moderate positive correlation between angling effort and number of fish captured (r = 0.62, p< 0.00). Angling effort explained 38 % of the variance observed in number of fish landed (R^2= 0.38).

<u>Daytime Predator Observations - Coleridge</u>

Piscivorous predators were observed on 55 of the 63 days of the study. African fish eagles were seen on 32 days (51 % of the days), white-breasted cormorants on 31 days (49 %) and otters on 22 days (35 %). I observed 17 instances of fish killed by predators during the study period. African fish eagles caught the majority of fish (9), followed by white-breasted cormorants (7), and one fish was taken off an angler's line by an otter (most likely spotted-necked otter). A statistically significant negative relationship of moderate strength exists between cormorant observation days per week and weekly angling effort (r = -0.74, p = 0.02), while there was little to no relationship between both fish eagle and otter observation days per week and angling effort (Fig. 13).

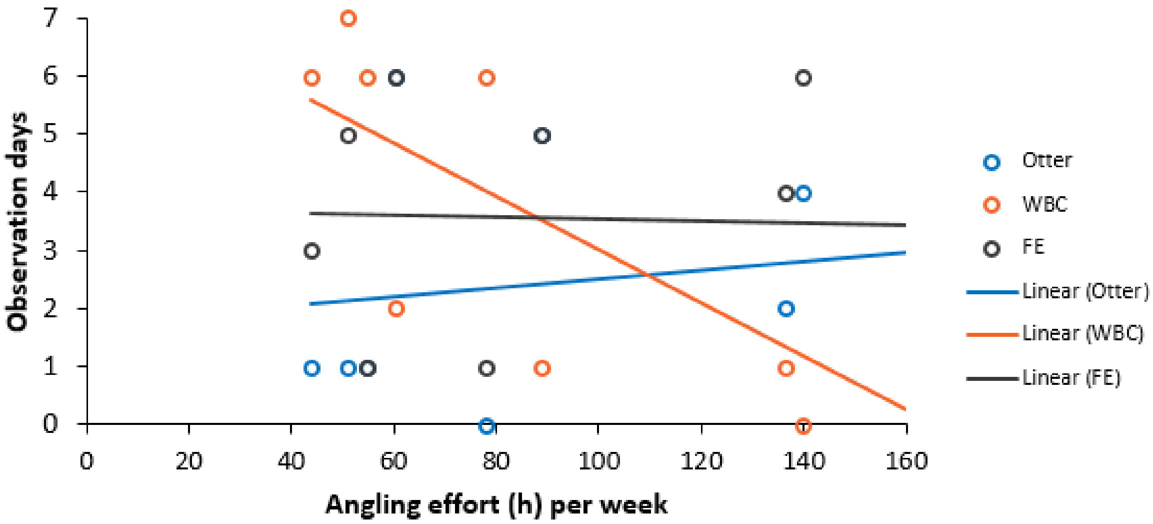

Figure 13: Relationship between weekly angling effort (h) and the corresponding number of days per week on which the respective predators were observed at the weirs. A Pearson's correlation revealed a statistically significant negative relationship of moderate strength exists between cormorant observation days per week and weekly angling effort (r = -0.74, p = 0.02), while there was little to no relationship between both fish eagle and otter observation days per week and angling effort.

<u>Daytime Predator Observations – Weirs</u>

Piscivorous predators were observed on 29 of the 49 days of the study. Otters were recorded on 25 days (51 % of the days), white-breasted cormorants on 1 day (2 %) and fish eagles on 4 days (8 %). Only one instance of predation was observed during the study when a spotted-necked otter caught a fish. The number of otter and FE observation days per week both showed a weak negative correlation with weekly angling effort, but in both instances this trend was not statistically significant (Fig. 14). As only one observation was made of a WBC visiting the weirs no meaningful correlation between WBC observation days per week and angling effort could be made.

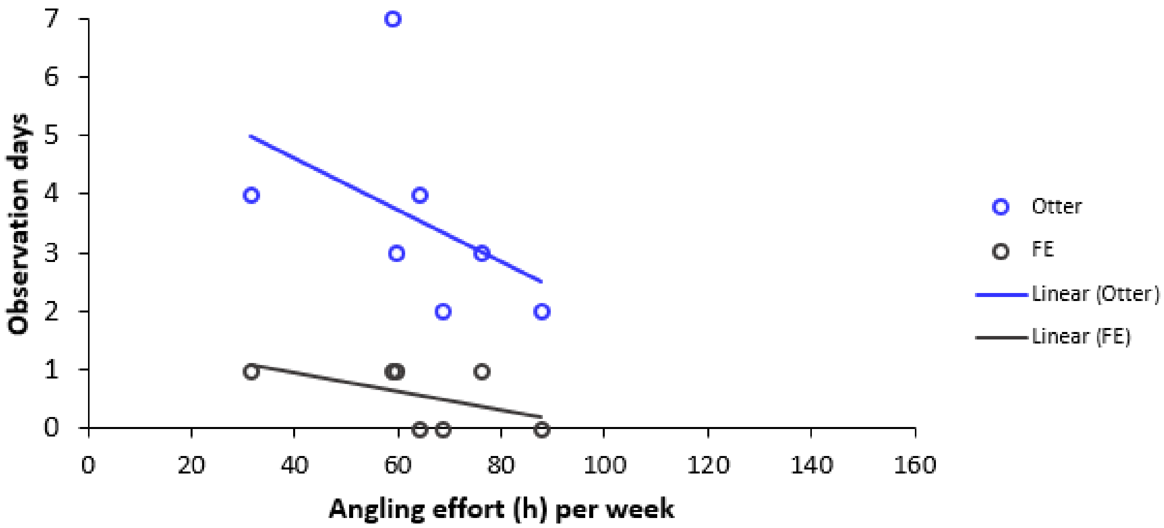

Figure 14: The relationship between weekly angling effort (h) and the corresponding number of days per week on which the respective predators were observed at the weirs. The number of otter and FE observation days per week both showed a weak negative correlation with weekly angling effort, but in both instances this trend was not statistically significant ($p > 0.05$).

Discussion

My study illustrated high short-term survival probability (0.97 and 0.93 in Lake Coleridge and the weirs respectively), but low annual survival probability (0.18 and 0.02 in Lake Coleridge and the weirs respectively) of rainbow trout (*Oncorhynchus mykiss*) at a fly-fishing estate in South Africa where catch-and-release fishing is practiced. The high survival probability of fish over the short-term in both Lake Coleridge (Table 4) and the weirs (Table 6) was in contrast to my predictions, and likely indicates that C&R had a limited effect, at least in the short-term, on fish survival. It is unlikely that fish mortality more than a week post-release can be directly ascribed to C&R, and many studies investigating short term effects of C&R only monitored fish for up to 5 days post-release (e.g. Anderson *et al.* 1998 – 16 h; Hall *et al.* 2009 – 5 days; Boyd *et al.* 2010 -72 h). Furthermore, Mongillo (1984) found that 90 % of C&R mortality occurs within 48h post-release, and Boyd *et al.* (2010) reported similar results. While I did not observe any external signs of reduced condition in fish that were caught two, three, or even four times, I cannot exclude the possibility of cumulative fitness consequences for fish repeatedly caught and released over longer periods of time. However, seeing as recapture probability of fish was low at both Coleridge (Table 4) and the weirs (Table 6), it is a reasonable assumption to make that, in general, fish are not caught repeatedly on a regular basis, thereby likely allowing fish to recover between far spaced capture events. The low long term survival probability obtained for Coleridge and the weirs is therefore likely caused by factors other than, or in addition to, C&R. Water quality, weather conditions, food availability, higher water temperatures in summer months, and predation are all factors that potentially impact fish survival probability. For example, Boyd *et al.* (2010) reported increased mortality from C&R in elevated water temperatures. Since the annual survival estimates in my study were calculated from recapture data collected in winter, it might in reality be even lower due to the possible increase in mortality of fish caught and released in summer months. A shortage of informative fisheries data is often seen as a limiting factor for quantifying predator-induced fish losses (Marzano *et al.* 2013), and the absence of similar studies on trout survival in the South African fly-fishing industry hinders my ability to make meaningful comparisons to other studies in an attempt to illuminate potential impacts of predators on fish survival. To my knowledge this is the first study to determine the survival and recapture rates of trout stocked on a fly-fishing estate in South Africa. Therefore, there was no comparable study, in terms of environmental conditions and locality, against which to measure my findings. Further studies along similar lines, conducted at various fly-fishing properties around South Africa, is needed and would generate valuable information on the viability of trout stocking, and aid in unravelling the relationship between predator prevalence and fish survival.

In line with my predictions, fish stocked in Coleridge had a higher apparent survival probability than fish stocked in the weirs, and this was especially perceptible in long term survival with Coleridge fish having almost nine times the annual survival probability of weirs fish. Poledník *et al.* (2004) suggested that high densities of "enclosed" prey may incite otters and other predators to intensify predation to levels higher than deemed normal, and this could potentially hold true for small waters at Millstream such as the weirs. Indeed, the proportionately high prevalence of otters at the weirs and may be a contributing factor to the lowered survival probability of fish in these waters My finding was in line with the expected outcomes of this study – Coleridge is much larger than the weirs, and is also deeper with several trenches more than two meters deep. These properties would increase the difficulty for predators and anglers to capture fish, with more space being available for fish to escape and hide. Overall angling success was highest at the weirs at 0.66 fish caught per hour spent angling, while overall angling success at Coleridge was 0.59 fish per hour spent angling. This is likely because the small sizes of the weirs allow anglers to cast their flies across the entire water body, while this is impossible at Coleridge, and only anglers on float tubes (who are in the minority) have access to the entire area of this water body. Fish stocked in Coleridge also had lower recapture probabilities than fish stocked in the weirs (Table 4; Table 6) and this supports the notion that fish in Coleridge have a greater chance of avoiding being angled, likely providing fish with more time to recover from capture between C&R events. Furthermore, anglers that frequent Coleridge are usually more experienced anglers, compared to those fishing the weirs at Millstream (Kemp pers. comm.). Since novice anglers injure proportionately more fish than experienced anglers, (principally during hook removal, Meka 2004), injuries to Coleridge fish were therefore likely to be fewer, and this may contribute to the higher apparent survival probability of fish stocked in Coleridge. .

Water pollution could also be a contributing aspect to the observed differential survival between the study sites – the weirs are located within the Witpoort River and upstream pollution events are a frequent problem, while Coleridge is fed by groundwater that is generally of better quality (Vincent pers. comm., Manager, Millstream Farm).

Fish size is another aspect that needs to be considered when explaining the differential survival at the two study sites – fish stocked in Coleridge are generally larger than those stocked in the weirs (Kemp pers. comm.). Both clawless and spotted-necked otters are generally thought to prefer fish below 200 mm in length (Rowe-Rowe 1977a; Kruuk & Goudswaard 1990; Lejeune 1990). Fish eagles foraging at Ndumu GR, KZN, have been reported to regularly capture fish up to 3 kg in size (Tomkinson 1975), and therefore can be considered likely to capture larger fish at the study site. White breasted cormorants have been reported to prey on fish up to 290 mm in length (Rand 1960) and prey up to at least 376 g can be swallowed (Whitfield & Blaber 1979). Very small trout are also likely to be targeted by the reed cormorant, in addition to other predators. Trout are also known to cannibalise smaller trout (Vik *et al.* 2001), although most of the fish stocked are probably far too large for this to occur. However, size still plays an important role in fish fitness, with larger fish generally occupying higher positions in the social hierarchy (Jenkins 1969).

While not tested in this study, a further factor that may warrant consideration is food availability. Coleridge has plentiful aquatic vegetation compared to the weirs (pers. obs.), and therefore likely has an abundance of aquatic invertebrates for trout to prey on. In contrast, fish in the weirs may be experiencing higher competition for food and so be more aggressive feeders and more likely to target anglers' flies. Although the highest overall angling success (fish/hour) was recorded at the weirs and not Coleridge, the weirs showed the greatest variation in angling success, with the number of fish landed in Coleridge correlating slightly better with angling effort (Fig. 11) than it did in the weirs (Fig. 12). I suspect this is at least partly due to the higher experience levels of anglers frequenting Coleridge than those frequenting the weirs, and so angling effort produced more consistent results at Coleridge than it did at the weirs.

Daytime predator visitation was highest at Coleridge, with predators being seen on 87 % of the days during the 2016 study period that took place at Coleridge, while only on 59 % of the days at the weirs during the 2017 study period. These findings matched my prediction of higher predator prevalence at Coleridge than at the weirs; Coleridge is situated comparatively far away from cottages and other sources of human disturbance such as roads frequented by guests, and the lowered level of disturbance likely contributed to the higher prevalence of predators. The large open water that is Coleridge also provided large birds like WBC with adequate space for easy take-off and landing. A statistically significant negative trend was observed between WBC observation days per week and weekly angling effort, likely pointing to angler presence at Coleridge having a deterrent effect on WBC, and likely supports the notion that human disturbance plays a role in WBC prevalence at waters. However, it was not possible to discern whether the increase in WBC observations was as a result of reduced angling activity or because of seasonal change as these two determinants happened to coincide with one another. Coleridge has five jetties on its banks from which anglers can cast, and WBC regularly used these as perch and sunning sites (pers. obs.). Jetties on fly-fishing properties are known to be attractants of WBC (Vincent pers. comm.) and this could very likely have contributed to the high prevalence of WBC at Coleridge compared to the weirs. On one occasion I also observed a FE utilising a jetty to dry off and regain its strengths after capturing a trout from Coleridge. FE were likewise more prevalent at Coleridge than at the weirs.

Otters were the exception when it came to predator preference of the study sites- being most prevalent at the weirs and seemingly not affected by the higher levels of human disturbance. This finding is in contrast with my expectations and also with the study done by Nel & Somers (2007) who reported that the presence of otter sign was negatively correlated with human utilisation of water bodies. The banks of the weirs have proportionately more vegetation cover than Coleridge and are also shallower, and this could explain otter preference for these waters - Nel & Somers (2007) also found the presence of African clawless otter signs, such as spraints, to be more prevalent at water bodies 1 - 2m in depth as opposed to deeper waters, and also linked vegetation cover to the prevalence of otter sign. Adequate vegetation cover and piled boulders also seem to be factors influencing the abundance of both otter species (Nel & Somers 2007; Reed-Smith 2010), and these are plentiful along the weirs. In a study on carnivore predation of livestock in Slovakia highlights the potential importance of vegetation cover in depredation – the study reports major predator-induced losses in sheep flocks situated less than 500 m from the forest edge in comparison to sheep flocks situated further away (Rigg *et al.* 2011). Ease of hunting in shallow water could further explain the higher otter prevalence at the weirs – otters foraging at shallower depths in coastal water are known to be more successful in capturing prey than in deeper waters (Nel & Somers 2007). The layout of the weirs also allow otters to move between weirs by means of scurrying up or down the inclines connecting the individual weirs, or at some places to reach the next weir by crossing a very narrow strip of open land. In contrast, at Coleridge otters wanting to move to the adjacent waters cannot do so without exiting the water and crossing a broad bank with little vegetation cover. The results of this may point towards the possibility that suitable cover and improved hunting conditions offset the deterrent effect of human activity at water bodies on otters. Otters at Millstream could likely have become habituated to human presence and therefore the reported deterrent effect of human utilisation of water bodies (Nel & Somers 2007) may not apply as strongly at this locality. The observations in this study align with those of Gallant *et al.* (2009), who found habitat-related factors to be more important determinants of river otter (*Lontra canadensis*) habitat use than anthropogenic factors.

Spotted-necked otters (*Hydrictis maculicollis*) were the species most often observed – although a positive species-level identification was not always possible. Spotted-necked otters are morphologically better adapted for a piscivorous lifestyle than African clawless otters (*Aonyx capensis*) (Rowe-Rowe 1975). Rowe-Rowe (1977b) investigated the diet of both otter species inhabiting a trout area, and found trout in only 4 % of African clawless otter spraints compared to in 56 % of spotted-necked otter spraints. Conversely, in a pilot study conducted on a fly-fishing property near Dullstroom, I found trout in 42 % of African clawless otter spraints analysed (de Vos 2015, unpublished, Appendix B, Fig. B 3). Based on this knowledge it is likely that a high prevalence of otters could impact fish stocks at fly-fishing properties. This could be especially true if the stocked fish have underdeveloped anti-predator behaviour as has been shown for some hatchery-reared fish (Olla *et al.* 1998), or if fish have limited escape and hiding space due to the spatial properties of water bodies.

The recreational angling sector are often at odds with piscivorous wildlife (e.g. Poledník *et al.* 2004; Werner & Dorr 2006), and studies have obtained mixed findings as to the impacts of fish predators on species of recreational angling importance (e.g. Čech & Vejřík 2011; Butler 1994). My findings suggest that C&R has limited effects on the apparent survival of rainbow trout, at least in the short-term, and I therefore suspect other factors such as predator prevalence, likely contribute to the low long term survival probability of fish at the study site. Otter prevalence was highest at the weirs, and fish survival probability was lowest at the weirs, potentially pointing towards otters negatively impacting fish stocks. Exact quantification of fish mortality resulting from different sources will require more controlled conditions, and will be especially difficult to determine under field conditions without invasive and resource-intensive actions. Repetition of this study following management actions to reduce predation would likely provide a clearer idea of the impact of predators on fish stocks and aid in assessing the success of management decisions. A number of strategies could be employed to overall improve long term survival probability of fish stocks, including mitigating predation, altering water bodies to improve suitability for trout, and establishing angling guidelines that will reduce impacts of C&R on fish stocks. Although this study did not measure the direct impacts of predators on fish stocks, it did indicate that certain water bodies seem to be targeted by predators more than others. There is also the possibility that night-time predator visitation rates to different water bodies might reflect differently from what I recorded in this study (especially for otters which are often – although not exclusively - nocturnal). Nonetheless, my findings did indicate that habitat preferences of predators should be taken into account when planning mitigation strategies. Further elaboration on management actions to improve fish survival and reduce predator impacts are discussed in Chapter four.

CHAPTER FOUR: GENERAL DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

The questionnaire showed that all respondents believed that they were experiencing stock losses to predators, however the perceived extent of these losses varied greatly between respondents. These findings support my prediction of wide-spread reports of predator-induced losses to fish stocks, but only partially supports my prediction that fish predators are perceived as posing an extensive threat to fish stocks with less than a third of respondents claiming extensive losses due to depredation. Otters and cormorants had the highest perceived level of threat, while fish eagles and cormorants were generally seen as posing little threat to fish stocks. A large proportion of respondents believed that fish predators did attract guests to the property, or that guests enjoyed seeing some of these predators. However, the majority of respondents did not consider this attraction to compensate for fish losses from an economic perspective. A few respondents mentioned that otters were particularly elusive and rarely seen by guests, but that otters could potentially be a tourist attraction if they were more easily seen. This is in line with a study conducted by Dumalisile *et al.* (2005) who reported that 90 % of tourist respondents reported interest in seeing otters and were willing to pay a fee for a trained guide to show them otters. They concluded that otters have the potential to enhance ecotourism in the area (Eastern Cape Wild Coast, South Africa) and so provide a source of income to local communities (Dumalisile *et al.* 2005).

The current perceived lack of economic benefit derived from predators, together with the fact that all respondents reported predator-induced fish losses, highlights the need to address this matter. Research into the views of visitors to fly-fishing properties is needed as well as the potential of fish predators to provide economic advantages for properties by means of ecotourism to possibly offset costs incurred from predator-induced losses.

The findings we obtained from our mark-recapture based experiments potentially supports the notion that predators play a substantial role in fish losses. The high weekly survival probability of fish, in contrast with my prediction of low survival, suggests that catch-and-release angling (C&R) is not causing high levels of mortality in fish as it is unlikely that fish mortality more than a week post landing would occur as a direct result of C&R. Generally, fish landed for a second (or even third or fourth time) were in good condition and seemingly showed little fitness consequences from their previous capture (pers. obs.), corroborating the likelihood that C&R is not causing major stock losses. Mongillo (1984) and Boyd *et al.* (2010) found that 90 % of C&R mortality occurs within 48h after release. High short-term survival therefore probably acquits C&R but this leads to the question of what is responsible for such low long term survival probability of fish. The low long term survival probability was in line with my predictions, and there is a number of factors that might be contributing to these findings. Although this study did not attempt to directly quantify predator impacts on fish stocks, in light of their observed daytime prevalence at my study sites it is likely that predators are contributing to low long term survival probability of fish. Also this study does not account for possible sub-lethal effects of C&R such as a potential decrease in anti-predator behaviour. Furthermore the research presented here was conducted in winter to early spring, and given the increased sensitivity of trout to C&R in elevated water temperatures (e.g. Klein 1966; Schisler *et al.* 1996;), data collected during summer could potentially yield even lower long term estimates of fish survival.

Environmental conditions can potentially contribute to the low long term survival probability of fish, with factors such as water temperature, dissolved oxygen, and pollutants having been shown to negatively impact trout fitness and survival (e.g. Swift 1981; Alabaster & Lloyd 1982; Reid *et al.* 1997; Linton *et al.* 1998; Person-Le Ruyet *et al.* 2008). Records kept by Millstream show that a statistically significant downward trend in angling success (in terms of fish caught per rod) occurred over the period of 2005 to 2015, and that 2015 was the year of the lowest mean fish/rod (Appendix C, Fig. C 1). Rainfall records kept by Millstream over the period of 2008-2015, shows that the years of 2013 to 2015 were particularly dry years, with 2015 experiencing the lowest rainfall recorded from 2008-2015 (Appendix C, Fig. C 2). Furthermore, 2015 was the third year in a three year 'dry spell' (2013, 2014, and 2015) with annual rainfall for 2013, 2014 and 2015 respectively decreasing by 9 %, 11 % and 13 % in relation to mean annual rainfall over the 2008 – 2015 period. Drought causes an increase in the surface area to volume ratio of water bodies (decreased water levels) and increases the physical extremes, such as temperature and dissolved oxygen of water bodies (Magoulick & Kobza 2003). During the drier years at Millstream, fish therefore likely lost part of their habitat and were more exposed to extremes in water conditions. These conditions could potentially explain the observed decrease in angling success. Additionally, drier environmental conditions likely had multiple impacts on piscivorous predators. Decreases in water levels of natural water bodies and the prey they contain most likely increased the reliance of predators on artificial water bodies such as those on fishing properties and the constant food supply provided by the stocking of fish. Lower water levels and other drought-related effects possibly increased the ease with which certain predators could hunt fish. For example, African clawless otter have been shown to hunt more successfully in shallower waters and their presence have been preferentially linked to water bodies of 1-2 m in depth as opposed to those deeper than 2 m (Nel & Somers 2007).

Following the low angling success of 2015, Millstream increased the overall number of fish stocked in 2016 by 42 % compared to 2015 (Appendix C, Fig. C 3). If an influx of predators did occur over the course of the drier years, the increase in stocking would have provided predators with an even larger food source and likely further increased predator numbers on Millstream. Millstream management have observed an increase in otter presence on the property over the preceding five years (Kemp & Vincent pers. comm.), and the conditions and actions as described above likely contributed to this. It is also plausible that otters will seek refuge on properties where there are no mitigations measures in place against them, such as Millstream (Kemp & Vincent pers. comm.).

Preventative measures against fish predators are often considered to be ineffective, or highly variable in efficacy, or too costly (e.g. Draulans & van Vessem 1985; Kloskowski 2005; Quick *et al.* 2004; Bregnballe *et al.* 2015), and most measures are in fact symptomatic treatments of the problem. The questionnaire section of my research revealed that lethal measures are the most prevalent mitigation measure against fish predators on the fly-fishing properties represented by interviews. Culling predators may be a suitable short term mitigation strategy, but it is like many other mitigation measures a symptomatic treatment of the problem. WBC , for example, are wide ranging birds regularly travelling more than 10km between roosting and foraging sites (Olver & Kuyper 1978; Brooke *et al.* 1982), and killing birds at Millstream merely vacates a predatory niche that is most likely to be filled by other individuals. Similarly attempting to reduce otter numbers by translocation or culling only opens up space for different individuals to occupy. The opinions of visitors to fly-fishing properties should also be deliberated when deciding on mitigation strategies – the questionnaire showed that managers believe that guests enjoy viewing piscivorous predators, and several anglers at Millstream communicated their love of nature. Mitigating depredation should be done in such a manner as to least offend visitors and so as not to distract from guest experience. Ideally, preventative measures should be aimed at addressing causal factors of human-wildlife conflicts. Environmental characteristics that influence the appeal of foraging sites to predators is a prime example of a causal factor that deserves recognition. Valuable information on mitigating depredation, through manipulating the foraging environment by decreasing the ease of hunting for predators, could be gathered in the differential observation in predators between Coleridge and the weirs. The different foraging environments of Coleridge and the weirs (in terms of size and depth of water bodies, vegetation cover, presence of jetties, and level of human-disturbance), attracted predators differentially with otters being most prevalent at the weirs, but cormorants and fish eagles most prevalent at Coleridge. This partially supported my prediction that predator visitation would be lower at waters closer to sources of human-disturbance with fish eagle and cormorants being most prevalent at the quieter water which is Coleridge. However, otter visitation rates contrasted with my expectations and were most prevalent at the weirs. As predicted, human-presence (angling effort) did correlate negatively with cormorant visits at Coleridge, but there was little to no correlation between human-presence and the visitation rates of otters or fish eagles.

Optimal foraging theory is based on mathematical modelling that predict how animal behaviour patterns might be favoured by natural selection (Stephens & Krebs 1986). Optimal prey selection models are based on two main factors: prey profitability and encounter rate (Danchin *et al.* 2008). Prey profitability is the energy content of a prey item versus the handling time for that prey item (i.e. time taken to capture and eat prey). Prey encounter rate is determined by prey abundance and the subsequent length of intervals between prey encounters (Danchin *et al.* 2008). By altering certain aspects of water bodies one can increase the availability of refuges for fish to avoid predators, and thereby decrease prey encounters, or one can increase the difficulty for predators to capture fish and thereby increase the handling time of prey. This would lead to a decrease in the profitability of trout as a prey item and, accordingly the predictions of optimal foraging theory, lead predators to favouring more profitable prey. Indeed, Russel *et al.* (2008) reported that the presence of fish refuges in ponds consistently reduced cormorant foraging success in comparison to ponds without refuges. Increasing depth and size of water bodies will likely decrease otter hunting success, while removing or altering jetties in such a way as to prevent cormorants from utilising them as perching sites will likely reduce the foraging appeal of water bodies to cormorants. Jetties have indeed been linked to cormorant nuisances on fishing properties in the Dullstroom area (Vincent pers. comm.).

The high popularity of C&R at fishing properties that participated in the questionnaire, and also at Millstream, highlights the importance of minimizing adverse effects in caught and released fish. Establishing angling guidelines can decrease the effects of C&R on fish and so reduce the chances of predators targeting fish weakened from C&R. Better physical condition of fish will most likely increase the effort taken by predators to capture fish, in effect decreasing the profitability of the prey. In their review on C&R mortality, Bartholomew & Bohnsack (2005) concluded that the anatomical location where a fish is hooked is the greatest factor determining mortality. However, other factors such as the use of j-hooks as opposed to circle hooks, use of natural bait, warm water temperatures and increased playing and handling times all contributed to fish mortality. The use of barbed j-hooks also cause slightly higher mortality than using barbless j-hooks (Bartholomew & Bohnsack 2005). Boyd *et al.* (2010) found no C&R mortality of rainbow trout in water temperatures below 20°C, but mortality increased to 16 % for water temperatures equal to or greater than 23°C. They concluded that the Montana Fish and Wildlife Department's angling closure policy (drought fishing policy) which dictates that waters containing salmonids be closed when maximum water temperature reaches or exceeds 23°C for three consecutive days, is a valid manner to reduce C&R mortality (Boyd *et al.* 2010). Rainbow trout have been shown to be more resistant to elevated water temperatures when periods of cooler temperature occur between temperature peaks, allowing respite from thermal stress (Hokanson *et al.* 1977). Providing trout with refuge against high temperatures (such as deeper sections in water bodies) is therefore, in all likelihood, a valuable tool to alleviate the effect of C&R induced thermal stress, especially during summer months. This factor plays a possible part in the higher survival probability estimated for Coleridge, which is much deeper than the weirs. Restricting angling to the cooler times of the day in summer months, can also potentially improve fish survival at Millstream.

Begon *et al.* (1990) identify three general types of resources needed by living organisms: the elements that make up their bodies, the energy required to perform their activities, and the spaces needed to carry out their life cycles. Food resources at a fishing property like Millstream will always be high (due to artificial stocking of fish) and is therefore unlikely to be a factor limiting predator numbers. However, by selectively modifying habitats one can regulate suitable “space” as a resource and thereby limit the number of predators dependent on that resource. Availability of suitable vegetation cover and the presence of boulders near the water’s edge has been linked to the presence of African clawless and spotted-necked otters (Nel & Somers 2007; Reed-Smith 2010). Similarly, by decreasing the availability of suitable cormorant perching sites near water bodies, one is likely to increase intraspecific competition and in the process limit cormorant numbers on the property. Coleman *et al.* (2005) reported that landscape factors such as water depth and bottom substrate of lakes affects foraging site selection in double-crested cormorants (*P. auritus*), highlighting how knowledge of cormorant habitat preferences can be utilized in managing cormorant-fisheries conflicts. Altering habitat characteristics in such a way as to decrease the appeal of fishing properties to cormorants is a potential avenue of mitigation to consider and may be a better long-term solution compared to other preventative measures such as scaring devices, which the cormorants can become accustomed to.

A range of potential avenues of mitigation exist to alleviate human-predator conflict in the South African fly-fishing industry, and the effectiveness of these at different localities and under differing conditions requires investigation. As shown by my research, HWC does occur in the South African fly-fishing industry. The extent and prevalence of these conflicts has the potential to increase, especially in light of factors such as climate change and an ever expanding human population – which respectively leads to an increase in droughts and other climatic extremes and also to the loss of habitat important to, amongst other species, piscivorous predators. Both the African clawless otter and spotted-necked otter are listed as Near Threatened on the IUCN Red List with habitat loss listed as a major threat to both species (Jacques *et al*. 2015; Reed-Smith *et al.* 2015). Despite the negative impacts of trout introduced for fly-fishing purposes, the habitat that these properties provide to many indigenous species, should be considered when environmental regulations pertaining to the fly-fishing industry are made. The seemingly common occurrence of otters on fishing properties points to the potential importance of suitable, albeit not necessarily completely natural, habit provided by this form of land use. However, for these properties to provide a continuous habitat for piscivorous predators, ways of mitigating HWC that are both beneficial for predator conservation as well as the economics of the fishing property are needed. Looking into the possibility of creating income from the presence of predators, and/or employing suitable long-term mitigation measures to reduce predator-induced damage, must be done in a scientifically rigorous manner so as to allow the quantification of success from various strategies.

Recommendations

In light of the findings presented in this dissertation, my own observations during the course of this research, as well as the published research of others, I make the following recommendations pertaining to legislation, mitigation of HWC, and improvement of fish survival in the South African fly-fishing industry:

Legislation

Legislation pertaining to the invasion status of trout is a contentious matter in the fly-fishing industry. The miscellany of negative impacts that introduced species, such as trout, can have is well documented, yet based on my research I conclude that the following aspects should be considered when decisions on legislation that could impact South Africa's fly-fishing industry are made:

- Fly-fishing properties provide a habitat to many indigenous species, including spotted-necked otter and African clawless otter, species that are respectively listed as Vulnerable and Near Threatened (Mammal red list).
- Although the habitat provided by fly-fishing properties to indigenous species is often not completely natural, fly-fishing properties are likely still a more environmentally friendly form of land-use compared to many alternatives such as mining, plantations, intensive agriculture or residential development.
- Efforts are needed to bridge the gap between government, conservation scientists, and fly-fishing industry stakeholders in order for legislation to be constructed in such a way as to optimise sustainable development in terms of conservation and economic viability.
- I recommend further research into fly-fishing property utilisation by indigenous species, and especially threatened species, and also how this compares to alternate forms of land-use is. Further research along similar lines to questionnaire section of my study could also prove valuable at discerning factors underlying HWC in the fly-fishing industry.

Mitigating Predator-induced Fish Losses

The seemingly common occurrence of otters and other fish predators on fly-fishing properties points to the potential importance of suitable, albeit not necessarily completely natural, habit provided by this form of land use. However, for these properties to provide a continuous habitat for piscivorous predators, ways of mitigating HWC that are both beneficial for predator conservation as well as the economics of the fishing property are needed. The following are measures that I believe have potential in mitigating predator-induced fish losses, and deserve further research:

- Providing refuges for fish against predators - By altering certain aspects of water bodies one can increase the number of refuge locations available for fish to avoid predators and thereby decrease prey encounters, or one can increase the difficulty for predators to capture fish and thereby increase the handling time of prey. This would lead to a decrease in the profitability of trout as a prey item and, according the predictions of optimal foraging theory, lead predators to favouring more profitable prey. Indeed, Russel *et al.* (2008) reported that the presence of fish refuges in ponds consistently reduced cormorant foraging success in comparison to ponds without refuges.
- Increasing the depth and size of waters – This will likely decrease otter hunting success, as studies have shown that otters are more successful in hunting in shallower water closer to shore, and the presence of otter signs have been linked preferentially to water bodies of 1-2m in depth as opposed to those being 2-5m in depth (Nel & Somers 2007). Deeper sections in water bodies will also provide fish with added refuges to avoid predation as well as providing respite from high ambient temperatures. Increasing the size of water bodies will likely increase the difficulty for predators to locate fish and also provide the fish with more space to escape predators. The higher survival probability of fish in Coleridge compared to the weirs can likely be attributed, at least in part, to the larger size of Coleridge.
- Increasing competition between predators for resources other than food - By selectively modifying habitats one can regulate suitable "space" as a resource and thereby limit the number of predators dependent on that resource. Availability of suitable vegetation cover and the presence of boulders near the water's edge has

been linked to the presence of African Clawless and spotted-necked otters (Nel & Somers 2007; Reed-Smith 2010). Selectively reducing vegetation cover around waters will reduce the cover available to otters for resting and breeding and also likely reduce the appeal of these waters as foraging sites. Similarly reducing the number of perching sites available to avian predators such as removing or altering jetties in such a way as to prevent cormorants from utilising them as perching sites will likely reduce the foraging appeal of water bodies to cormorants.

- Ecotourism initiatives incorporating predators – A study conducted by Dumalisile et al. (2005) at the Eastern Cape Wild Coast reported that 89.5% of tourist respondents reported interest in seeing otters and were willing to pay a fee for a trained guide to show them otters. They concluded that otters have the potential to enhance ecotourism in the area and so provide a source of income to local communities (Dumalisile et al. 2005). Providing guided tours to fly-fishing property visitors to see or photograph predators like otters could potentially provide economic compensation for fish losses especially if otters are relatively easy to see at the property. Research into the views of anglers and other fly-fishing property visitors towards fish predators could similarly provide valuable insights

Improving Fish Survival

The findings of my study likely indicates that C&R angling in winter and early has little effect on trout stocked at the study site, as short term (weekly) fish survival was high. Due to unforeseen circumstances I was not able to include summer fieldwork on fish survival probabilities, and given the sensitivity of trout to increases in temperature, it is likely that C&R may well have an effect on fish survival in summer. For this reason, and also the fact that healthier fish are harder targets for predators, I include recommendations to limit the effects of C&R on trout as far as possible.

- Closing waters to anglers during periods of extreme heat – Boyd et al. (2010) did a study on C&R induced mortality in rainbow trout in elevated water temperatures. The study was done in response to the Montana Fish and Wildlife Department's angling closure policy (drought fishing policy), where waters are closed to anglers when daily maximum water temperatures exceeds 23°C for a set period of time. Boyd et al. (2010) found no C&R mortality of rainbow trout in water temperatures below 20°C, but mortality increased to 16% for water temperatures equal to or greater than 23°C and they therefore concluded the policy to be a valid strategy to preserve fish stocks. Although it would likely be unsuitable for fly-fishing properties to close waters to angling altogether, one could perhaps urge anglers to not fish during the heat of the day in summer and to take special care when releasing fish when temperatures are high.

- Providing thermal refuges for fish - Rainbow trout have been shown to be more resistant to elevated water temperatures when periods of cooler temperature occur between temperature peaks, allowing respite from thermal stress (Hokanson *et al.* 1977). Providing trout with refuge against high temperatures (such as deeper sections in water bodies) is therefore, in all likelihood, a valuable tool to alleviate the effect of C&R induced thermal stress, especially during summer months.
- Establishing angling guidelines to decrease the effects of C&R on fish - In their review on C&R mortality, Bartholomew & Bohnsack (2005) concluded that the anatomical location where a fish is hooked is the greatest factor determining mortality, however other factors such as the use of j-hooks as opposed to circle hooks, use of natural bait, warm water temperatures and increased playing and handling times all contributed to fish mortality. The use of barbed j-hooks also cause slightly higher mortality than using barbless j-hooks (Bartholomew & Bohnsack 2005). Educating anglers on proper C&R protocols can aid in protecting fish stocks – anglers should be urged to use circle hooks or barbless j-hooks, reduce playing time, and to correctly handle fish and minimize handling time and air exposure.
- Employing specialized "recovery-bags" to aid in the recovery of C&R fish – Research into the use of recovery-bags have shown promising results, reducing lactic acid levels in fish as well as decreasing recovery times (Farrell et al. 2001a; Farrell et al. 2001b; Brownscombe et al. 2013). It may well be worth looking into recovery gear that will suit the particular circumstances at Millstream and promote the use thereof at the farm.

Most importantly I recommend further research into the dynamics of HWC in the South African fly-fishing industry – including, but not limited to: baseline studies of fish survival probability against which to measure the impacts of various environmental conditions and management actions; in depth study of factors underlying stakeholder perceptions of HWC; scientifically rigorous employment of different predator mitigation measures and their impacts; and research on the economic and environmental feasibility of tourism initiatives centred around fish predators such as otters and avian predators.

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APPENDICES

Appendix A

Supplementary material to Chapter 2

Questionnaire

<u>Demography</u>

1. How long have you been involved in the fly-fishing industry?

<2 years	
2-5 years	
5-10 years	
10-20 years	
20 + years	

2. How are you involved in the fishing property?

Owner	
Manager	
Both owner and manager	

3. How long have you been involved with the current fishing property?

<2 years	
2-5 years	
5-10 years	
10-20 years	
20 + years	

4. Gender:

Male	
Female	

5. What is your age?

20-25	
25-30	
30-40	
40-50	
50+	

6. Where is the fishing property located?

7. How large is the fishing property?

8. How many dams are present on the property?

9. Approximate size of largest stocked dam?

10. Approximate size of smallest stocked dam?

11. Average dam size on the property?

12. Is there a river/ stream on the property?

13. Which fish species are stocked on the property?

14. Which species occur naturally/ is present but not stocked on the property?

15. How often do you stock fish?

16. How many fish (weight or numbers) do you stock when restocking (per individual dam as well as in total)?

17. What is the stocking density of fish on the property?

Fish predators

18. Are you experiencing fish losses to predatory animals?

Yes	
No	

19. If yes, how would you rate these losses?

Small	

Medium	
Extensive	

20. Which of these fish predators are present on your property? 21. Are they present year round or seasonally?

Species	Presence/Absence	Seasonality
Otters		
Water mongoose		
Cormorants		
Herons		
Fish eagle		
Other (Please specify)		

22. How would you rate the threat posed to stocks by these predators on a scale of 1 – 5 (1 = no threat; 5 = very high threat/ considered a serious pest)?

Species	Threat
Otters	
Water mongoose	
Cormorants	
Herons	
Fish eagle	
Other (Please specify)	

23. Do you employ preventative measures (e.g. fencing, shooting) to reduce predation?

Yes	
No	

24. If no, why not?

25. If yes, which measures do you employ? 26. Which predatory species are targeted by these preventative measures?

Preventative measure		**Species targeted**
Fencing regular		
Fencing electrical		
Lines/ nets over dams		
Scaring devices		
Human patrolling		
Trapping		
Shooting – fatal		
Shooting – scaring		

27. If trapping takes place, what is done with captured animals? (E.g. relocated/ destroyed etc.?)

28. Do you think the fish predators present on your property attract tourists/ guests?

Yes	
No	
Maybe	

29. From an economic perspective, does this compensate or make up for the fish losses experienced?

Yes	
No	
To some extent	

<u>Catch-and-release angling</u>

30. Do you employ catch-and-release angling?

Yes	
No	

31. For what reason do you/ do you not employ catch-and-release angling?

32. If yes, how do you employ catch-and-release angling?

Permanently in all dams	
Permanently in designated dams	
Permanently for fish under a certain size	
Permanently for fish above a certain size	
Catch-and-release angling is optional – fishermen's discretion	
Catch-and-release angling is not allowed	

33. If catch-and-release is practiced seasonally, please specify the seasons:

Summer	
Autumn	
Winter	
Spring	

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Faculty of Natural and Agricultural Sciences
Ethics Committee

E-mail: ethics.nas@up.ac.za

Date: 23/08/2016

ETHICS SUBMISSION: LETTER OF APPROVAL

Dr T McIntyre
Department of Zoology and Entomology
Faculty of Natural and Agricultural Sciences
University of Pretoria

Reference number: EC160721-060
Project title: Human-wildlife conflict in South African fly-fishing industry: perceptions regarding fish predators

Dear Dr McIntyre,

We are pleased to inform you that your submission conforms to the requirements of the Faculty of Natural and Agricultural Sciences Ethics committee.

Please note that you are required to submit annual progress reports (no later than two months after the anniversary of this approval) until the project is completed. Completion will be when the data has been analysed and documented in a postgraduate student's thesis or dissertation, or in a paper or a report for publication. The progress report document is accessible of the NAS faculty's website: Research/Ethics Committee.

If you wish to submit an amendment to the application, you can also obtain the amendment form on the NAS faculty's website: Research/Ethics Committee.

The digital archiving of data is a requirement of the University of Pretoria. The data should be accessible in the event of an enquiry or further analysis of the data.

Yours sincerely,

Chairperson: NAS Ethics Committee

Table A 1: Summary of the number of dams and mean dam size on the represented properties.

	Responses (n)	Mean (± SE)	Range
Number of dams on property	19	5.16 (± 0.94)	1 – 14
Dam size	16	6.87 ha (± 2.23 ha)	0.28 – 29.38 ha

Table A 2: Summary of the reasons given to why respondents do not employ mitigation measures.

Reasons	Number of responses
Nature conservation	4
Depredation not important enough	2
Legal reasons	2
Birders also utilise property	1
Stock only large fish	1
Lack of manpower	1

Table A 3: Summary of the reasons given to why catch-and-release angling is employed on properties.

Reasons	Number of responses
Ethical reasons	5
Fishing is just a hobby	3
To protect fish stocks	9
Economic viability	7

Appendix B

Supplementary material to Chapter 3

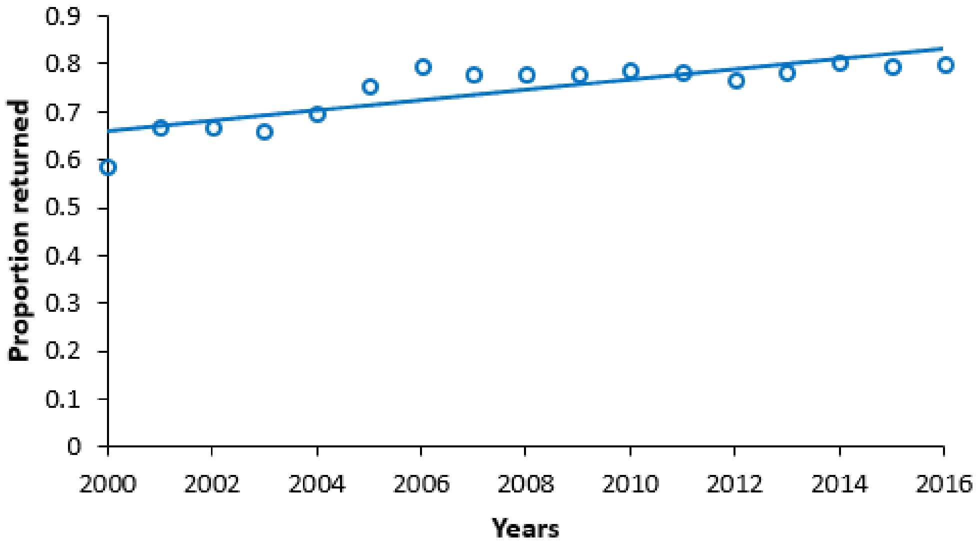

Figure B 1: Proportion of angled fish returned (caught-and-released), on Millstream Farm over the period of 2000 – 2016. A Pearson's correlation revealed a statistically significant, strong overall upward trend in the proportion of fish released over the years (r = - 0.85, p < 0.05).

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Animal Ethics Committee

PROJECT TITLE	**Human-wildlife conflict in the fly-fishing industry: Do catch-and-release angling increase predation on fish stocks?**
PROJECT NUMBER	**EC028-16**
RESEARCHER/PRINCIPAL INVESTIGATOR	**M de Vos**

STUDENT NUMBER (where applicable)	**UP_11022282**
DISSERTATION/THESIS SUBMITTED FOR	**MSc**

ANIMAL SPECIES	**Trout**	
NUMBER OF ANIMALS	**500**	
Approval period to use animals for research/testing purposes		**May 2016 –May 2017**
SUPERVISOR	**Dr T McIntire**	

KINDLY NOTE:

Should there be a change in the species or number of animal/s required, or the experimental procedure/s - please submit an amendment form to the UP Animal Ethics Committee for approval before commencing with the experiment

APPROVED	Date 14 June 2016
CHAIRMAN: UP Animal Ethics Committee	Signature

S4285-15

Investigating otter diet on a fly-fishing estate: Are otters a management concern?

Project Report

Marié de Vos

Department of Zoology and Entomology

University of Pretoria

South Africa

Supervisor: Dr. T. McIntyre (Mammal Research Institute, University of Pretoria).

Co-supervisors: Dr. G. Hall (Mammal Research Institute, University of Pretoria).

Prof. M.J. Somers (Centre for Wildlife Management, University of Pretoria).

Prof. M.N. Bester (Mammal Research Institute, University of Pretoria).

Abstract

Otters are often involved in human-wildlife conflicts in the aquaculture, fishing and sport-fishing industries. The Dullstroom area in the Mpumalanga Province, South Africa, supports an extensive recreational fly-fishing industry. This study investigated African clawless otter (*Aonyx capensis*) diet on a private fly-fishing estate near Dullstroom. Macroscopic analyses of spraints showed that African clawless otter utilize a variety of food sources, with crab being the dominant prey item in terms of percentage occurrence (PO = 100 %), relative percentage of occurrence (RPO = 40 %), and percentage dry mass (PDM = 91 %). These results are in agreement with several other studies that found crab to be the most important prey of African clawless otters. The PO (42 %) and RPO (17 %) of fish (mostly rainbow trout (*Oncorhynchus mykiss*)), are however much higher than what was found in similar studies and suggest that otters might indeed be considered a management concern for the Mpumalanga fly-fishing industry. Camera traps deployed to monitor otter activity patterns, showed that African clawless otters were mostly active at night, and had a slightly crepuscular trend in activity levels. Camera trapping also confirmed the presence of another semi-aquatic predator, the water mongoose (*Atilax paludinosus*), while no recordings of spotted-necked otter (*Hydrictis maculicollis*) were made. Tissues of rainbow trout were analysed for stable isotopes of carbon and nitrogen to investigate the potential of this technique for inferring the

origin of trout remains found in otter spraints. Results indicated slight isotopic differences between river-caught trout and dam-caught trout, however a larger sample size is needed to confirm these results. The findings of this study places African clawless otter in direct conflict with fly-fishing estate management. Given the recent upgrading of the African clawless otter from a conservation status of Least Concern to Near Threatened, monitoring and mitigation of the situation is urgently required.

Relevant figures:

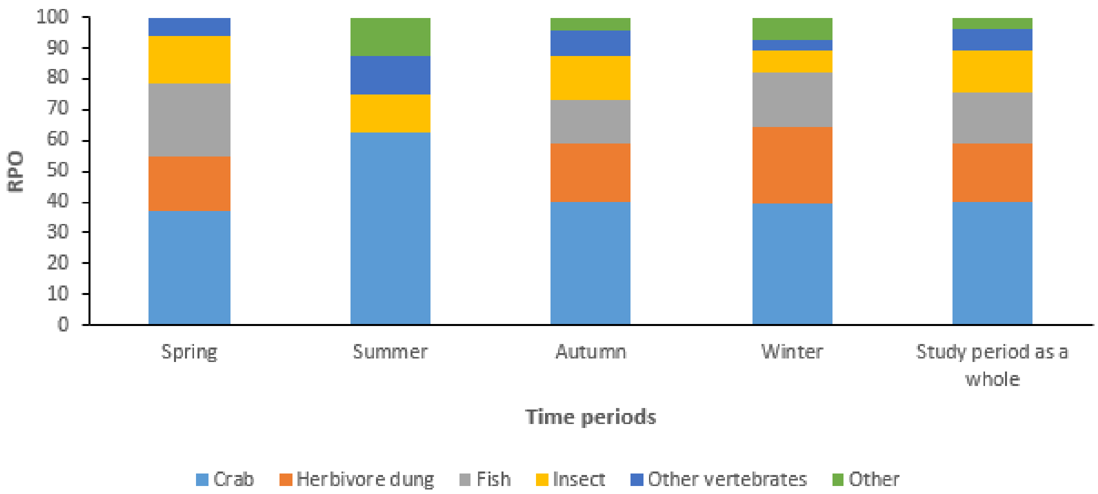

Figure B 2: Relative percentage of occurrence (RPO) of each prey category during the calendar seasons and the study period as a whole. Crab was identified as the dominant item found in spraints for the study period as a whole based on RPO (crab RPO = 40 %), followed by herbivore dung (19 %), fish (17 %), insects (13 %), other vertebrates (7 %), and other items (4 %). RPO = (Total number of occurrences of a specific prey category in all spraints / Total number of occurrences of all prey categories in all spraints) X 100.

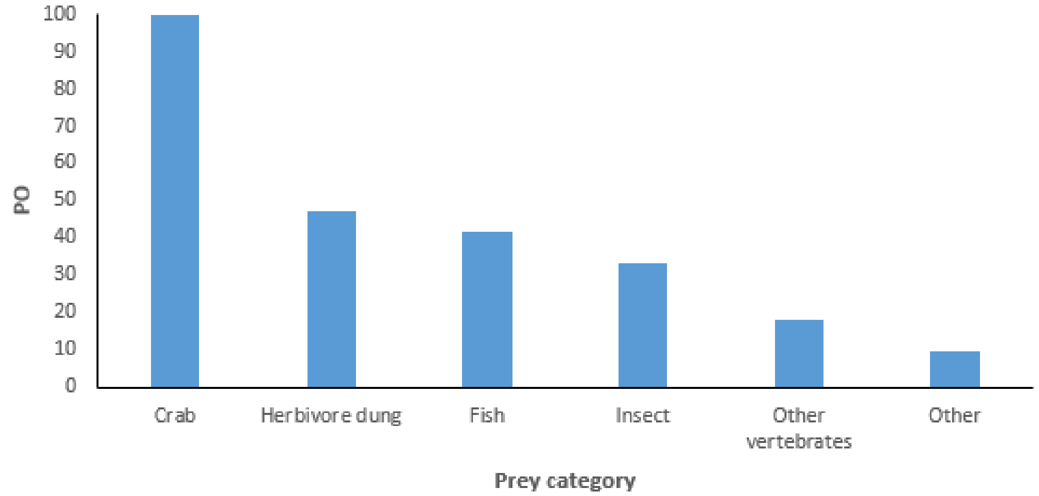

Figure B 3: Percentage of A. capensis spraints, collected during the study period, that contained the respective prey categories (crab, herbivore dung, fish, insects, other vertebrates, and other items) (PO = percentage occurrence). Crab had the highest PO, occurring in all spraints (100 %), followed by herbivore dung (47 %), fish (42 %), insects (33 %), other vertebrates (18 %), and other items (10 %) over the entire study period. PO = (number of spraints containing a specific prey category/ total number of spraints) X 100.

Angling effort and success – Supplementary figures

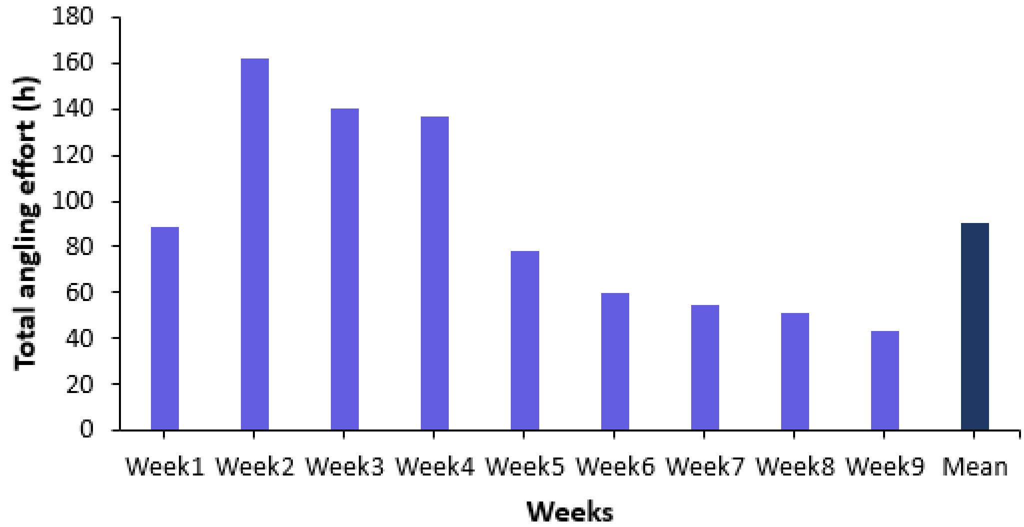

Figure B 4: total weekly angling effort (h) as well as mean weekly angling effort (h) recorded at Lake Coleridge during the 2016 study period.

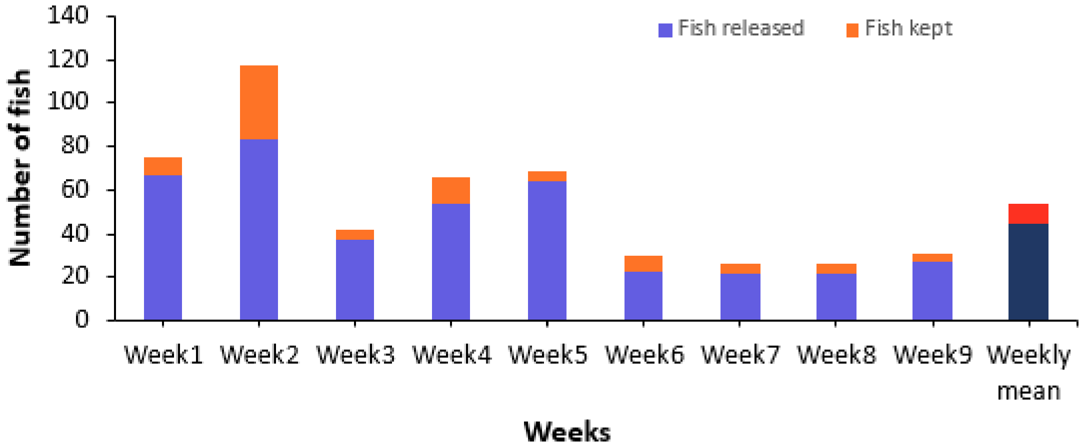

Figure B 5: Weekly number of fish landed (number released + number kept) as well as the mean weekly number of fish landed during the 2016 study period at Coleridge.

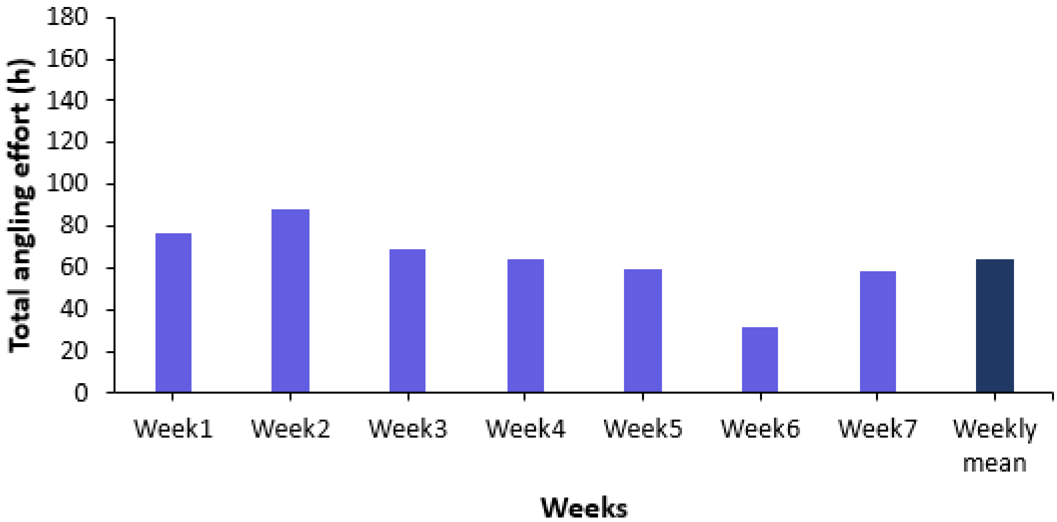

Figure B 6: Total weekly angling effort (h) and the mean weekly angling effort (h) recorded at the weirs for the 2017 study period.

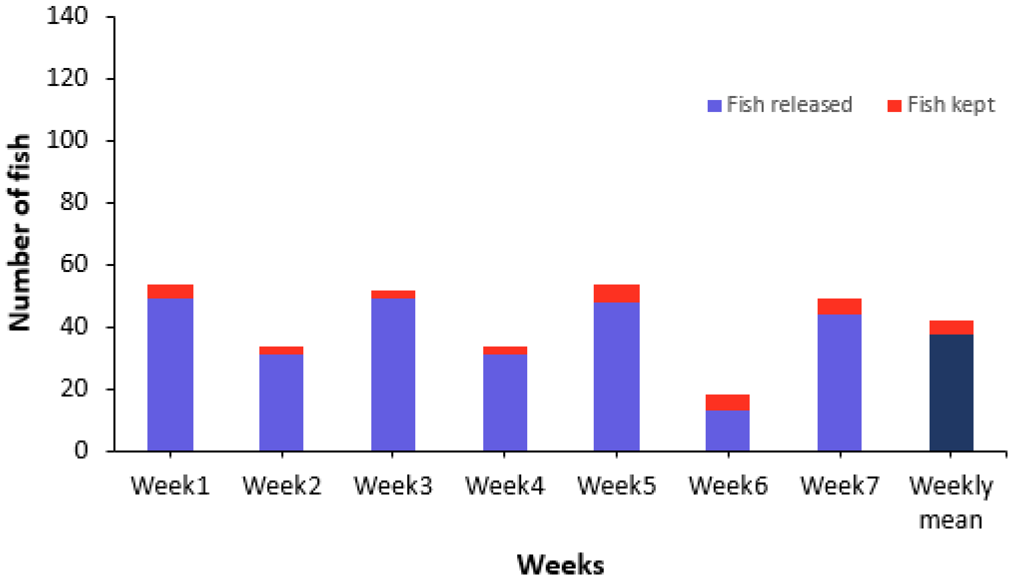

Figure B 7: Weekly number of fish landed (number released + number kept) as well as the mean weekly number of fish landed during the 2017 study period at the weirs.

Appendix C

Supplementary material to Chapter 4

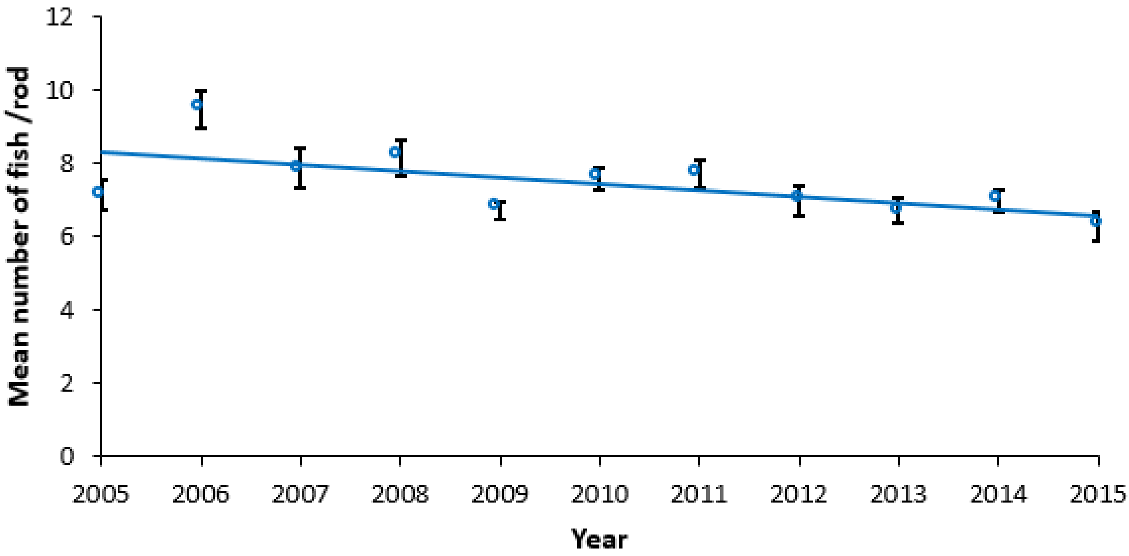

Figure C 1: Mean number of fish caught per rod (angler) at Millstream farm, for the period of 2005 – 2015. Error bars represent standard error. A Pearson's correlation revealed an overall downward trend of moderate strength in the mean fish/rod over the years that is statistically significant (r = - 0.653, p = 0.03).

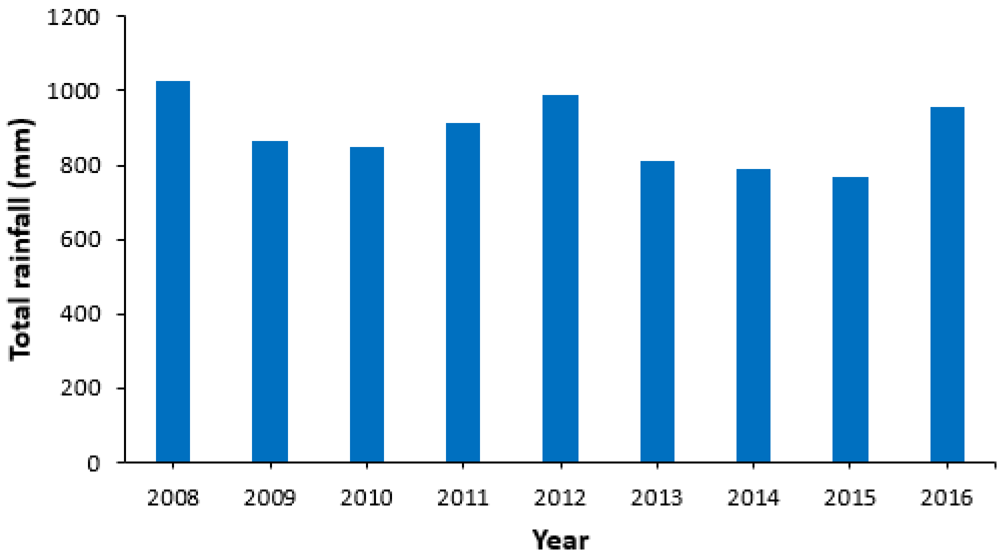

Figure C 2: Total annual rainfall collected on Millstream for the years of 2008 – 2016. Annual rainfall for 2013, 2014 and 2015 was respectively lower than mean annual rainfall for 2008 – 2015 by 9 %, 11 % and 13 %.

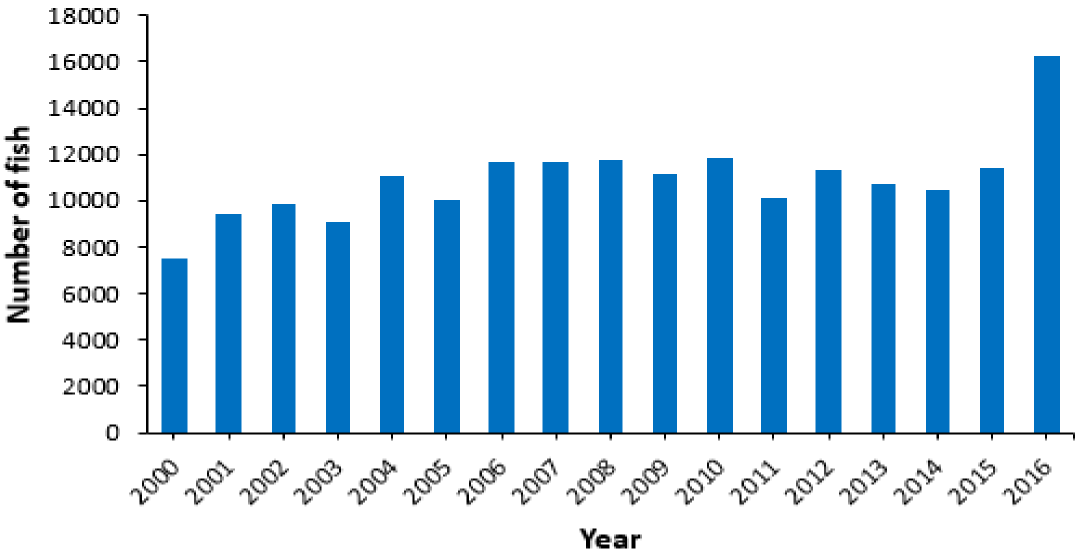

Figure C 3: The number of fish stocked at Millstream on a yearly basis for the period of 2000 – 2016. In 2016 Millstream increased the number of fish stocked by 42 % compared to 2015.