The role of Albertan anglers in tracking and controlling the invasive Prussian carp *Carassius gibelio* (Bloch, 1782)

by

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Abstract

The recent invasion of the Prussian carp (*Carassius gibelio*) in freshwater environments in central Canada threatens native aquatic species and ecosystems. The fish's hardiness, fecundity, and monozygotic reproduction pose challenges to their eradication, making population suppression and preventing spread priorities when it comes to addressing the invasion. Accurate distribution information is essential for targeting such efforts but is challenging to obtain given the logistics of continually sampling all locations within Prussian carp's potential range. Could resource users be used in a citizen science program to generate species distribution data? Here we investigate whether reports of Prussian carp by recreational anglers in Alberta, Canada could have application as a cost-effective alternative to or complimentary tool for traditional population distribution sampling and early warning systems for aquatic invasive species (AIS). Specifically, we ask 1) What factors affect an angler's willingness to report Prussian carp? (Chapter 2) and 2) To what extent does the distribution of Prussian carp generated by angler reports predict the distribution of the species determined by traditional biological sampling methods? (Chapter 3) To address these questions, we surveyed Albertan anglers in the summer of 2019, and in addition to having them report sightings of Prussian carp, asked a variety questions regarding characteristics that may influence their likeliness to report Prussian carp.

Our survey revealed that anglers' personal attachment to freshwater fisheries in Alberta and their perceived need for action to protect the fishery are important characteristics for predicting anglers' willingness to report Prussian carp, as well the angler's location (i.e., within or outside the province's largest urban center - Calgary; Chapter 2). These results suggests that in addition to detailing the ecological impact of the Aquatic Invasive Species (AIS), fisheries managers could encourage behaviours and programs that develop anglers' personal attachments

to the fishery and frame the threat of AIS in ways that highlight the effects of the invasion on their angling experience or the aspects of the aquatic environment they are attached to. Clarifying how action by anglers addresses the threat posed by AIS such as Prussian carp, so the efficacy of any proposed behaviour is understood, may also increase reporting.

Gathering reports of Prussian carp by recreational anglers in Alberta revealed that anglers can be a powerful resource for tracking an invasive species' distribution when compared with biological sampling; 88% of the Prussian carp reports aligned with regions known to be invaded based on biological sampling, and for every report of Prussian carp received in a HUC-8 area (hydrological unit code 8; the second finest Albertan watershed unit), the probability that area was invaded (as indicated by biological sampling) increased by more than 10 times (Chapter 3). We also found a positive relationship between anglers' fish identification abilities and likelihood of reporting Prussian carp. Anglers that fished more frequently were also more likely to have correctly identified Prussian carp, although the mechanism behind this relationship, be it sampling effort or angling specialization, is still unclear.

This greater understanding of the factors that affect angler engagement in pro-conservation behaviours such as AIS reporting could aid in campaigns that aim to use such reports to determine AIS distributions. Beyond reporting, information on angler motivations could aid managers in investigating opportunities for anglers to aid in AIS removal efforts.

Preface

This thesis is an original work by Natasha Pentyliuk. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "The role of Albertan anglers in tracking and controlling Prussian carp (*Carassius gibelio*)", animal ethics: AUP00003174, April 2019, human ethics: Pro00090898, June 2019.

Some of the research conducted for this thesis forms part of an Mitacs accelerate fellowship in partnership with Alberta Conservation Association (ACA). The data collection for the eDNA sampling in Chapter 3 was completed partnership with ACA. The data collection for the survey, the analysis for both chapters, and as well as the manuscript composition contained in this thesis is my original work. Dr. Stephanie Green assisted with the data analysis and contributed to manuscript composition and edits for the entire thesis, and Dr. Howie Harshaw helped with Chapter 2. Dr. Stephanie Green was the supervisory author.

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The unique challenges of the past year mean I am especially thankful for all the support my friends and family were able to give me while I completed this thesis. To my partner, Colin Bodor, the quality of your IT support is rivaled only by your emotional support – both of which were key to the completion of this research.

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CHAPTER 1: GENERAL INTRODUCTION

Aquatic Invasive Species (AIS) are the second biggest threat to freshwater fish in Canada next to habitat loss and degradation, affecting over 60% of endangered fish species in the country (Dextrase & Mandrak, 2006). AIS have also demonstrated their ability to wreak economic havoc; for example, AIS in the Great Lakes region cost Americans alone well over $100 million annually in direct economic losses and indirect costs such as loss of environmental benefits and social impacts (Lansing et al., 2012).

Options for addressing an invasion vary depending on the resources available, the habitat invaded, and the life history traits of the species in question. When eradication, i.e., complete elimination of the species from its non-native range, is not possible (as is the case for many invasions of AIS that are fecund and spread across large, interconnected habitats), the goal becomes preventing spread and suppressing AIS to minimize their ecological effects (Green & Grosholz, 2021). Population suppression involves various approaches to the removal of the species, and spread prevention is promoted in part by programs that target vectors of spread such as anglers who may be transporting AIS by accident on un-cleaned gear and watercrafts, or via the transfer of live bait (Seekamp et al., 2016).

Targeting efforts and resources for AIS suppression and spread prevention requires understanding the distribution of the species, especially for taxa that can take hold in new areas quickly following limited introductions (i.e., those with high reproductive rates and/or the ability for monozygotic reproduction). Efforts to describe the distribution of AIS are usually carried out by professionals via biological sampling methods such as environmental DNA sampling (i.e., "eDNA" sampling the water column for fragments of the organisms' DNA), electrofishing, or other labour and time-intensive processes (Evans et al., 2017).

Managers are increasingly turning to citizen science to gather ecological information about species of interest, such as their population distribution; relying on large numbers of public participants to report information on sightings of species that, in the context of AIS, could be used to flag areas of concern (Fairclough et al., 2014; Martelo J et al., 2021; Phillips et al., 2009; Sullivan et al., 2014). For example, the annual Christmas bird count and the eBird website/application for logging bird sightings by birders have proven to be key sources of avian biodiversity data (Sullivan et al., 2014). In the aquatic realm, recreational users of aquatic habitat such as anglers are beginning to be recognized and used for their ability to identify and sample a variety of fish species (Fairclough et al., 2014; Martelo J et al., 2021; Støttrup et al., 2018). Despite their frequent use (Fuller & Neilson, 2015), the efficacy of reports by non-professionals for predicting the distributions of terrestrial invasive species is poorly understood (Crall et al., 2011; Gallo & Waitt, 2011), let alone reports of AIS. The likelihood of AIS being reported in a waterbody is likely driven by a number of factors, including how many anglers use the area, because increasing fishing pressure increases the chance of AIS being detected. The likelihood of AIS being reported, if present, may also be affected by anglers' abilities to identify species as non-native and thus in needing reporting, as well as their willingness to report the invasive species.

An aquatic invasion for which there is growing interest in investigating the utility of recreational anglers for tracking species distribution and aiding in control is Prussian carp (*Carassius gibelio*). Prussian carp have spread across Europe, harming native species and reducing angling opportunities (Özuluğ et al., 2004; van der Veer & Nentwig, 2015). Unfortunately, the species now has a foothold in North America, with the invasion being confirmed in the Canadian prairies in 2006 (Elgin et al., 2014). Biological sampling by the provinces has found the species to be currently restricted to the Bow, Red Deer, and South Saskatchewan River drainages of Alberta and Saskatchewan (Docherty et al., 2017; Elgin et al., 2014), with the last effort to confirm the distribution being completed in 2019. Prussian carp are extremely hardy and fecund; individuals can clone themselves through monozygotic reproduction, and with conditions in most waterbodies in central Canada able to support Prussian carp, it only takes one individual to invade new habitats (Docherty et al., 2017). Eradication from the large, interconnected waterbodies in which Prussian carp are already present in central Canada is not feasible, so suppression and spread prevention are key (Docherty et al., 2017). The allocation of resources to carry out these objectives must be informed by the species' distribution, but regularly re-sampling all the possible locations Prussian carp may persist (i.e., anywhere) is prohibitively time and labour intensive.

The province of Alberta, home to a large portion of Prussian carp's non-native range in central Canada, registered an estimated 303,212 licenced anglers in 2015, which translates to roughly 14.5 anglers per km^2 of water (AEP, 2015) In contrast, the neighboring invaded prairie province of Saskatchewan has a ratio over 5 times lower, at 2.7 anglers per km^2 (Government of Saskatchewan, 2010). If reports of Prussian carp seen/caught by this large force of anglers across the province could reliably predict the actual distribution of these species, the engagement of recreational anglers could have potential as a cost-effective AIS early warning system or alternative to certain types of traditional population research. The possibility of such a reporting network raises two key questions: (1) What factors affect an angler's willingness to report Prussian carp? (Chapter 2) and (2) To what extent can reports of Prussian carp by anglers be used to reliably predict the distribution of the species, as compared with distribution determined by traditional biological sampling methods? (Chapter 3).

Chapter 2's investigations into the factors affecting anglers' willingness to report Prussian carp aims to help answer the following question: What are the characteristics of anglers that are more likely to participate in this Prussian carp reporting program? Knowing this, we may gain insight into how managers can best target and tailor their communications and outreach initiatives to leverage and enhance these characteristics.

Chapter 3's investigation into the use of angler reports to characterize the distribution of Prussian carp will address two specific questions: (1) How well do reports of invasive Prussian carp by recreational anglers in Alberta predict the species' distribution generated by traditional biological sampling methods? (2) What covariates should be considered when assessing the accuracy of the species' distribution generated from angler reports?

By addressing these questions, this thesis research will provide key information on the extent to which engaging recreational anglers could be a cost-effective alternative to - or complimentary tool for - traditional population distribution research.

CHAPTER 2: FACTORS AFFECTING ANGLER ENGAGEMENT IN AQAUTIC INVASIVE SPECIES REPORTING

Introduction

Aquatic Invasive Species (AIS) are the second biggest threat to freshwater fish in Canada behind habitat loss and degradation, affecting over 60% of endangered fish species in the country (Dextrase & Mandrak, 2006). The recent invasion of Prussian carp (*Carassius gibelio*) into freshwater ecosystems in the Canadian prairies is of particular concern because it threatens native aquatic ecosystems and fish populations, with implications for the recreational fisheries of the invaded provinces. Prussian carp are native to Siberia but their invasion has spread across Europe where they have taken over waterbodies and reduced the populations of native species (Özuluğ et al., 2004; van der Veer & Nentwig, 2015). The provinces of Alberta and Saskatchewan are currently the only confirmed locations in North America where Prussian carp have become established; their current distribution is believed to include the Bow, Red Deer, and South Saskatchewan River drainages (Docherty et al., 2017; Elgin et al., 2014).

C. gibelio is not the province's first non-native Carassius fish: goldfish (*Carassius auratus*), have been established in the Canadian prairies for decades, but while wild goldfish can look identical to their Prussian carp cousins, the more recent invader's life history traits have enabled it to be an especially substantial threat (Docherty et al., 2017; Rylková et al., 2010). Prussian carp's hardiness suggests that few locations in the prairies are off the table as potential habitats for the invader, and their high fecundity and monozygotic reproductive abilities mean that a single fish could result in a waterbody's invasion (Docherty et al., 2017). These characteristics pose a challenge to eradication efforts, especially in large, inter-connected waterbodies such as rivers and streams (Docherty et al., 2017).

Suppressing established populations and preventing the spread of Prussian carp to additional water bodies beyond its current range are priorities when it comes to addressing the invasion, requiring a nuanced understanding of the species' distribution. Alberta's last province-wide sampling effort by professionals using biological sampling techniques (e.g., electrofishing, eDNA sampling, etc.), to understand the distribution of Prussian carp was completed in 2019. However, continually sampling the immediate area around the perimeter of the species' known distribution and all the areas where a Prussian carp could establish were they to be introduced (i.e., most of Alberta) is a massive undertaking. Developing alternative methods for gathering information on the distribution of Prussian carp from numerous locations across Alberta, such as through citizen science programs that engage resource users, could help flag and direct the government's limited resources to sampling areas of greatest concern.

The use of citizen science (i.e., public participants in scientific research) in ecological research is becoming increasingly widespread, as is research into how best to apply and manage the approach's incredible data-collecting abilities (Phillips et al., 2009). In particular, citizen science reporting platforms are increasingly used to determine distribution of a variety of species across ecosystems (Phillips et al., 2009). For example, the eBird (a longstanding web application used to log bird sightings) and the annual Christmas bird count have proven to be key sources of avian biodiversity and distribution data (Sullivan et al., 2014). In the aquatic realm, recreational users of aquatic habitat such as anglers are beginning to be recognized and used for their ability to identify and sample a variety of fish species (Fairclough et al., 2014; Martelo J et al., 2021; Støttrup et al., 2018).

Alberta, Canada is home to more than 280,000 anglers (AEP, 2015) and there is growing interest in investigating whether this resource user group has the ability to identify, report, and potentially control non-native Carassius species. Recent work suggested that Albertan anglers may be unlikely to report sightings of invasive species, and instead have been thought to be a vector of AIS spread (Docherty et al., 2017). Studies of factors influencing willingness to engage in pro-conservation behaviours provide mixed evidence that education and outreach campaigns focused on awareness of the conservation issue alone can change one's willingness to participate (Jordan, Gray, Howe, Brooks, & Ehrenfeld, 2011). Instead, it has been suggested that awareness of conservation issues act in concert with other characteristics and perspectives (see 'Literature Review' below), to determine one's willingness to participate in pro-conservation behaviour to address said concerns (Drake et al., 2014; Knight et al., 2010; Larson et al., 2015; Martín-López et al., 2007; Shaw et al., 2012; St. John et al., 2010; Zanetell & Knuth, 2004). The extent to which such factors influence recreational angler engagement in AIS reporting is unknown.

Here we investigate factors affecting recreational angler engagement in reporting AIS using Prussian carp in Alberta as a key test case. Specifically, we conduct a survey of Albertan anglers in which we assess their willingness to report Prussian carp as indicated by their self-reported likelihood of reporting Prussian carp (if given the opportunity). We also gathered information about their: 1) perceptions about the state of the recreational fishery in Alberta; 2) level of concern about the fishery; 3) perceived locus of authority over the fishery; 4) dependence on the fishery; 5) sense of community; and 6) angling participation. We also assessed the extent to which informational/educational tools can be used to increase the frequency and accuracy of anglers' reporting of AIS such as Prussian carp by testing the effect of an information intervention presented within the questionnaire on respondents' stated willingness to report Prussian carp. We used these data to address the following key research question: What characteristics of anglers make them more likely to participate in reporting Prussian carp? With those characteristics identified, we then investigate how managers can best target and tailor their communications and outreach initiatives to leverage these characteristics to enhance tracking of the species' distribution and spread.

Literature review: potential drivers of engagement in AIS reporting

Analyses of involvement in citizen science has been primarily constrained to looking at the efficacy of particular activities or campaigns on increasing participation (C. B. Cooper et al., 2007; Jordan et al., 2011). To date, little research related to citizen science has sought to comprehensively understand the factors and personal characteristics that contribute to the participatory behaviour – such thorough survey and analysis is often completed by researchers investigating participation in other pro-conservation behaviours beyond citizen science such as environmental stewardship or engagement in environmentally-risky behaviours (Drake et al., 2014; Knight et al., 2010; Larson et al., 2015; Martín-López et al., 2007; Shaw et al., 2012; St. John et al., 2010; Zanetell & Knuth, 2004).

Numerous papers have investigated people's willingness to participate in pro-conservation behaviours, examining several dimensions of questions or characteristics. Although the conceptual and theoretical approach to organizing their questions differed greatly, the dimensions investigated in the survey by Zanetell and Knuth (2004) encapsulated most of the relevant components examined in other studies (see proceeding text in this section for discussion of these studies). Our survey addresses six conceptual areas (i.e., dimensions) proposed to be related to engagement in pro-conservation behaviour that we anticipate likely influence anglers' willingness to participate in reporting AIS. The five dimensions from Zanetell and Knuth (2004) are: 1) perception about the state of the fishery; 2) level of concern about the fishery; 3) perceived locus of authority over the fishery; 4) dependence on the fishery; and 5) sense of community. Our final dimension is 6) Angling participation, which included questions regarding time spent angling not asked by Zanetell and Knuth (2004).

Perception about the state of the fishery: Perception about the state of the fishery encompasses perceptions about the health of Alberta's fisheries and the role of AIS in the province. While encouraging understanding of fisheries health and the issues facing aquatic conservation efforts (such as the threat of AIS) is important, there is mixed evidence that increased knowledge of ecological processes alone can change willingness to participate in pro-conservation behaviours (Jordan, Gray, Howe, Brooks, & Ehrenfeld, 2011). Instead, is has been suggested that such conceptualizations act in concert with our other factors motivating pro-conservation behaviour, providing context for their perceived consequences (Drake et al., 2014; Knight et al., 2010; Larson et al., 2015; Martín-López et al., 2007; Shaw et al., 2012; St. John et al., 2010; Zanetell & Knuth, 2004).

Level of concern about the state of the fishery: Level of concern about the fishery is a dimension that addresses the consequence of the perceptions of fishery health, not the perceptions themselves (Zanetell & Knuth, 2004). For example, if someone perceives the fishery to be in a poor state, the consequence of this perception may be a higher level of concern for the fishery. This is not to say that questions are always clearly in one dimension or another. Drake et al., (2015), for example, asked questions regarding perceptions about various natural resources management practices, touching upon multiple dimensions all at once: their perceptions on the fisheries, the level of concern for the fishery, and the perceived locus of authority.

Locus of authority over the fishery: An angler's perspectives regarding top-down (i.e., government to community to individual) or bottom-up (i.e., individual to community to government) management (i.e., perceived 'locus of authority') could affect the extent to which they would be willing to participate in pro-conservation behaviours, as well as the extent to which they adopt a personal responsibility of maintaining fisheries health. For example, Lauber (Lauber, 1996) recognized locus of authority over the fishery as an important predictor of participation in – and perceived 'fairness' of - natural resource management decisions, despite the locus of authority scale proposed by Zanetell and Knuth (2004) failing to produce significant results. Perceived locus of authority can also affect anglers' attitudes surrounding a behaviour's need and utility (St. John et al., 2010), especially if the behaviour's efficacy is dependent upon the actions of a third party (Knight et al., 2010). In the context of this study, an angler's likelihood of reporting Prussian carp may be related to their confidence that the government is properly addressing the invasion even if reports are made. Alternatively, anglers could be less likely to report Prussian carp if they believe the location is already known and their report is not really needed – a sort of bystander effect.

Dependence on the fishery: The relationship between an angler's dependence on the fishery and pro-conservation behaviour was investigated by Zanetell and Knuth (2004) as it pertained to a Venezuelan freshwater fishery. Other papers have also investigated emotional dependence natural resources, though less explicitly: focusing instead on what could be markers of connection and perhaps emotional/ social dependence, such as recreation specialization or involvement in the community (Cooper, Larson, Dayer, Stedman, & Decker, 2015; Copeland, Baker, Koehn, Morris, & Cowx, 2017a). We investigated anglers' dependence on the freshwater fishery in Alberta both practically (i.e., their dependence on fishing for food) and emotionally, to identify the relationship between the well-being of Alberta's fisheries and the personal well-being of our participants. This relationship could be important to understanding a participant's motivation to carry out behaviours related to protecting the fishery.

Sense of belonging to the angling community: Sense of belonging to the community has been quantified through investigating the different ways an angler participates in the angling community and learning about the social aspects of anglers' fishing habits. One's investment in or sense of belonging to the community surrounding a resource has shown to be an important predictor of the likelihood a person will participate in pro-conservation behaviours surrounding that resource (Knight et al., 2010; Larson et al., 2015; Zanetell & Knuth, 2004) – as have social norms regarding pro-conservation behaviours (Drake et al., 2014; Shaw et al., 2012; St. John et al., 2010). While social norms were not thoroughly explored in this paper due to what we perceived as minimal awareness surrounding both the existence of Prussian carp and their reporting conventions at the time of the survey, other social aspects of angling such as their participation in the angling community, or how often they fish with others, were investigated, and could perhaps give insight into potential opportunity for the enforcement of social norms. Previous work on the extent to which angling is intertwined with participants' lives revealed relationships between pro-environmental behaviour and recreation specialization (Beardmore et al., 2015; C. Cooper et al., 2015; Copeland et al., 2017a).

Angling participation: Finally, previous work on angling participation has demonstrated a link between pro-conservation behaviour and recreation specialization – of which time spent angling is a component (Beardmore et al., 2013; Copeland et al., 2017a; Needham et al., 2009; Scott & Shafer, 2001). In the case of anglers reporting AIS, we focused on behaviours frequently associated with specialization that would facilitate application of this research; quantified as the amount of time spent engaging with the activity as a measure of the level of interaction an individual has with angling.

Methods

Survey development

We conducted an online survey of Albertan recreational anglers in the summer of 2019 to evaluate engagement by anglers in reporting AIS such as Prussian carp and the factors affecting their reporting behaviour. In addition to asking questions to determine the characteristics that may influence an angler's reporting of invasive Prussian carp, we also investigated consistency between stated willingness to participate in reporting and willingness to engage in other pro-conservation behaviours. The various pro-conservation behaviours assessed included: 1) willingness to report Carassius, 2) willingness to release Carassius, 3) willingness to consume Carassius, 4) frequency that they take fish from one water body to another, 5) adherence frequency to "clean, drain, dry", and 6) adherence frequency to angling regulation (such as catch/procession limits and catch-and-release rules; Table 2.1).

Our survey also included questions related to the six conceptual areas that we anticipated could influence angler's willingness to participate in AIS reporting: 1) perception about the state of the fishery; 2) level of concern about the fishery; 3) perceived locus of authority over the fishery; 4) dependence on the fishery; and 5) sense of community, and 6) angling participation (Table 2.1; Figure 2.1). In addition, we asked questions regarding anglers' use of technology to engage in angling-related activities, as well as questions regarding general demographic information. We collected anglers' demographic information as both a means of comparing our study sample to the greater angling population in the province, and to include as independent variables predicting anglers' willingness to report.

Use of technology to engage in angling: Determining anglers' use of technology provided a sense of their potential ability to engage with the technological aspects of common platforms used to report AIS (Table 2.1). For example, asking individuals to photograph AIS requires anglers to have a camera while fishing – something more likely to be the case among smart phone users. The potential use of angling-related smart phone applications for conservation initiatives such as reporting is being investigated by management agencies (S. Hamilton, personal communication, January 2021). Thus, while use of technology may not play a key role in influencing willingness to report in the way that social factors do, it could be of particular interest to those looking at implementation of future reporting platforms. For these reasons we asked whether they have a cell phone and/or smart phone, and if they did have a smart phone, the question regarding their app use determined whether they use fishing/angling-related apps. The distribution method the angler heard about the survey by was also determined (Table 2.1).

Demographic information: Demographic information included age, gender, and their postal code. The first three characters of their postal code make up their Forward Sortation Area (i.e., FSA). FSAs are composed of three characters: the first is a letter indicating the province (in Alberta this is "T"), the second character is a number (where "0" means rural and all other digits indicate the area is urban), and the last digit, together with the previous two characters, refers to a specific geographic district. We used the anglers' FSA to classify where they lived, with respondents assigned to one of the four regions: Edmonton, Calgary, other urban areas, or rural areas (Table 2.1; Figure 2.1).

Perception about the state of the resource: To evaluate angler perceptions about the state of fisheries resources, we asked four questions regarding their perception of the current health of Alberta's freshwater fisheries (Table 2.1; Figure 2.1). The respondent's broad perceived state of the fishery was explored by having them rate Alberta fish population compared to when they started fishing in the province (on a five-point interval scale of "much worse" to "much better"). To specify the survey's context as being about invasive fish, we also ask about the perceived effect of AIS on Albertan fisheries, where anglers indicated their perception to be no effect, a weak effect, or a strong effect. Campaigns by the province to encourage awareness of AIS and stop their spread into/ around the province is one avenue by which anglers could have heard of local AIS threats, along with message boards and community-led discussions in fishing-related groups they may participate in. The extent to which these perceptions were engaged with/ thought about was then explored with a question regarding the frequency that invasive fish are discussed (with the response options; never, sometimes, and frequently). Anglers' perceived extent to which humans affect the fishery (i.e., extent to which they think it is us humans that are to blame for harm done to the fisheries), was also assessed, allowing us to explore the extent to which the various variables in this dimension inform the extent to which they think it is said humans that need to take action and was asked as a statement that the respondent would rate their degree of agreement to on a seven-point interval scale from "strongly disagree" to "strongly agree". Anglers' perceived extent to which humans affect the fishery was also a subject investigated in the dimensions regarding anglers' level of concern over fishery and their perceived locus of authority over fishery (Table 2.1; Figure 2.1).

Level of concern over the fishery: We investigated anglers' level of concern over the fishery via two questions; one regarding the angler's concern for fish populations, and the other their perceived need for more fishery protection in Alberta (Table 2.1; Figure 2.1). Both questions were asked as statements that the respondent would rate their degree of agreement to on a seven-point interval scale from "strongly disagree" to "strongly agree" (Table 2.1; Figure 2.1).

Locus of authority over the fishery: To evaluate anglers' perceived locus of authority over the fishery, we asked respondents to rate their degree of agreement to on a seven-point interval scale from "strongly disagree" to "strongly agree" with four statements regarding level of responsibility for fisheries health in terms of: 1) sense of personal responsibility, 2) their perception individuals should be doing more, 3) their perception communities should be doing more, and finally, 4) their perception provincial government should be doing more (Table 2.1; Figure 2.1).

Dependence on the fishery: We investigated anglers' dependence on the fishery to explore relationships between the well-being of Alberta's fisheries and the personal well-being of our participants. In addition to inquiring upon their emotional dependence to the fishery, their practical dependence was measured with questions about respondents' dependence on fish as food. Both these questions were asked as statements that the respondent would rate their degree of agreement to on a seven-point interval agreement scale.

Sense of belong to the angling community: We investigated anglers' sense of community by asking them to respond to a statement about the extent to which the felt they belonged to the angling community in Alberta on a seven-point interval scale from "strongly disagree" to "strongly agree" (Table 2.1). We also explored the ways that anglers participated in the angling community, such as if the respondent: received angling-related newsletters and/or magazines, read/ viewed angling-related discussions online, participated in angling-related discussion online, attended angling-related functions/ activities in-person, and/or helped to plan/coordinate angling-related functions/activities. Finally, to gain further insight into the social aspects of their fishing habits, anglers were asked if they had friends or family that fish (as a binary yes/ no), and the frequency with which respondents fish with others (five point interval scale from "I always fish alone" to "I always fish with another person"; Table 2.1; Figure 2.1).

Angling participation: We assessed angling participation by asking respondents' about how many years they had fished, their number of years of fishing in Alberta, and their (anticipated average) days fishing per year (Table 2.1; Figure 2.1).

Information intervention: Finally, to assess the extent informational/educational tools about AIS can be used to increase the frequency and accuracy of anglers' reporting we also included an information intervention within the questionnaire. During the survey, participants were randomly assigned to one of four groups, with one-quarter of participants given information about Prussian carp as a popular fish for consumption, one-quarter given information about the potential harm Prussian carp may bring to native species and fisheries, one-quarter given both pieces of information, and one-quarter given neither information types (control group), with all respondents receiving additional baseline text about the species (Table A2.1).

Reporting Carassius: Towards the end of the questionnaire, we also provided respondents with information about how to identify *Carassius auratus* (goldfish) and *Carassius gibelio* (Prussian carp) and differentiate them from other similar Albertan species. Respondents were then asked if they had seen either Carassius species while fishing in Alberta, and if they had, asked to report the locations of those sightings. Respondents were then given instructions on how to report either Carassius species going forward, either via email or an online reporting platform (invasivereport.ca) managed by the research team. At the end of the survey, respondents were given the option to consent to further contact, enabling us to compared stated willingness to report to actual reporting rates by survey respondents (see 'Comparing actual reporting to stated willingness to report' section below).

Survey distribution

Initial survey of anglers

We constructed the survey using the online survey software Qualtrics (Qualtrics, Provo, UT), and distributed it for online completion by respondents between July and September 2019. Our distribution channels included email listservs (Alberta Conservation Association, Alberta Invasive Species Council, Sherwood Park Fish and Game Association, and other local Alberta Fish and Game Associations), Facebook pages (including Alberta Conservation Association, Sherwood Park Fish and Game Association, 'other' Fish and Game Associations, Alberta Fishing Addicts, and Alberta Fishing Buddies), Twitter (the Alberta Conservation Association twitter account), and through online public forums (the Alberta Outdoorsman).To reach anglers that may not use electronic means to engage with the angling community, we also distributed physical materials linking to the survey and reporting platform in the form of contact cards and flyers at 21 fishing locations and outdoor retail stores (such as Canadian Tire and the Fishing Hole), around Alberta, with a focus around central/southern Alberta.

To encourage participation and completion of the survey, we employed a lottery-style monetary incentive (Laguilles et al., 2011). Those who provided their email at the end of the survey were entered for a chance to win a $200 Cabela's/ Bass Pro gift card, with a second gift card available to those who provided their email *and* consented to further contact regarding the study. The names for the two respective draws were pulled on September 11, 2019, and

September 18, 2019. The two winners both consented to have their winning announced, which also acted as further advertising for the survey.

Comparing actual reporting to stated willingness to report

To determine the extent to which an angler's stated *willingness* to report from our initial survey reflects *actual* reporting for invasive Carassius spp., we sent out a follow-up one question survey in December 2020 (just over a year later), via email to participants that consented to further contact. These follow-up surveys were distributed after the summer fishing season when participants would have had the opportunity to sight Carassius spp. The follow-up question ascertained if they had seen any Carassius in all of 2020 and if they had, whether they had reported the sighting prior to our follow up survey.

Analysis

We quantitatively assessed the effect of our various factors (Table 2.1; Figure 2.1) on anglers' willingness to report Prussian carp using generalized linear modelling (GLM) and compared patterns of stated willingness to report to actual reporting using our survey data. All analyses were conducted in R statistical analysis software, version 3.6.1 (R core team. 2019).

Data processing and variable reduction

Given the large number of potential explanatory variables available from the survey (n = 26), we first conducted three variable reduction steps: the creation of aggregate (i.e., summative) variables, removal of correlated variables, and exclusion of variables with no relationship to willingness to report when assessed individually.

Aggregate variable creation

We first evaluated whether certain combinations of our explanatory variables were related in a manner such that they could be aggregated into summative variables. To do so, we entered the eligible variables into a Principal Components Analysis (PCA) – a psychometrically sound method of determining the extent to which variables contribute to another latent variable (Field et al., 2012)- using the packages *psych* (Revelle, 2019) and *corpcor* (Schaefer et al., 2012). Many variables were not eligible to be assessed with a PCA because they were binary or otherwise not continuous (Table 2.1), and so were later treated as individual independent (i.e., explanatory) variables in statistical models of the relationship with willingness to report (see next section). Along with continuous variables, we included variables that used interval scale data from the survey within the PCA analysis (DeVellis, 2016; Lubke & Muthén, 2004).

Using Bartlett's test of sphericity (which is the extent to which the variables' correlation matrix resembles an identity matrix), we identified that correlations between anglers' age, years fishing in Alberta, days fishing per year, dependence on fish as food, and perceived state of the fishery were too low (i.e., <0.05) to warrant inclusion within a factor analysis such as PCA. This left us with nine candidate variables that were sufficiently correlated to warrant factor analysis via PCA: sense of belonging to the angling community (from the sense of community dimension), emotional dependence on fishing (from the dependence on the fishery dimension), concern for fish populations and perceived need for more fishery protection (both from level of concern for the fishery dimension), perceived extent humans affect the fishery (from the perception about the state of the fishery dimension), and finally, sense of personal responsibility, perception provincial government should be doing more, perception communities should be doing more, and perception individuals should be doing more (all from the from locus of authority dimension; Table 2.1). The determinate of correlation matrix was 0.045: far above the minimum value of 0.00001 to ensure there is not too much multicollinearity. We also used the Kaiser-Meyer-Olkin (KMO) to ensure all the variables had at least some base-level of relatedness to other (thus supporting their presence in a PCA; Field, 2012). The KMO test returns a Measure of Sampling Adequacy (MSA) for each variable in the PCA, where a value 0.70 or over is considered “good”, and 0.80 or above is “great” (Kaiser, 1974), and variables below this value may not be related enough to the other variables and should be considered for removal. With MSAs for each value between 0.71 and 0.85 (which is referred to as “good” and “great”, respectively, by Kaiser (1974), and an overall MSA of 0.81, the removal of any variables was not deemed necessary.

We then created a principle component model of our nine variables with the *psych* package (Revelle, 2019) using the package’s *principle()* function. Visually examining the scree plot of eigenvalues against number of factors suggests the extraction of two factors based on Kaiser’s criterion (Kaiser, 1974; Figure 2.5). Upon assessing the variables that loaded on to each factor, two separate conceptual dimensions revealed themselves: variables related to anglers’ perceived need for action, and those that were relating to their personal attachment to the fishery (Table 2.2). Because we anticipated these two factors to be theoretically related and at least somewhat correlated with each other, we opted for an oblique rotation on the standardized loading (where rotate= “oblimin”), to account for this relatedness, using the package G*PArotation* (Bernaards & Jennrich, 2005). While the un-rotated loadings suggested dividing the nine variables into the same two components as the orthogonal rotation, the oblique rotation made the split of variables more pronounced, with four variables loading on one factor, and the remaining five on the other (Table 2.2).

We then assessed the internal consistency of these two factors using Cronbach's alpha (Table 2.2). Minimum acceptable values for a Cronbach's alpha value varies between sources; Cortina (1993) outlines how scale size, number and relatedness underlying factors, and number of component variables can all effect alpha in ways that can confuse attempts at determining unidimensionality. While alpha values above 0.80 are acceptable by most standards (Kline, 2013), considering the relatedness of the factors, the number of variables, and the scale sizes, we opted for a minimum alpha of 0.60 as suggested by Nunally and Bernstein (1994) for exploratory research.

The first aggregate factor from the PCA consisted of five variables that together conveyed an angler's perceived need for action to be taken to protect Alberta's fisheries and aquatic ecosystems (Cronback's alpha = 0.83; Table 2.2: the respondent's perceived need for more fishery protection, their perceived extent humans affect the fishery (i.e., extent to which they think that people are to blame for harm done to the fisheries), and thus the extent to which they think it is said humans that need to take action, as reflected by the remaining three questions regarding their perception provincial government should be doing more, perception communities should be doing more, and perception individuals should be doing more.

The second aggregate factor determined by the PCA is the dimension pertaining to their personal connection to the fishery, which consists of four variables that come together to portray how fisheries-related affairs personally relate to the respondent: their general emotional dependence on fishing is investigated, their sense of belonging to the angling community, their concern for fish populations, and their sense of personal responsibility to the health of the fishery (Table 2.2; Cronbach's raw alpha = 0.68).

All of the component variables were assessed as statements that the respondent was asked to rate their degree of agreement with on a seven-point interval scale from 'strongly disagree' to 'strongly agree' (Table 2.1; Figure 2.1). We converted responses to a numeric scale where 1 = 'strongly disagree' and 7 = 'strongly agree', allowing us to obtain average values for each variable. To create values for each aggregate variable (perceived need for action to protect the fishery and their personal connection to the fishery), we calculated the averaged value of responses among their respective component variables. We then used these average values of perceived need for action to protect the fishery and their personal connection to the fishery as individual explanatory variables for use into the next stage of the analysis. We selected this method over other approaches such as using component loadings because all the nine component questions were measured on the same scale, and to increase the ease of interpretation of later results (Field et al., 2012).

Bivariate relationships with willingness to report

Variable aggregation resulted in 16 potential explanatory variables; we therefore sought to reduce the complexity of our analysis further by performing bivariate analyses relating each of the revised independent variables and willingness to report (response variable). Prior to our bivariate analyses, multi-level factor questions were converted into dummy binary variables; In particular, because very few respondents (<2%) selected "no effect" regarding perceived strength of effect invasive species has on Alberta's fisheries the variable was treated as a binary between "strong effect" and "weak effect". In addition, the frequency that invasive fish were discussed with others (e.g., friends, family, or online), had the ordinal factor response options of "never", "sometimes", and "frequently", and thus were broken up into two dummy-loaded variables, treating "sometimes" as the baseline for the two other levels.

Eight independent variables had a significant bi-variate relationship with willingness to report ($p>0.05$); 1) how long the angler had been fishing, 2) how long the angler had been fishing in *Alberta*, 3) whether they thought invasive fish were having a strong effect on Alberta's fisheries, 4) whether they discussed invasive fish frequently, or 5) never, 6) if a respondent lived in Calgary, 7) their personal attachment to the fishery, and 8) their perceived need for action to be taken to protect Alberta's fishery.

Information intervention

In addition to the seven variables procured from the survey questions, we also assessed the efficacy of the information intervention by comparing willingness to report between groups given different types of information about Prussian carp during the survey using ANOVAs and Kruskal Wallis tests. We found no significant differences between groups (i.e., $p> 0.05$) in which 1) respondents were given information about Prussian carp as a popular fish for consumption, 2) respondents were given information about the potential harm Prussian carp may bring to native species and fisheries, 3) respondents given both pieces of information, and 4) respondents given neither information types (control group; Figure A2.1).

Assessing collinearity among explanatory variables

Next, we assessed co-linearities between the eight remaining individual explanatory variables (including perceived need for action to protect the fishery and their personal connection to the fishery) that we hypothesized may influence willingness to report (response variable;

Table 2.1) by first calculating variance inflation factors (VIFs) using the QuantPsyc package (Fletcher, 2012) to get each variable's score in terms of effect of multicollinearity on response. VIFs can also be interpreted with the tolerance statistic, which is the reciprocal of VIF (1/VIF). Generally, a tolerance statistic score of <0.2 indicates the variable exhibits too much collinearity to be treated as separate variables going forward (Menard, 2002). Both years fishing and years fishing in Alberta had a tolerance statistic of >0.2, so one needed to be chosen to carry forward, and the latter variable had the stronger relationship with willingness to report out of the two. The VIF scores for the remaining seven variables were all within acceptable parameters.

To further ensure all potential instances of collinearity were identified, we also assessed the bi-variate correlations between all candidate explanatory variables with a correlation table with the Hmisc package (Frank & Harrell, 2021). The two variables (out of the seven candidates at this point) with the greatest correlation between them were our two summative variables from the PCA: perceived need for action to protect the fishery, and personal attachment to the fishery. When assessed with Spearman's correlation they were significantly and positively correlated ($r_s = 0.349$, p-value < 2.2e-16). Considering tolerance statistics for these two variables were above 0.80, and the R^2 value (i.e., r_s) of 0.35 is not particularly high, we chose not to completely exclude one of the variables from the analysis. Instead, we opted to first include only perceived need for action along with the other uncorrelated set of explanatory variables in our model of willingness to report Prussian carp (this model is called the 'partial' model; Figure 2.3), and then added personal attachment to the fishery (called the 'full' model; Figure 2.4) to see how the variables' effect magnitude and directions change once the variable and its collinearity were considered.

Evaluating multiple predictors of willingness to report through generalized linear modeling

To determine the direction and magnitude of the relationships between the variables predicted to affect angler willingness to report, we constructed and evaluated generalized linear models (GLM) with a quasibinomial distribution using the package MuMIn (Bartoń, 2019) in R statistical analysis software, version 3.6.1 (R core team. 2019).

Anglers' willingness to report (response variable) was re-scaled between 0 and 1 into a sort of proportional response (0 being "very unlikely" to report, and 1 being "very likely" to report). To account for this quasibinomial distribution, we set the family=binomial in our GLMs (Zuur et al., 2007). We included seven explanatory variables in the full model: 1) years fishing in Alberta (numeric), 2) whether they thought invasive fish were having a strong effect on Alberta's fisheries (binary; 0/1), 3) whether they discussed invasive fish frequently (compared to 'sometimes'; binary; 0/1), 4), whether they discussed invasive fish never (compared to 'sometimes'; binary; 0/1), 5) if the respondent lives in Calgary (binary; 0/1), and 6) their personal attachment to the fishery (numeric between 1 and 7), and 7) their perceived need for action to be taken to protect Alberta's fishery (numeric between 1 and 7). Due to the collinearity between personal attachment to the fishery and perceived need for action, we opted to first include only perceived need for action along with the other uncorrelated set of explanatory variables in our model of willingness to report Prussian carp (this model is called the 'partial' model; Figure 2.3), and then added personal attachment to the fishery (called the 'full' model; Figure 2.4) to see how the variables' effect magnitude and directions change once the variable and its collinearity were considered.

Starting with the partial models' six variables, we conducted backward model selection; iteratively removing non-significant explanatory variables (i.e., the one with the highest non-significant p-value [significance of p =0.05]), and re-fiting the model until the either all remaining terms were significant at a 90% significance level, or the removal of any more terms would not drop the Akaike Information Criterion (AIC) – an estimate of prediction error, or the quality of a model relative to its parsimony - by 2 or more (Field et al., 2012; Zuur et al., 2007). The resulting coefficients and confidence intervals for the final 'partial model' model are presented in Table 2and Figure 2.3. We then ran the model again with the addition of personal attachment to the fishery (i.e. the full model; Table 2; Figure 2.3). According to the AIC, no further variable removed were required from the full model. Pseudo-R^2 for GLMs should be interpreted with caution and are not typically regarded as representative of the predictive power of the model, but more generally as a gauge of the model's substantive significance (Field et al., 2012). For our models, we chose to present Nagelkerke R^2, which is an ad hoc correction to normalize the value and have a maximum value of 1.0 (Nagelkerke, 1991).

Comparing actual reporting to stated willingness to report

Finally, we compared the relationship between stated angler's willingness to report (from the original long-form survey) to their actual report rate (from the follow-up surveys). The small sample size limited statistical analysis options; only 64 people had seen Carassius in 2020 and responded to the December 2020 follow-up survey. Using their email addresses to link the identity of the follow-up survey responses to the original survey, we compared average willingness to report scores for respondents who had reported their sighting to those who had not reported there sighting using a chi-squared test.

Results

In total, 3,480 respondents began our Qualtrics survey in 2019, and 2,548 (73%) finished it. We conducted statistical analysis only on complete cases, excluding records where any of the questions that were to be analysed were incomplete or invalid, such as those that selected “prefer not to say” in a question that was to be treated as continuous or ordinal. Upon removal of these records, we were left with 1,439 complete records for our data analysis.

The average respondent was 46.3 years old (± 13.9 years), with respondent ages spanning more than eight decades. Of all respondents, 85.9% of participants in our sample were men, and 13.3% were women. Those from rural Alberta made up 22.0% of our 1,439 respondents, while 15.0% were from Calgary, 12.8% were from Edmonton, and the remaining 50.2% were from other urban areas or municipalities (Table 2.1).

More than half of respondents (51.1%) heard of the survey via email; a similarly high percentage of respondents (42.3%) selected “other” as the method in which they heard of this survey. Those that selected “other” option had an opportunity to specify themselves with a text response, and ~83% of them did, revealing that at least 79% of the individuals that selected “other” heard of the survey via some sort of social media, with Facebook making up 68% and other platforms such as twitter, Instagram, and angling forums making up the remaining 11% – all avenues that we did not predict to be as important a distribution method at the time of the survey’s creation. 4.7% of respondents heard of the survey via “word of mouth”, and the remaining 1.9% of respondents heard about the survey at an angling-related location (i.e., at a fishing location, at a retail store, and/or with a flyer/information card) (Table 2.1).

In total, 90.3% of respondents indicated that they had a smart phone, and of those 47.3% indicated that they used fishing-related apps on their smart phones (Table 2.1).

Angler participation in pro-conservation behaviours related to AIS

Respondents' stated likelihood of carrying out several of the pro-conservation behaviours had heavily skewed distributions. The skew was most extreme regarding the respondent's likelihood of releasing Carassius if they were captured, with nearly 91.2% of respondent's indicated they were "very unlikely" to release Carassius back into the water if they caught it (Table 2.1). When asked about their willingness to consume Carassius, respondents were asked if they would consider eating Prussian carp; 14.0% of respondents said "yes", 26.7% said "maybe", and 59.3% said "no" – ratios that did not vary significantly between the treatments given (Table 2.1). The frequency with which respondents reported moving fish from one water body to another and their reported adherence to angling regulation (such as catch/procession limits and catch-and-release rules), were also very skewed, with 95.5% of respondents selecting "never" and 97.6% selecting "always" for each of the questions, respectively. Respondents' adherence to "clean, drain, dry", however, was slightly more varied, with 80.7% saying they "always" clean, drained, and dried their boat between waterbodies, and 5.7% indicating they "never" did so (Table 2.1).

Willingness to report was also skewed towards high reported likelihood, with 87.0% of respondents selecting "very likely" or "somewhat likely", and only 9.4% selecting either "very unlikely" or "somewhat unlikely" combined (Table 2.1). Those who indicated that they were "very unlikely", "somewhat unlikely" or "unsure" in their likelihood of reporting were given an opportunity to elaborate in a text response on what was preventing them from reporting; ~28% (n=60) of the text responses said the reason they were unlikely to report was because they didn't know how, ~20% (n=43), typed the response "nothing", 16.5% (n=36) suggested the effort to report was too great (or that they were "lazy"), 6.4% (n=14) suggested their lack of faith in managers/ the government to do anything of use with the data anyway, 6% (n=13) said the location was already known, 3.2% (n=7) said they were not confident in the identification abilities, 1.4% (n=3) said they liked Prussian carp, and the remaining 6% (n=13) gave confusing, unclear responses (Table 2.1).

Potential predictors of anglers' willingness to report Prussian carp

Information treatment

Presenting additional information about Prussian carp to survey respondents (either about the effects of the invasion (the *effects treatment*), or potential for them to be a food fish (the *taste treatment*) tended to increase willingness to report sightings of the species, but this effect was not significant. There were no significant differences in willingness to report between those that received either of these treatments and those that did not ($p > 0.05$).

Demographics

Willingness to report did not have a significant relationship with the respondents' age, nor their gender. While respondents from Edmonton, other urban locations, or rural areas responded similarly in their willingness to report, individuals from Calgary tended to be less willing to report on average, as is suggested by a Wilcoxon rank sum test with continuity correction comparing those from Calgary to all other areas ($W = 150442$, p-value <0.001), as well as the results of when the variable was included in either the partial or full GLM (full GLM P-value = 0.003; Table 2.2; Figure 2.4).

Perspectives on the fishery

When asked how the angler rated the general health of fish populations in the Albertan waterbodies compared to when they started fishing in Alberta, most (62.8%) respondents selected "worse" or "much worse", while only 11.1% selected "better" or "much better". While the relationship between perceived state of the fishery and willingness to report Prussian carp was not significant from bivariate tests, and therefore not included in the GLM, there was a week interaction between the how long the respondent had been fishing in Alberta and their perception of the province's fisheries health when assessed with a Spearman's rank correlation (r_s = -0.262, p-value < 2.2e-16): on average, the longer the angler had been fishing in Alberta (i.e., the farther they were able to look back), the worse they perceived the change in the fishery to be.

Respondents who perceived stronger effects from invasive species on the health of fish population in Alberta were on average more willing to report, though the relationship was not significant when assessed in a bivariate relationship with willingness to report and the variable was not included in our GLM (Table 2; Figure 2.6). Due to skew of the responses where almost no-one (<2%) selected "no effect", the variable was treated as a binary between "strong effect" and "weak effect". The results of a Wilcoxon rank sum test with continuity correction suggested that those that think invasive species have a "strong effect" were more willing to report Prussian carp (W = 215501, p-value = 0.010), although this significance did not persist in the either GLM (Table 2.2; Figure 2.7).

To determine the effects of the frequency that invasive fish were discussed with others (e.g., friends, family, or online), the ordinal factor options of "never", "sometimes", and "frequently" were broken up into two dummy-loaded variables, treating "sometimes" as the baseline. Those that responded "frequently" were more willing to report Prussian carp;

significantly so when assessed with a Wilcox (W = 152924, p-value< 0.001), but not in either of the GLMs. Those that responded "never" were less willing to report Prussian carp; significantly so when assessed with a Wilcox (W = 147570, p-value< 0.001), but not so much in the GLM – interestingly, the effect was marginally/ almost significant in the partial GLM (partial GLM odds ratio=0.694, CI: 0.485-1.006, p-value=0.050), but this significance was diminished with the addition of personal attachment to the fishery to model (full GLM odds ratio = 0.751, CI: 0.522-1.094, p-value=0.129, Table 2.2, Figure 2.3; 2.4).

Dependence on the fishery

There were originally two questions that we asked regarding anglers' dependence of the fishery, but the anglers' emotional dependence was incorporated into the PCA summative variable regarding their personal connection to the fishery, leaving only one question; anglers' dependence on fish as food was determined by the respondent's level of agreement to the statement "I depend on angling as a food source", and garnered a variety of responses. While the relationship between the respondent's dependence on fish as food and willingness to report tended towards the positive overall, the relationship was not significant from bivariate comparison and was not included in the GLM.

Sense of community

All 1,439 respondents in the analysis' data frame indicated that they had friends or family that fish, while the frequency respondents fish with others was more normally distributed and also had no relationship with willingness to report as assessed in bivariate comparison and was not included in the GLM (Table 2.1). Whether the respondent 1) receives angling-related newsletters and/or magazines, 2) reads/ views angling-related discussions online, 3) participates in angling-related discussion online, 4) attends angling-related functions/ activities in-person, and/or 5) helps plan/coordinate angling-related functions/activities had no significant relationship with their willingness to report Prussian carp (Table 2.1).

Angling participation

Variables describing angling participation investigated topics related to angler specialization and level of interaction with angling and tended to have positive, though not significant, relationships with willingness to report. Anglers had been fishing for an average of 37.2 (SD$\pm$ 15.2 years) years, placing the average age that someone started fishing at 9 years old – just a few years before the average age they started fishing in Alberta, at age 14.2 (32.04 years ago (SD$\pm$16.2 years; Table 2.1). How long the angler had been fishing overall, how long the angler had been fishing in Alberta, and their age were all highly correlated. Participants that had been fishing in Alberta for longer reported being more likely to report sightings of Prussian carp. However, while this relationship was suggested significant by a Spearman's rank correlation test (r_s =0.057, p-value = 0.029), a Spearman's rank correlation test revealed it had a significant positive relationship with the personal attachment to the fishery (r_s =0.075, p-value = 0.00425), so was not significant in the GLMs (i.e., removal decreased model AIC by more than 2; Table 2.1; Figure 2.3; 2.4).

The average number of days respondents estimated they would fish in the entire year of 2019 (*days fishing per year*) was 47.8 (SD$\pm$29.1 days). The number of anticipated days fishing per year generally saw an increase with willingness to report, though not significantly so (Table 2.1).

Perceived need for action to protect the fishery

Respondent's perceived need for action to conserve the fishery is an aggregate variable consisting of the average value of the following variables: perceived need for more fishery protection, perceived extent humans affect the fishery, perception provincial government should be doing more, perception communities should be doing more, and perception individuals should be doing more. In the partial model that did not yet include personal attachment to the fishery, perceived need for action had a significant positive relationship with willingness to report (partial GLM odds ratio=1.136, CI: 1.004 – 1.283, p-value: 0.040), yet once personal attachment to the fishery was added to the model, the effect of the perceived need for action diminished to the point of no significance (full model odds ratio: 1.049, CI: 0.919 - 1.194, p-value= 0.474).

Personal connection to the fishery

Anglers' personal attachment to the fishery (quantified as an aggregate variable consisting of the average value of their sense of personal responsibility, sense of belonging to the angling community, concern for fish populations, and emotional dependence on fishing; Table 2.1) had a strong, positive effect on willingness to report (full model odds ratio: 1.263, CI: 1.106 - 1.439, p-value< 0.001; Table 2.2 Figure 2.3; 2.4).

Comparing actual reporting to stated willingness to report

Our follow-up survey in December 2020 was sent out to the 2,360 respondents who left valid emails and consented to further contact. Of these, 1,282 responded (54%), with 95% (n=1,218) reporting not seeing Carassius spp. during their fishing activities in 2020 and 5% (n=64) reporting that they had. Of the respondents that sighted fish, 47% (n=30) had reported their sighting prior to our follow up survey and 53% (n=34) had not yet reported their sighting. When comparing the two groups, a Wilcoxon Signed-Ranks Test indicated that stated willingness to report Prussian carp sightings was significantly higher among anglers who reported their sightings of the species during the 2020 fishing season compared with anglers who spotted Carassius spp., but did not report (W= 383, p-value = 0.050). In particular, 80% (n=24) of anglers who reported their sightings also stated they were "somewhat likely" or "very likely" to report during the initial survey, compared to those who had not reported, where only 68% (n=23) selected these same options.

Discussion

Importance and application of the results to AIS management

We found that greater personal connection to the fishery was associated with an increase of 26.3% (full model odds ratio CI: 10.6% - 43.9%) in willingness to report. A greater perceived need for action to be taken to protect Alberta's fishery was also associated with an increase of 13.6% (partial model odds ratio CI: 0.4% - 28.3%) in willingness to report, however, much of the variation in willingness to report associated with perceived need for action is adopted by personal attachment to this fishery when it is included in the model. Finally, if a respondent lived in Calgary, they were 41.8% less likely to be willing to report Prussian carp (full model odds ratio CI 16.7% - 58.9%).

Our results suggest that in motivating angler engagement in reporting sightings of invasive Prussian carp, the species should not just be described by the general harm they may inflict on native populations, but by how the invasion may harm the angler's fishing experience and the aspects of the aquatic habitats that they hold dear. While it is important for outreach initiatives to communicate the ecological impacts of the threats they are concerned with (in this case, the threat of invading Prussian carp), the results of this study suggest such outreach should go further, encouraging personal attachment to the fishery, and framing the threat in similarly personal terms.

Furthermore, the significance of anglers' perceived need for action in driving their willingness to report Prussian carp highlights the importance of making it clear just how a particular threat is operating in terms of what can be done to address it. If anglers are asked to report Prussian carp, they should be able to draw clear lines between how Prussian carp are inflicting harm, how the plan to control the invasion is addressing that harm, and exactly how their report figures into that process.

While respondents from Calgary (the largest metropolitan centre in the province with ~30% of the province's population at 1.3 million people) were significantly less likely to report Prussian carp compared with residents in the rest of the province, the drivers behind this relationship are unclear. Residing in this urban centre did not have a significant relationship (i.e., low collinearity) with any of the other variables for which we examined influence willingness to report. However, Calgary is located at the western edge of the known Prussian carp sampling distribution, and it could be that the lower likeliness to report in that area is a symptom of diffuse responsibility (and/or bystander effect): anglers could be less likely to report in places such as Calgary where they perceive a high likelihood of others reporting AIS, essentially assuming there is reduced need for their own reporting (Buntaine & Daniels, 2019). Supporting this notion, we found that 6% of respondents who provided text explanations for why they were less likely to report Carassius said it was because the location where they had or anticipate a citing is "already known", and of these 12 individuals, 6 were from Calgary. If there is a 'sweet spot' of angler density, such a phenomenon could be contributing to why the number of reports in each area were not directly proportional to Carassius density and could have contributed the relative unwillingness of Calgarians to report Prussian carp. We suggest that future endeavors could investigate the role of the bystander effect and diffuse responsibility to explain this pattern.

While several effects were not shown to be significant when assessed alongside the rest of the variables in a GLM, bivariate comparisons with willingness to report showed significant relationships at levels of at least p=0.05, indicating that while they had relationships with willingness to report, the portion of the variation in willingness to report was shared with the other variables we looked at. Specifically, how long the angler had been fishing in Alberta had a positive relationship with willingness to report, but this was not significant on the GLM. In addition, respondents who discussed invasive species frequently with others were more willing to report Prussian carp, while those that never discussed them were associated with lower rates of willingness to report, on average. Whether they thought invasive fish were having a strong effect on Alberta's fisheries also had a positive relationship with willingness to report, though was not a significant predictor within the GLM. The lack of significant effects on willingness to report for these three variables when considered concomitantly may be explained by the extent to which they, along with other variables that ended up in the final GLMs, explain overlapping portions of the variance in willingness to report to some degree – not so much that the VIF or backwards model selection would suggest removing any of these variables, but enough to diminish their significance.

Drivers of willingness to report AIS and theory of planned behaviour

The importance of anglers' personal attachment to the fishery and their perceived need for action to protect the fishery can be interpreted in the context of the theory of planned behaviour, a social-psychological model that suggests behavioural intentions are contributed to by three factors: attitudes toward the behavior, subjective norms (what they believe others usually do, which contributes to social pressure), and perceived behavioral control (Kan &

Fabrigar, 2017). Other contributors to behavioural intentions include anticipated regret (Sheeran & Orbell, 1999), descriptive norms (i.e., what other people are actually doing; (Rivis & Sheeran, 2003), self-efficacy (Armitage et al., 1999), and moral obligation (the perceived moral righteousness of a behaviour; (Bamberg & Möser, 2007). In particular, characteristics of an angler's personal attachment to the fishery could be viewed as related to a variety of the aforementioned factors: one's sense of personal responsibility could be related to the factors self-efficacy and moral obligation (Armitage et al., 1999; Bamberg & Möser, 2007), or personal attachment to the fishery could be interacting with other dimensions we identified, such as their sense of belonging to the angling community, concern for fish populations, and emotional dependence on fishing), to contribute to the angler's attitudes about the behaviour (Kan & Fabrigar, 2017).

In addition, anglers' perceived need for action to protect the fishery, as characterized via the summative variable's five component questions, may also be related to a variety of behavioural intentions; Both the extent to which anglers' perceive humans cause impacts to the fishery, as well as their perceived need for more fishery protection, reinforce the theory of planned behaviour's emphasis on the importance of characteristics such as attitudes toward the behaviour (i.e., AIS reporting) and perceived behavioural control (Kan & Fabrigar, 2017). Finally, anglers' perceptions regarding locus of authority over the fishery may reinforce the importance of subjective and descriptive norms, as well as self-efficacy and moral obligation (Armitage et al., 1999; Bamberg & Möser, 2007; Kan & Fabrigar, 2017; Sheeran & Orbell, 1999). Future research identifying the mechanisms of willingness to report could explicitly examine whether these and other aspects of the theory of planned behaviour are at play by creating a survey that includes a comprehensive array of questions that touch on the various aspects of the theory.

Effect of pre-existing knowledge on willingness to participate

Counter to our expectation, far more respondents were aware that Prussian carp was invasive in Alberta (74%) than we had anticipated. Given broad awareness of the invasion, in hindsight investigating the role of social norms (i.e., perception of what is "normal" or "what everyone else is doing") would have been a useful addition to the survey to understand drivers of participation (Drake et al., 2014; St. John et al., 2010). In particular, previous work has suggested that the more a behaviour is socially normalized in a community, the more likely a member of that community is to carry out the behaviour. A perceived lack of reporting by other anglers could also contribute to the "defeatist attitude" discussed by Zanetell and Knuth (2004). Conversely, anglers in Alberta could be affected by the apposing phenomena of the bystander effect, where in places the angler perceives a high likelihood of others reporting AIS, they perceive a reduced need for their own reporting (as is discussed in the later section concerning why Calgarians were less likely to report).

Pre-existing knowledge concerning invasive Carassius species in Alberta could also explain why the information intervention we conducted did not appear to influence stated willingness to report – it could be that none of the information supplied in the information intervention went beyond what was already known by most of the participants. The base level of knowledge given to all treatment groups (including the "control" group), may have also decreased potential differences in knowledge between all groups; All participants were told that Prussian carp and goldfish are aquatic invasive species and to reduce the risk of these invasive fish spreading to new areas, they should not be returned to the water if they are caught. This statement was included to meet the conservation objective of ensuring that all respondents (even the~600 people in the control group) obtained some knowledge about why they should remove and report Carassius (Table A2.1).

Effect of Angler's level of concern for the resource on willingness to engage in conservation

Because anglers' perceived need for action to protect the fishery had a significant positive relationship with willingness to report, one might expect that anglers who perceived the state of the fishery to be worse would be more willing to report AIS. Surprisingly, respondents' perceived state of the fishery since they began fishing in Alberta did not have a significant relationship with their willingness to report. However, how long respondents had been fishing in Alberta did have a significant relationship with willingness to report (via bivariate testing, but not in the GLM), and the longer the angler had been fishing in Alberta (i.e., the farther they were able to look back), the worse they perceived the change in the fishery to be.

Another layer of complexity in the relationship between perceived state of a natural resource and anglers' willingness to participate in actions related to its conservation, is apathy; Previous studies have investigated situations where people felt like a situation has gotten so bad that it is a "lost cause" and creates what Zanetell and Knuth (2004) calls a "defeatist attitude about perceived insurmountable problems". This phenomenon suggests a 'sweet spot' of perception regarding the condition of a resource in need of conservation action. This is further supported by our results when respondents who stated they were unlikely to report Prussian carp were asked via text response to elaborate, ~6.4% (14/218) of anglers explicitly referenced lack of faith in managers, and many others gave reasons that could be contributed to by such sentiments:

~16.5% (36/218) portrayed their lack of willingness to either their own laziness or the perceived amount of effort reporting would take, and another ~19.7% (43/218) gave the enigmatic response of “nothing”.

Further research into factors affecting anglers’ perceived state of the fishery would promote greater understanding of whether a person’s perception of the impact of their conservation-related behaviour affects the likelihood of them engaging in such behaviours. Perceptions that there are factors limiting the efficacy of one’s pro-conservation behaviours could possibly undermine one’s probability of participating in such activities no matter how much they would be otherwise willing to take action (Drake et al., 2014; Knight et al., 2010). In the context of this study, whether someone believes their report would have an impact on the fishery may depend on their faith in the government’s ability to or likelihood of taking action against Prussian carp based on their report – factors affected by the government’s actual activities surrounding such efforts, and the extent to which they make others aware of such actions and their effects (Knight 2010, Drake 2014). If managers could demonstrate and persuade anglers that they are taking action and that those actions have results, then anglers may perceive benefits from their participation. Another “third party” that an angler could perceive as hampering the efficacy of their own actions could be other anglers, and the extent to which they perceive others are removing and reporting the AIS that they see. This phenomenon is related to social norms (which is discussed further in “the effect of pre-existing knowledge on willingness to report”) and should be investigated further in future studies (Knight 2010, Drake 2014).

Sources of skew in responses to morally-pertinent questions

Overall, angler's stated willingness to participate in pro-conservation behaviours (i.e., anglers' willingness to report or release Carassius, or the frequency they move fish from one water body to another, or adhere to angling regulation), were heavily skewed towards positive responses (i.e., more likely to conduct the behaviour than not), precluding their use as response variables in our statistical analysis. This effect has been observed in other studies and may be explained by the social desirability bias, where the assumed socially or 'morally-correct' answer is selected disproportionately as the result of either self-deception or other-deception (Nederhof, 1985). Social desirability bias could be appropriately accounted for in future studies by adopting a variety of tactics, including asking a variety of questions indirectly associated with the behaviours and characteristics of interest (Nederhof, 1985).

Other factors that could contribute to skew towards high willingness to report are suggested in the text responses from respondents who explained why they said they were "very unlikely", "somewhat unlikely", or "unsure" in their likelihood of reporting (which is 73% of the 287 that answered in one of these three ways); Of these respondents, ~28% (n=60) responses said the reason they were unlikely to report is because they don't know how – an odd choice given they were told in the question they were to be given the details on how to do that very thing in the proceeding question (i.e., we thought respondents would assume "knowing how" would not be an issue). Among the ~20% (n=43) that typed the response "nothing", it is unclear whether respondents meant that nothing was stopping them and thus they made a mistake indicating they were not likely to report, and so the validity of leaving them in their original willingness to report dimension is also called into question. Future research should explore in more depth the reasons respondents supply for what would be stopping them from engaging in pro-conservation behaviours such as reporting AIS.

Accounting for these various sources of skew could result in a more normal distributions, which would in turn increase the reliability of many of this study's results, as well as the variety of statistical approaches available for the analysis. For example, while there is a positive relationship between an angler's willingness to report and their actual likeliness to report, that association could have perhaps been stronger if we had asked the question is a way where there was no confusion around how to report, and had addressed social desirability bias (Nederhof, 1985).

How our answer structures limited the analysis, especially for the PCA

Another factor that put restrictions on how we analysed and thus interpret our results was our use of non-continuous or non-interval answer options such as binary, multiple choice, or non-continuous ordinal answers. The use of binary questions in PCA is contentious, and when allowed by some it is done with numerous stipulations around type of factor the binary is describing, how many binary questions are in your PCA, what you plan to do with the results, among other restrictions (DeVellis, 2016; Lubke & Muthén, 2004). This limited the variables that were candidates for the PCA to continuous or interval, despite there being latent variables that could be hypothesised connecting most of the questions to their respective original dimensions, (or a variety of other hypothetical combinations). For example, sense of community was originally hypothesised to have potentially made its own aggregate variable, but only the questions that ended up going into the variable regarding the angler's personal connection to the fishery were eligible for the PCA.

Comparing respondents to the angler population at large

Where licenced anglers in Alberta spent an average of 14.3 days fishing in 2010 (Zwickel, 2012), the participants of this survey spent an average of 47.8 (SD$\pm$29.1 days)– more than three times as many days, which could suggest that our sample is capturing a relatively more “invested in fishing” portion of the wider angling population. How we distributed this survey could have contributed to this outcome; In particular, we primarily distributed the survey through platforms that would involve an angler engaging in angling-related behaviours (i.e., reading angling-related newsletters, participating on forums, etc.). Anglers that engage in these platforms or spaces would naturally be more likely to encounter the survey. The length of the survey could have also been prohibitive to its completion – while ~3,500 people started the survey, more than a quarter of those did not complete it. The difference in fishing days between participants in this study and anglers at large could be a manifestation of the “non-response bias”, where those that respond to the survey are not representative of the general population, and thus the sample is not actually random (Duda & Nodile, 2010). Perhaps if non-response bias is better accounted for and the survey were to reach a more representational portion of the angling population, the relationship between willingness to report and the variables related to how invested the angler is in fishing could be strengthened and made more detectable. Besides keeping the survey as brief and simple as possible, segmenting the sample along demographics, distribution channel, or other characteristics of interest can also help address non-response bias (Duda & Nobile, 2010).

In addition to surveying those who fish less frequently, the results of our survey also suggest that capturing a more representative sample of Albertan anglers would require adjusting the survey distribution methods to capture more anglers that are female, older, and possibly those living in large urban centres. In our survey, 85.9% of participants were male, which is 8.7% more men than the 77% average reported for Alberta in 2010 (Zwickel, 2012), and is also greater than the 79% of resident Canadian anglers in 2015 (Fisheries and Oceans Canada, 2019). The average age of our survey participants was 46.3 years old (SD $\pm$ 13.9 years), which is within the 45-64 years old range that has been reported as the largest group within Albertan anglers (Zwickel, 2012), and anglers in Canada overall (if at the slightly younger end of the range) (Fisheries and Oceans Canada, 2019). Finally, around ~53% of all Albertans live in either Edmonton or Calgary (Goverment of Alberta, 2020), opposed to the 27.8% of our sample. It is possible that our survey under-represented Alberta's two largest cities by ~22.1%. However, the distribution of Albertans is not necessarily proportional to the distribution of its anglers, as those who do not live in the province's largest cities could have closer connection to waterbodies and the fishing they facilitate and are thus over-represented in the angling community (Copeland et al., 2017a).

Tables

Table 2.1 Survey questions, associated response types/options, and the abbreviated name by which variables are referred to within conceptual areas investigated in our survey of Alberta anglers' willingness to engage in pro-conservation behaviours related to invasive Prussian carp.

Variable name	**Survey Question/Statement**	**Description**
Angler participation in pro-conservation behaviours related to AIS		
Willingness to report Carassius	If you were to catch a Prussian carp or goldfish, how likely are you to report it?	Very unlikely (67) Somewhat unlikely (68) Unsure (152) Somewhat likely (354) Very likely (898) Prefer not to say
Likelihood of releasing Carassius	If you were to catch a Prussian carp or goldfish, how likely would you be to release these invasive fish back into the water, letting it live?	Very unlikely (1313) Somewhat unlikely (40) Unsure (52) Somewhat likely (9) Very likely (25) Prefer not to say
Willingness to consume Carassius	Would you consider eating Prussian carp?	No (854) Maybe (384) Yes (201)
Frequency respondents move fish from one water body to another	I take fish or bait from one waterbody to another.	Never (1374) Sometimes (54) About half the time (7) Most of the time (2) Always (2) Not Applicable/ Don't know/ Prefer not to say

Adherence frequency to “clean, drain, dry”	I "clean, drain, and dry" my boat before moving it between waterbodies.	Never (82) Sometimes (48) About half the time (11) Most of the time (137) Always (1161) Not Applicable/ Don't know/ Prefer not to say
Adherence frequency to angling regulation (such as catch/procession limits and catch-and-release rules)	I adhere to angling rules such as catch/ possession limits and catch-and-release rules.	Never (7) Sometimes (4) About half the time (2) Most of the time (22) Always (1404) Not Applicable/ Don't know/ Prefer not to say
Use of technology to engage with angling		
Distribution method	How did you hear about this survey?	Email (735), In-person at a retail store (11), In-person at a fishing location (7), A flyer/information card (10), Word of mouth (68), Other (608)
Cell phone use	Please select one of the following regarding cell phone use:	I use a smart phone (1299), I use a cell phone, but it is not a smart phone (80), I do not use a cell phone (33), I prefer not to say (27)
App use	If cell phone use = they have a smart phone:	I use fishing/angling-related apps on my cell phone (615)

	Please select one of the following regarding the use of fishing apps on your smart phone:	I do not use fishing/angling-related apps on my cell phone (674) I prefer not to say (10)
Demographic information		
Where in Albertan the respondent is from: Edmonton, Calgary, other urban areas, or rural areas.	Please fill out the following with your information: Postal code - include space in middle (e.g., T7E 2L4) (note: the first 3 characters (i.e., Forward Sortation Area), determined where they lived.)	Edmonton (184) Calgary (216) other urban areas (722) rural areas (317)
Age	Please fill out the following with your information: Year of birth.	Year of birth was converted to age at time of the survey (2019). Mean= 46.26 years, ± 13.9 years standard deviation.
Gender	Your gender.	Male (1236), Female (191), Non-binary / Other (8), Prefer not to say (4)
Perceptions about the state of the fishery		
Perceived extent humans affect the fishery	Please indicate your level of agreement with the following statement(s): Human activities are affecting fish populations in Alberta.	Strongly disagree (25) Disagree (28) Somewhat disagree (46) Neither agree nor disagree (84) Somewhat agree (222) Agree (465) Strongly agree (569) Don't know/ prefer not to say

Perceived fishery state	How would you rate the general health of fish populations in the Albertan waterbodies you are familiar with, compared to when you started fishing in Alberta? (i.e., fish abundance, ecosystem health, etc...).	Much worse (270) Worse (634) About the same (375) Better (130) Much better (30) Don't know/ prefer not to say
Perceived effect of AIS	What effect do you feel each of the following factors have on the health of fish populations in Alberta? Invasive species:	No effect (28), Weak effect (335), Strong effect (951), Don't know/Prefer not to say (125)
Frequency invasive fish are discussed	How often do you discuss invasive fish with others (e.g., friends, family, or online)?	Never (210) Sometimes (913) Frequently (306) Prefer not to say/ don't know (10)
Level of concern for the fishery		
Concern for fish populations	Please indicate your level of agreement with the following statement(s): I have concerns about the future of Alberta's fish populations.	Strongly disagree (37) Disagree (17) Somewhat disagree (15) Neither agree nor disagree (61) Somewhat agree (156) Agree (421) Strongly agree (732) Don't know/ prefer not to say
Perceived need for more fishery protection	Please indicate your level of agreement with the following statement(s): Alberta's fish	Strongly disagree (51) Disagree (87) Somewhat disagree (99) Neither agree nor disagree (229)

	populations need more protections than they have now.	Somewhat agree (296) Agree (326) Strongly agree (351) Don't know/ prefer not to say
Perceived locus of authority over the fishery		
Perception provincial government should be doing more	What is your level of agreement with the following statement(s) about fisheries management? The provincial government should be doing more to protect the health of Alberta's fish populations and aquatic ecosystems.	Strongly disagree (35) Disagree (40) Somewhat disagree (64) Neither agree nor disagree (154) Somewhat agree (294) Agree (423) Strongly agree (429) Don't know/ prefer not to say
Perception communities should be doing more	What is your level of agreement with the following statement(s) about fisheries management? Communities should be doing more to protect the health of Alberta's fish populations and aquatic ecosystems.	Strongly disagree (28) Disagree (25) Somewhat disagree (37) Neither agree nor disagree (144) Somewhat agree (297) Agree (509) Strongly agree (399) Don't know/ prefer not to say
Perception individuals should be doing more	What is your level of agreement with the following statement(s) about fisheries management? Individuals should be doing more to protect the health of Alberta's fish populations and aquatic ecosystems.	Strongly disagree (24) Disagree (12) Somewhat disagree (24) Neither agree nor disagree (62) Somewhat agree (212) Agree (523) Strongly agree (582) Don't know/ prefer not to say

Sense of personal responsibility	Please indicate your level of agreement with the following statement(s): I have a responsibility to act in a way that maintains the populations that I fish.	Strongly disagree (72) Disagree (1) Somewhat disagree (2) Neither agree nor disagree (5) Somewhat agree (22) Agree (251) Strongly agree (1086) Don't know/ prefer not to say
Dependence on fishery		
Dependence level as food	Please indicate your level of agreement with the following statement(s): I depend on angling as a food source.	Strongly disagree (307) Disagree (431) Somewhat disagree (114) Neither agree nor disagree (250) Somewhat agree (205) Agree (107) Strongly agree (25) Don't know/ prefer not to say
Emotional dependence on fishing	Please indicate your level of agreement with the following statement(s): I depend on angling for my emotional well-being.	Strongly disagree (49) Disagree (76) Somewhat disagree (52) Neither agree nor disagree (219) Somewhat agree (349) Agree (354) Strongly agree (340) Don't know/ prefer not to say
Sense of community		
Sense of belonging to the angling community	Please indicate your level of agreement with the following statement(s): I feel I am part of the angling and/or fishing community.	Strongly disagree (41) Disagree (17) Somewhat disagree (24) Neither agree nor disagree (86)

		Somewhat agree (165) Agree (495) Strongly agree (611) Don't know/ prefer not to say
Receives angling-related newsletters and/or magazines	If you are a member of any angling societies, associations, clubs, or groups, how do participate with them? (Select all that apply) (note: This multiple choice question was later converted into binary dummy variables describing whether or not they did the specific activities described.)	1)(Baseline) I do not participate in any angling societies, associations, or groups, online or in person 2) I receive angling-related newsletters and/or magazines (439) 3) I read/ view angling-related discussions online (670) 4) I participate in angling-related discussion online (357) 5) I attend angling-related functions/ activities in-person (211) 6) I help plan/coordinate angling-related functions/activities (70)
Reads/ views angling-related discussions online		
Participates in angling-related discussion online		
Attends angling-related functions/ activities in-person		
Helps plan/coordinate angling-related functions/activities		
If friends or family fish	Do you have friends or family that fish?	No (0), Yes (1439)
Frequency respondent fishes with others	How often do you fish alone or with someone else?	I always fish alone (4) Most of the time I fish alone (206) About half the time I fish, I fish alone (351) Most of the time I fish with at least one other person (628)

		I always fish with another person (250) Don't know/ prefer not to say
Angling participation		
Years fishing	In what year did you start fishing/angling? (Best guess is okay) (note: Year (date) was converted to total years fishing at time of survey [2019])	Mean= 37.2 years
Years fishing in Alberta	In what year did you start fishing/angling in Alberta? (Best guess is okay) (note: Year (date) was converted to total years fishing in Alberta at time of survey [2019])	Mean= 32.0 years
days fishing per year	How many days do you estimate you will go fishing in the entire year of 2019?	Mean= 47.8 days in 2019

Table 2.2 The standardized factor loadings (with an oblique rotation) from a Primary Components Analysis for variables within two conceptual areas that may influence angler willingness to report Prussian carp: anglers' perceived need for action to protect the fishery, and their personal connection to the fishery. Eigenvalues, percent (%) variance, and alpha values (α), are also supplied for the two extracted components/ variables. Factor loadings > 0.60 are bolded.

		Varimax (oblique) rotated factor loadings	
Dimension	**Variable**	**Perceived need for action**	**Personal connection to the fishery**
Locus of authority	Sense of personal responsibility	0.209	**0.756**
Sense of community	Sense of belonging to the angling community	0.178	**0.839**
Level of concern for the fishery	Concern for fish populations	0.489	**0.704**
Dependence on the fishery	Emotional dependence on fishing	0.131	**0.567**
Perception about the state of the fishery	Perceived extent humans affect the fishery	**0.654**	0.326
Level of concern for the fishery	Perceived need for more fishery protection	**0.748**	0.209
Locus of authority	Perception provincial government should be doing more	**0.843**	0.232
Locus of authority	Perception communities should be doing more	**0.851**	0.189
Locus of authority	Perception individuals should be doing more	**0.759**	0.261
	Eigenvalues	3.11	2.10
	% of variance	0.35	0.23
	α	0.83	0.69

Table 2.3 The tabulated results for the partial model and full model investigating the role of various characteristics on anglers' willingness to report Prussian carp. Values given include the Nagelkerke r-squared value (R^2), the estimates (B), the estimates' standard error (SE B), the odds ratio, and the *P*-value for each variable.

Dimension	**Variable**	**R^2**	***B***	***SE B***	**Odds**	***P***
Partial model		0.034				
	constant		0.817	0.363	2.265	0.024
Perceptions about the sate of the fishery	Discusses invasive species frequently (vs 'sometimes' baseline)		0.239	0.187	1.270	0.202
Perceptions about the sate of the fishery	Perceives invasive species to have a strong effect on Alberta fisheries		0.152	0.145	1.164	0.297
PCA summative variable	Need for action to protect the fishery		0.128	0.062	1.136	0.040
Perceptions about the sate of the fishery	Discusses invasive species never (vs 'sometimes' baseline)		-0.365	0.186	0.694	0.050
Demographic information	Lives in Calgary		-0.537	0.179	0.584	0.003
Full model		0.053				
	constant		-0.106	0.444	0.900	0.811
PCA summative variable	Personal attachment to the fishery		0.234	0.067	1.263	<0.000
Perceptions about the sate of the fishery	Discusses invasive species frequently (vs 'sometimes' baseline)		0.195	0.188	1.215	0.301

Perceptions about the sate of the fishery	Perceives invasive species to have a strong effect on Alberta fisheries	0.152	0.146	1.164	0.299
PCA summative variable	Need for action to protect the fishery	0.048	0.067	1.050	0.474
Perceptions about the sate of the fishery	Discusses invasive species never (vs 'sometimes' baseline)	-0.286	0.188	0.751	0.129
Demographic information	Lives in Calgary	-0.542	0.180	0.582	0.003

Figures

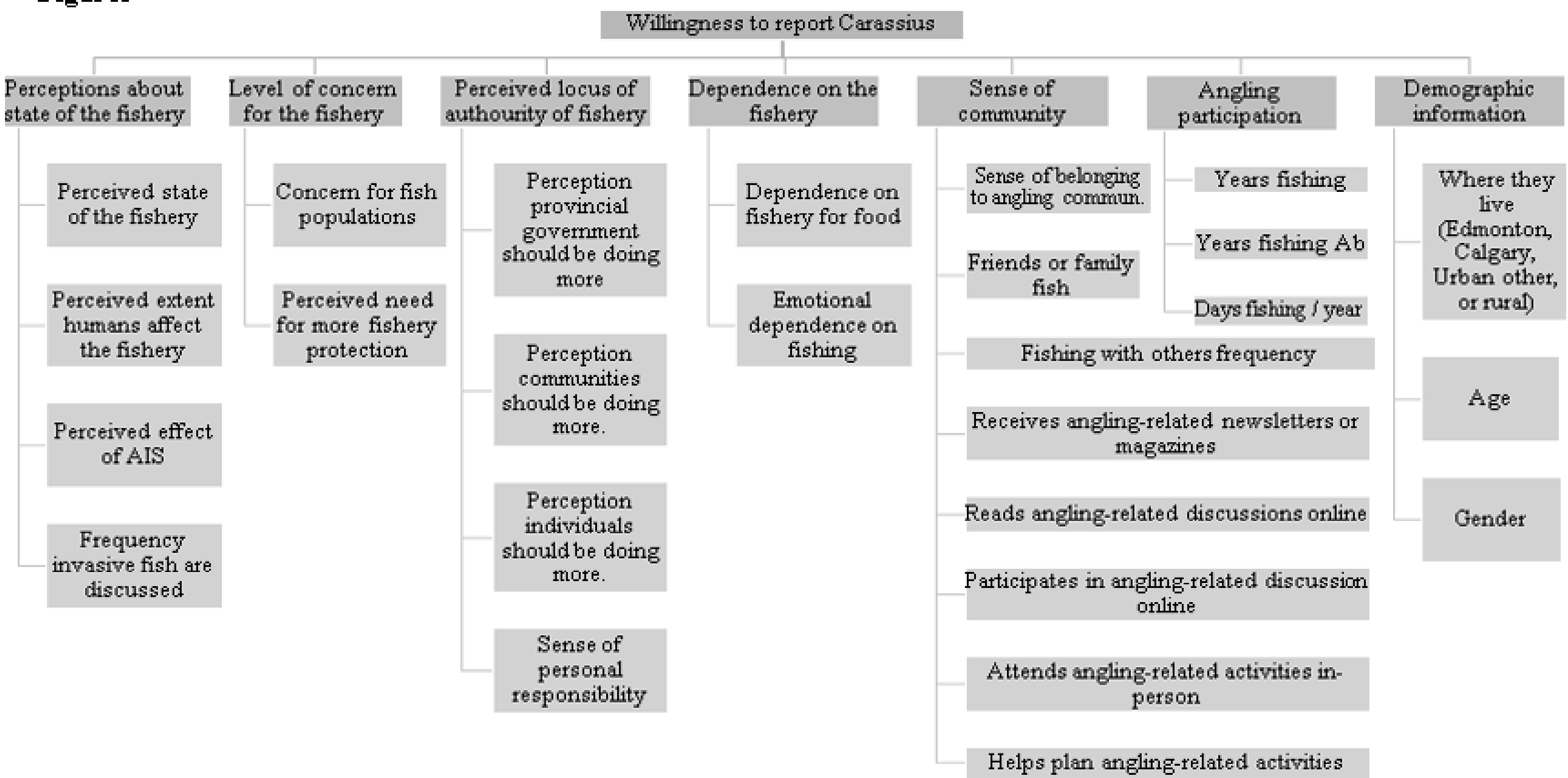

Figure 2.1 Angler characteristics that are assessed for relationships with willingness to report Prussian carp (*Carassius gibelio*): the name by which the variable may be referred (as abbreviated from the full questions from which the variable derived [Table 1]), and the dimensions in which the variables fell (before the Primary Components Analysis created the two summative variables): 1) perception about the state of the fishery; 2) level of concern about the fishery; 3) perceived locus of authority over the fishery; 4) dependence on the fishery; 5) sense of community; 6) Angling participation, and 7) demographic information.

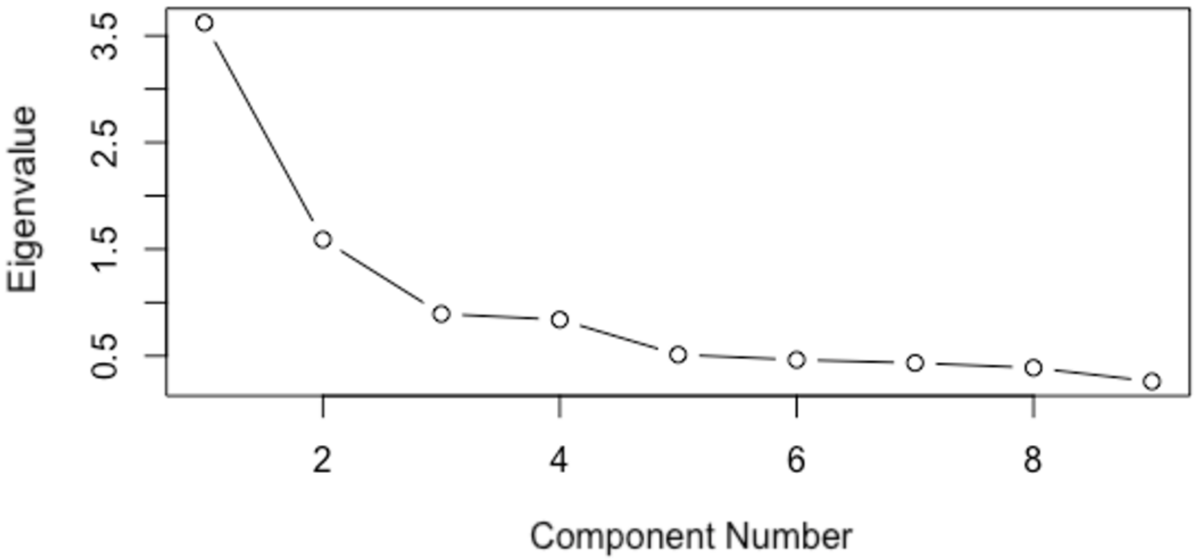

Figure 2.2 Scree plot of eigenvalues against number of components in the Primary Components analysis. Based on Kaiser's criterion that the number of eigenvalues above '1' should be considered (Kaiser, 1974), two components should be extracted from the nine variables that went into this analysis.

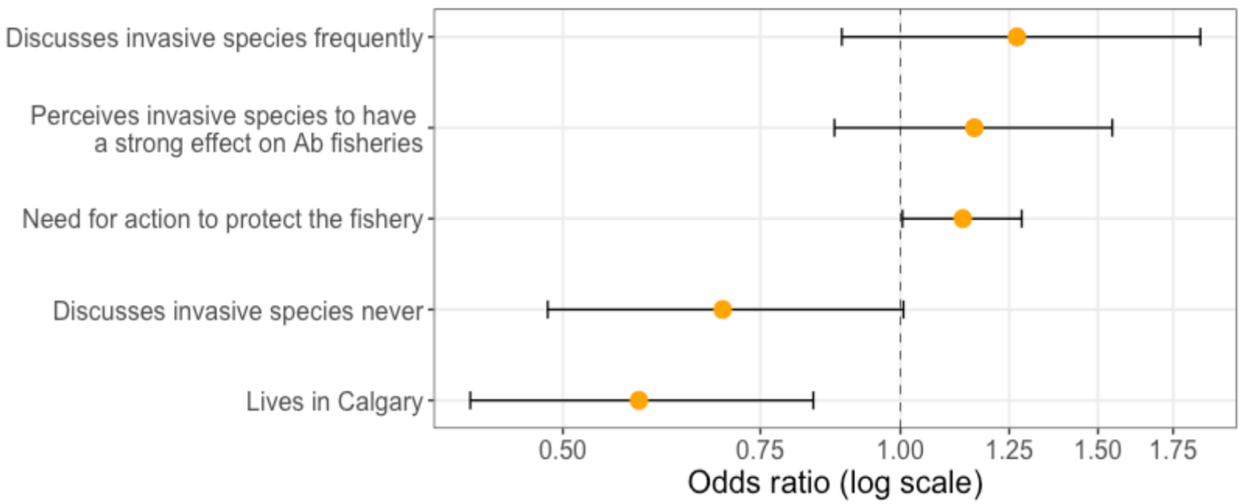

Figure 2.3 The odds ratios (± the respective 95% confidence intervals [CI]), for the 'partial' binomial GLM predicting angler willingness to report Prussian carp (*Carassius gibelio*), as predicted by the extent to which anglers: 1) discuss invasive species frequently, compared to sometimes (binary; 0/1; dimension: perception about the state of the fishery), 2) perceive invasive species to have a strong effect on Alberta fisheries (binary; 0/1; dimension: perception about the state of the fishery), 3) perceive a need for action to take place to protect the fishery (numeric from 0 to 7; PCA summative variable), 4) never discuss invasive species never, compared to sometimes (binary; 0/1; dimension: perception about the state of the fishery), and 5) live in Calgary (binary; 0/1; dimension: demographic information). Values that exceed the "1" dotted line are associated with an increase in angler willingness to report Prussian carp (dependent variable), while values below "1" are associated with a decrease in willingness to report. Variables that have CIs that cross "1" do not have a significant effect on willingness to report (at p = 0.05). The model p = 0.001, and the Nagelkerke R^2 = 0.034.

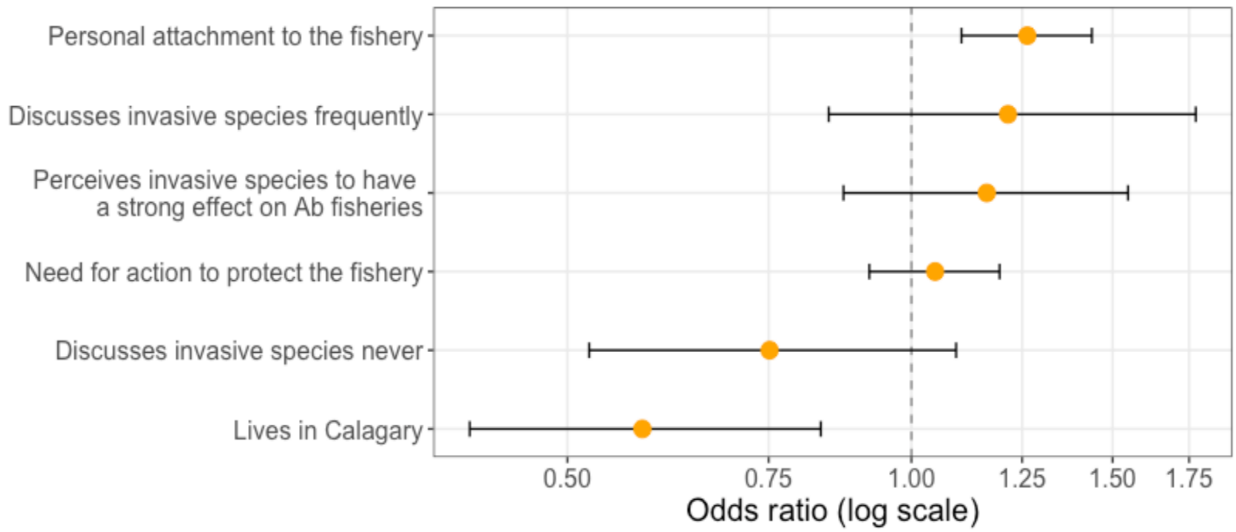

Figure 2.4 The odds ratios (± the respective 95% confidence intervals [CI]), for the ‘full’ binomial GLM predicting angler willingness to report Prussian carp (*Carassius gibelio*), as predicted by: 1) If they discuss invasive species frequently, compared to sometimes (binary; 0/1; dimension: perception about the state of the fishery), 2) If they perceive invasive species to have a strong effect on Alberta fisheries (binary; 0/1; dimension: perception about the state of the fishery), 3) their perceived need for action to take place to protect the fishery (numeric from 0 to 7; PCA summative variable), 4) If they never discusses invasive species, compared to sometimes (binary; 0/1; dimension: perception about the state of the fishery), 5) If they live in Calgary (binary; 0/1; dimension: demographic information), and 6) their personal attachment to the fishery (numeric from 0 to 7; PCA summative variable). Values that exceed the “1” dotted line are associated with an increase in angler willingness to report Prussian carp (the dependent variable), while values below “1” are associated with a decrease in willingness to report. Variables that have CIs that cross “1” do not have a significant effect on willingness to report (at $p = 0.05$). The model $p < 0.001$, and the Nagelkerke $R^2 = 0.053$.

Appendix

Table A2.1 The text for each of the four information treatments provided to anglers during the online survey: 1) Control: only received baseline text, 2) Effect-centric treatment: respondent received the baseline text as well as the effect-centric treatment text, 3) Edibility-centric treatment: respondent received the baseline text as well as the edibility-centric treatment text, 4) Combination treatment: in addition to the baseline text, respondents received both the effect-centric treatment text as well as the edibility-centric treatment text.

Text option	Baseline and treatment option text
Baseline text	You can help stop aquatic invasive species! Prussian carp and goldfish are aquatic invasive species found in water bodies in Southern Alberta and Saskatchewan. To reduce the risk of these invasive fish spreading to new areas, Prussian carp and goldfish should not be returned to the water if they are caught. There are no limits on size or quantity that can be caught. ***Treatment text*** If you were to catch a Prussian carp or goldfish, how likely would you be to release these invasive fish back into the water, letting it live?
Effect-centric treatment text	Prussian carp and goldfish may impact native and game-fish populations by competing with them for food and space. Removing invasive species like Prussian carp and goldfish may help maintain and protect these resources. Anglers like yourself are at the front lines of controlling the invasion.
Edibility-centric treatment text	Prussian carp are also edible and have been described to have a pleasant, subtle taste.

CHAPTER 3: USING REPORTS BY RECREATIONAL ANGLERS TO PREDICT THE DISTRIBUTION OF INVASIVE PRUSSIAN CARP IN ALBERTA

Introduction

Aquatic Invasive Species (AIS) are the second biggest threat to freshwater fish in Canada, affecting over 60% of endangered fish species in the country (Dextrase & Mandrak, 2006). AIS that are especially fecund and spread across large, interconnected waterbodies, pose a challenge in terms of achieving complete eradication. In these situations, the goal becomes the prevention of spread and the suppression of AIS to minimize their ecological effects (Green & Grosholz, 2021). To target the limited resources available necessary to achieve such objectives, managers must know an AIS's distribution; however, continually applying traditional biological sampling approaches across the entire potential geographic range in which an AIS could take hold is often too resource-intensive to be feasible.

The use of citizen science reporting platforms is increasingly recognized as a valid approach for collecting various types of ecologically-relevant data, including species distributions (Fairclough et al., 2014; Martelo J et al., 2021; Phillips et al., 2009; Sullivan et al., 2014). Engaging citizen scientists in sampling for and reporting potential AIS could help flag and direct manager's limited resources to sampling areas of greatest concern. However, the efficacy of reports by non-professionals at predicting the distributions of terrestrial invasive species is poorly understood (Crall et al., 2011; Gallo & Waitt, 2011), let alone reports of AIS.

Prussian carp (*Carassius gibelio*) is an invasive species that has already spread across Europe, threatening native aquatic ecosystems and fish populations, and is poised to do the same in the Canadian prairies (Özuluğ et al., 2004; van der Veer & Nentwig, 2015). The Canadian provinces of Alberta and Saskatchewan are currently the only confirmed locations in North

America where invasive Prussian carp (*Carassius gibelio*) have established; past biological sampling suggests their current distribution includes the Bow, Red Deer, and South Saskatchewan River drainages (Docherty et al., 2017; Elgin et al., 2014).

While Prussian carp are relatively new to Alberta, they are not the province's first Carassius invasion: goldfish (*Carassius auratus*) have been causing mounting harm to native ecosystems for decades (Docherty, Ruppert, Rudolfsen, Hamann, & Poesch, 2017). While the goldfish in public parks and people's home tanks are normally physically distinct enough from Prussian carp to avoid confusion, after a couple generations in the wild, descendants of released or escaped goldfish can revert to a colouring and form that makes them virtually indistinguishable from their *gibelio* sister lineage (Rylková et al., 2010). Unfortunately, the ecological impact of Prussian carp is expected to be even greater than that of the already harmful goldfish (Docherty et al., 2017).

Prussian carp can survive in an extremely wide range of environmental conditions and have high monozygotic reproductive rates, meaning that not only is most of Alberta susceptible to invasion, but only one individual fish is required to bring the invasion front to a whole new area (Docherty et al., 2017). Given that the species' life history traits make it resistant to eradication, population suppression and the prevention of spread are likely the best remaining management options. Alberta's last province-wide sampling effort by professionals using biological sampling techniques (e.g., electrofishing, eDNA sampling, etc.), to understand the distribution of Prussian carp was completed in 2019, and it would take a massive amount of resources to continually re-sample the province to ensure the distribution map is as up-to date as would be optimal for targeting suppression resources.

If enough of Alberta's >280,000 anglers (AEP, 2015) were able to identify, remove, and report aquatic invasive species (AIS) such as Prussian carp, such a force could have application as a cost-effective alternative to or complimentary tool for traditional AIS population tracking and early detection/rapid response.

Here we integrate information on the distribution of Prussian carp obtained from biological field sampling with sightings reports of the species from recreational anglers and a survey of those same anglers' fishing behaviour and knowledge to address two key research questions: How well does the distribution of invasive Prussian carp generated from reports by recreational anglers predict the species' distribution as documented through traditional biological sampling methods? What factors affect the accuracy of the reporting by the angling community?

To determine how well the distribution of Prussian carp generated from angler reports predicts the species' distribution generated from traditional biological sampling, we examined the extent and locations of overlap between two distributions of invasive Prussian carp: one generated from reports collected from recreational anglers in Alberta between July and December 2019, and another distribution determined from various biological sampling efforts completed by Alberta Environment and Parks (AEP) and Alberta Conservation Associated (ACA) from the species' initial sighting in 2006 through to the summer of 2019.

To identify factors affecting the accuracy of the distribution of Prussia carp generated from angler reports, we collected sighting data and information on angler characteristics via a survey between July and December 2019. We used these data to address two issues affecting species distribution data generated from angler reports. First, what factors affects whether an angler reports Prussian carp? We predicted an angler's probability of indicating they saw Prussian carp would be associated with 1) whether they also indicated they saw a goldfish, 2) their home's distance from the invaded area, 3) how frequently they fish, and 4) how well they can identify fish species (specifically, their ability to identify Prussian-carp look-a-likes, identify Prussian carp specifically as Prussian carp, and identify Prussian carp as invasive).

Second, we examined factors that may affect the accuracy of reporting by anglers, measured as whether a report of Prussian carp made by a recreational angler is in an area that biological sampling indicated was invaded (i.e., is more likely a correct ID), vs outside the invaded range (i.e., is more likely an incorrect ID). We expected that whether an angler's Prussian carp report is in an area the biological sampling indicated as invaded would be predicted by 1) how frequently the angler fishes, and 2) how well they can identify fish.

We hypothesised how frequently an angler fishes (i.e., their estimated days they predicted to be fishing in 2019), to be positively correlated with their likelihood of reporting Prussian carp, due to the functioning that angling frequency may have as a proxy for fishing effort – the more often an angler is fishing, the more opportunities they have to sight a Prussian carp. Angling frequency may also be associated with their angling specialization and therefor skills in identifying Prussian carp (Needham et al., 2009), which may also contribute to the positive relationship we hypothesise between how frequently an angler fishes and the likelihood of their report being affirmed by the sampling distribution.

We hypothesise that fish identification skills will translate to the accuracy of the angler's report and be positively correlated with the likelihood of a report being affirmed by the sampling distribution. In addition, an angler's fish identification skills may positively affect their confidence in reporting a potential sighting they have, and so we also hypothesise that an angler's fish identification skills would have a positive association with their likelihood of indicating they saw a Prussian carp.

While we hypothesise the distribution of Prussian carp generated from angler sightings will be correlated with their distribution as estimated by biological sampling, the relationship between goldfish sightings and the sampling distribution is harder to predict: the current distribution of goldfish in Alberta is unknown, though it is expected to be fairly widespread due to their extensive history in the province (Docherty et al., 2017). This poses an interesting complication for this study, where wild goldfish mis-identified as Prussian carp by anglers could cause over-estimation of the area indicated as invaded by the report distribution.

If the results of this research suggest that reports of AIS by recreational anglers in Alberta can sufficiently predict the species' distribution made by traditional biological sampling, engaging recreational anglers could have potential as a cost-effective alternative to - or complimentary tool for - traditional population research. Identifying the covariates that should be considered when assessing the accuracy of such report distributions would further allow managers to target their outreach initiatives and maximize the efficacy of their efforts and resources.

Methods

Data collection

Biological sampling

A range of biological sampling efforts have been conducted in Alberta, Canada to determine the presence and distribution of invasive Prussian carp since the species' presence in Alberta was confirmed in 2006 (Elgin et al., 2014). In 2018 and 2019 we updated the known distribution of Prussian carp in the province by sampling waterbodies across the province for the invasive fish's DNA (i.e., environmental DNA or 'eDNA'), a method that has been shown to be an effective tool in detecting various species in aquatic environments (Ficetola et al., 2008; Appendix: methods excerpt from ACA project description for 2018-2019). Together, 83 sites across Alberta were sampled for eDNA, 12 of which had results positive for Prussian carp (Figure 3.1).

Three replicates and one control sample of distilled water were collected at each site, with each sample being taken progressively upstream from the previous every 10 meters (For more details regarding the sampling equipment and procedures, see Appendix: methods excerpt from ACA project description for 2018-2019). The samples were then processed at the Department of Biological Sciences Molecular Biology Service Unit at the University of Alberta, which involved the identification of Prussian carp eDNA (when present). We used the results of the eDNA analyses to update visualizations of the known distribution of Prussian carp in the province.

In particular, we assessed and displayed the distribution of Prussian carp across the province at the level of hydrological unit code "8" (HUC-8), which is the second finest HUC available for Albertan watersheds at the subbasin level and are roughly the size of medium-sized river basins (Alberta Environment and Parks [AEP], 2017). HUC-8 areas positive for the species via biological sampling from here on referred to as the 'sampling distribution' or 'sampling map', and HUC-8 areas indicated as invaded by angler reports will be referred to as the 'report distribution' or 'report map'. Out of the available scales, HUC-8 are likely to be most appropriate for avoiding underestimating or overestimating invaded area based on the eDNA results of samples within the area (B. Schmidt, ACA, personal communication, January 2021).

Angler survey and reporting

To determine how well the Prussian carp distribution from angler reports (i.e., the 'report distribution') predicts their distribution from biological sampling (i.e., the 'sampling distribution'), and to identify the covariates that should be considered when assessing the accuracy of the report distribution, we administered an online survey via Qualtrics software (Qualtrics, Provo, UT), between July and September 2019. In addition to collecting reports of Carassius from Albertan anglers and information regarding the co-variates investigated in this chapter, the Qualtrics survey also collected responses regarding Chapter 2's investigation into the factors that affect an angler's willingness to report Prussian carp.

In-survey reporting

We constructed the survey using the online survey software Qualtrics (Qualtrics, Provo, UT), and distributed it for online completion by respondents between July and September 2019, as part of a larger survey aimed at identifying the characteristics associated with angler willingness to report (see Chapter 2 methods). It was in this survey that anglers were asked whether they had seen a Prussian carp or Goldfish during there fishing activities in Alberta, and if they had, asked to report the locations of those sightings. Respondents provided the details of each sighting in a text field, and while specific coordinates were encouraged, almost all the sightings had to be converted into coordinates post-survey based on the descriptions of the locations given by the respondents. Survey participants were also given the opportunity to provide their name and email, which were used to follow up with participants and gather additional sightings reports. Using the emails of those who submitted the post-survey reports (and their names to confirm when available), the identify of those who submitted reports post-survey were matched with their respective Qualtrics survey responses.

Post-survey reporting (i.e., invasivereport.ca)

Towards the end of the survey, we asked participants to report all future sightings of Prussian carp and Goldfish to our survey website invasivereport.ca, or the email contact@invasivereport.ca. The website had eight mandatory fields; first name, last name, email, the location of their sighting (as a text response – again, coordinates were encouraged but extremely rare), the date of the "catch" (which defaulted to the current date if no other date was provided), whether they thought the fish they caught was a Prussian carp or Goldfish (with descriptions and visual aids provided to help inform identification), the number of fish being reported in the submission (respondents could include multiple fish in a submission if they were of the same species and were caught on the same day in the same location),and finally, confirmation of their consent to submit the report. There were also three optional fields: a place to upload photos of the fish they suspect to be a Carassius to the website, a space for comments to clarify/ add detail to the rest of their report, and finally, an option to consent to further "study-related communications".

All communications aimed at increasing awareness of the survey and reporting platform (e.g., contact cards, flyers, and social media posts), included the need for those opting to email their sightings to include the same pieces of information in their report as the reports from invasivereport.ca.

Co-variates of reporting likelihood and accuracy determined in the survey

Within the online survey of Alberta anglers, participants were asked to estimate how many days they anticipated to be fishing that year and gave the postal code of their residence. Following data collection, postal codes were converted to coordinates (based on the point central to that given postal code), which were then used to create a new field: the minimum distance between the angler's home and the closest area (HUC-8) defined as invaded by the biological sampling (i.e., 'distance between where they live and the area indicated as invaded by the biological sampling').

We also gathered three additional variables related to each angler's regarded ability to identify fishes: 1) the ability to ID Prussian carp as invasive (a binary "can" or "cannot", based on a photo of the fish, 2) the ability to ID Prussian carp look-a-likes (a score out four regarding their ability to connect the correct name to photos of Prussian carp, Quillback, Lake Whitefish, and Goldeye from a drag-and drop question that also included five other fish that looked less like Prussian carp), and 3) the ability to ID Prussian carp as Prussian carp (a binary "can" or "cannot" based on whether they correctly identified Prussian carp in the same question that their ability to ID Prussian carp look-a-likes drew from).

Each sighting of Prussian carp or other Carassius was associated with the individual that submitted that sighting (and thus all the covariates that are associated with that individual), as well as whether that sighting was in a HUC-8 area the biological sampling defined as invaded.

For each HUC-8 area we summarised the total number of Prussian carp sightings contained within it, as well as the total number of other Carassius sightings. While we asked for the specific locations of the angler's Carassius sightings, we did not ask the specific locations of all the places the angler has fished and had not seen any Carassius.

Survey distribution

Materials supporting awareness of and participation in the main Qualtrics survey as well as the reporting platforms, were distributed through various platforms, including email listservs, Facebook pages, Twitter, and online public forums. To reach anglers that may not use electronic means to engage with the angling community, we also distributed contact cards and flyers at 21 fishing locations and outdoor retail stores around Alberta, with a focus around central/southern Alberta. For more details regarding survey distribution and response collection, see the Methods section of Chapter 2.

Analysis

We estimated the distribution of Prussian carp from angler reports (i.e., the 'report distribution'), from sightings submitted in the Qualtrics survey, to invasivereport.ca, or contact@invasivereport.ca between July 2019 (when the survey and report platform were launched), and January 1st, 2020. Reports submitted past January 1st, 2020 were not used in the comparisons between the report distribution and the sampling distribution to minimize the gap in time between angler reports and when biological sampling for Prussian carp took place; because Prussian carp's range could have expanded since the last biological sampling in 2018-2019, more recent angler reports could be reflect Prussian carp in areas that biological sampling indicated were not invaded.

Comparing species distributions generated from angler reports versus biological sampling

In order to evaluate the extent to which the distribution of Prussian carp estimated from angler reports (i.e., the 'report distribution') reflects the distribution as estimated by traditional methods of biological sampling (i.e., the ‘sampling distribution’), we first compared the extent to which the two distributions overlapped (i.e., % area), how much of the sampling distribution was missed by the report map, and how much the report map over-estimated the invaded area (i.e., % area; Figure 3.2, 3.3). To further evaluate how well the distribution of reports of invasive Prussian carp made by recreational anglers predict the species’ distribution as characterized by traditional biological sampling, we also used binary logistic regression (or ‘generalized linear models’ GLMs, family = binomial) to evaluate the probability an area (i.e., HUC-8 area; n = 422 areas) was invaded by Prussian carp as estimated by the biological sampling (binary response variable; 0/1) as predicted by two explanatory variables: 1) the total number of reports of Prussian carp in each watershed, and 2) the total number of other Carassius species in that area (Table 3.1).

Modeling whether an angler sighted Prussian carp

We then explore possible explanations for discrepancies between the two distributions using two additional binary logistic regressions. In particular, to evaluate the factors affecting the likelihood that an angler indicated they saw a Prussian carp (i.e., what are the drivers of angler identifying Prussian carp), we assessed potential relationships between whether each angler that responded to our survey indicated they saw Prussian carp (binary response variable; 0/1, n = 2,158 anglers) and 1) whether they also indicated they saw another (non-Prussian carp) Carassius (binary; 0/1) , 2) how far away they live from the invaded area (km /100, e.g., 200km= 2), 3) how frequently they fish (days per year), 4) their ability to ID Prussian carp as invasive (binary; 0/1), 5) their ability to ID Prussian carp look-a-likes (score between 0 and 4), and 6) their ability to ID Prussian carp as Prussian carp (binary; 0/1; Table 3.2).

Factors affecting the accuracy of angler reports of invasive Prussian carp

To evaluate potential drivers of the accuracy of angler's reports of Prussian carp, we used binary logistic regression to evaluate relationships between whether a report of Prussian carp was inside or outside an area known to be invaded (as documented through the biological sampling; i.e., binary response; 0/1; n = 440 reports) and 1) how frequently the angler who made the report fishes (days per year), 2) their ability to ID Prussian carp look-a-likes (score between 0 and 4), and 3) their ability to ID Prussian carp as Prussian carp (binary; 0/1) (Table 3.3). We excluded from this analysis the extent to which an angler could identify Prussian carp as invasive due to too few cases in this data frame where someone reported a Prussian carp but was unable to identify it as invasive. Our response variable in this model (i.e., 'accuracy' an angler report) assumes that the distribution of Prussian carp generated by biological sampling is reflective of the actual distribution of Prussian carp, so that angler reports made from locations within the sampling distribution can be conceived as "more likely to be correct".

All logistic regressions were implemented using the package MuMIn (Bartoń, 2019) in R statistical analysis software, version 3.6.1 (R Core Team, 2019). The binary logistic models were first created with the glm() function, where family=binomial. Next, for each model we assessed co-linearities between individual explanatory variables by calculating variance inflation factors (VIFs; QuantPsyc package; Fletcher, 2012). VIFs can also be interpreted with the tolerance statistic, which is the reciprocal of VIF (1/VIF). Generally, a tolerance statistic score of <0.2 indicates the two compared variables exhibit too much collinearity to be treated as separate variables going forward (Menard, 2002). Pseudo-R^2 for GLMs should be interpreted with caution and are not typically regarded as representative of the predictive power of the model, but more generally as gauge of the model's substantive significance (Field et al., 2012). For our models, we chose to present Nagelkerke R^2, which is an ad hoc correction to normalize the value and have a maximum value of 1.0 (Nagelkerke, 1991). The odds ratios and their confidence intervals were then presented in figures created in the sjPlot package (Lüdecke, 2021).

Results

Angler participation

In total, 3,500 anglers began the survey, with 2,619 respondents completing the question concerning their Carassius sighting history. Of those, 2,158 respondents completed the survey questions required for our analyses of the factors affecting how well the Prussian carp report distribution predicts the sampling distribution, and to identify the covariates that should be considered when assessing the accuracy of the report distribution map.

In total, we collected 657 reports of Carassius that were associated with co-variates hypothesized to affect the accuracy of the report distribution map, and thus could be eligible for use in our binary logistic models: 604 from the Qualtrics survey, and 53 either submitted to invasivereport.ca or contact@invasivereport.ca between July 2019 and January 1, 2020. Of the 657 Carassius sightings, 440 were of Prussian carp, 198 were of goldfish, and 19 sightings were of Carassius where the angler was not sure which species they saw. When “other non-Prussian carp Carassius” are referenced throughout this chapter, we are referring to the combination of the latter two categories of reports.

Angler characteristics

On average, anglers who responded to the survey reside an average of 75km (SD: $\pm$ 117km, median: 22.1km) from the edge of the nearest invaded HUC-8 (as determined from the distribution of Prussian carp via biological sampling; Figure A3.1). Overall, 679 (31%) of the anglers had a distance of "0", meaning they were located within an area the sampling distribution indicated as invaded (Figure A3.1). Of the 2,158 individuals who participated in the survey, the average days they went fishing per year was 47 days (± 29 days). Angler's ability to identify 'look-a-like' fish species (i.e., Prussian carp, quillback, lake whitefish, and goldeye) varied, with 316 (14.6%) scoring zero, 347 (16.1%) scoring one, 563 (26.1%) scoring two, 43 (2.0%) scoring three, and 889 (41.2%) scoring all four species correct. Of the look-a-like species, 66% correctly identified Prussian carp, 63% identified quillback, 56% identified Lake whitefish, and 52% identified goldeye. When asked to identify which of six fish species (Prussian carp, northern snakehead, quillback, mooneye, burbot, and rainbow trout) were invasive in Alberta (with pictures provided), 82% were able to correctly identify Prussian carp as invasive in the province.

Comparing species distributions generated from angler reports versus biological sampling

Biological sampling efforts across the province suggest that 79,031.5 km^2 of Alberta, or 32 HUC-8s, are invaded by Prussian carp (Figure 3.2, 3.3). We identified four HUC-8 areas of the sampling distribution map that were not covered by the Prussian carp report distribution map: Crowfoot creek (1464.9 km^2), Lower Red Deer river (3184.3 km^2), Threehills creek (2206.6 km^2), and Chin lakes (1381.1 km^2). These four areas together total 8236.9 km^2, meaning the Prussian carp report distribution missed 10.4% of the sampling distribution. However, both Crowfoot creek and Threehills creek are completely surrounded by other areas reported as invaded, so when these two areas are interpreted as invaded by the report distribution, that leaves only the 5.8% of the remaining 2 HUC-8s as "missed" by the report distribution (Figure 3.8).

By comparison, anglers reported at least one Prussian carp in 92,828.8 km^2 of the province, or 52 HUC-8s, covering an additional 13,797.3 km^2 – an increase from the sampling distribution area by 17.5%. Overall, we found that 54.8% of the area identified as invaded by angler reports was confirmed by biological sampling (Figure 3.1). However, 23 out of the 52 HUC-8s in the report distribution had only one Prussian carp sighting- 21 of which were not indicated as invaded by the sampling distribution (Figure 3.3).

When modeled in a binary logistic regression, both the total number of Prussian carp sightings and the total number of other Carassius sightings anglers reported in each HUC-8 had significant relationship to whether a HUC-8 contains Prussian carp in the sampling distribution, with a Nagelkerke R^2 value of 0.72 (Table 3.1).

The number of Prussian carp sightings a HUC-8 area contained had a strong positive relationship with the probability of the area being invaded in the sampling distribution; On average, each report of Prussian carp by an angler within a HUC-8 area increased the probability of the area being invaded in the sampling distribution by more than 10 times (odds ratio= 10.26: 4.4-29.7; Table 3.1, Figure 3.4). Conversely, the number of non-Prussian carp Carassius sightings a HUC-8 area contained had a negative relationship with the likelihood of the area being invaded by Prussian carp; on average, each report of other non-Prussian carp Carassius a HUC-8 area gained decreased the probability of the HUC-8 having Prussian carp in the sampling distribution by 69% (odds ratio=0.31: 0.16-0.51; Table 3.1, Figure 3.4).

Which covariates should be considered when assessing the accuracy of the report distribution?

Modeling whether an angler sighted Prussian carp

Several characteristics and behaviours of recreational anglers influenced an angler's probability of indicating they saw Prussian carp during the study and together explained 23% of the variation in reporting (Nagelkerke $R^2 = 0.23$; Table 3.2). In particular, whether or not they also indicated they saw a Carassius fish other than Prussian carp (e.g., goldfish) had a positive relationship with the odds that the angler indicated they saw Prussian carp: On average, also indicating they saw a non-Prussian carp Carassius increased the probability of an angler having seen a Prussian carp by almost 5.4 times (odds ratio= 5.37: 3.79-7.62: Table 3.2, Figure 3.5). The distance between the angler's home and the invaded area had a negative relationship with their odds of having reported Prussian carp: on average, for every 100km the angler's home is from the invasion, their probability of having seen Prussian carp decreases by 66% (odds ratio= 0.34: 0.25-0.45; Table 3.2, Figure 3.5). Whether the angler had correctly identified Prussian carp as an invasive species in Alberta had a positive relationship with their probability of having seen Prussian carp: on average, an angler's ability to correctly identify Prussian carp as invasive increased the probability of them having seen a Prussian carp by 2.5 times (odds ratio= 2.52: 1.51-4.45: Table 3.2; Figure 3.5). Finally, an angler's ability to identify Prussian carp look-a-likes (i.e., correctly assign the proper name to Prussian carp as well as four of its Albertan look-a-likes), had a positive relationship with their probability of having seen Prussian carp: on average, with each additional fish they were able to correctly identify, the probability of them having seen a Prussian carp increased by 22% (odds ratio= 1.22: 1.08-1.40; Table 3.2; Figure 3.5).

The remaining two variables did not have significant relationships with an angler's probability of having sighted Prussian carp: neither how frequently the angler fishes (i.e., their anticipated days fishing per year; odds ratio = 1.00: 0.99-1.01), nor their ability to identify Prussian carp as Prussian carp (odds ratio = 1.51: 0.95-2.41), had a significant relationship with probability of having seen Prussian carp (Table 3.2, Figure 3.5).

Factors affecting the accuracy of angler reports of invasive Prussian carp

Several characteristics and behaviours of recreational anglers influenced an angler's odds of their Prussian carp report being in a HUC-8 area the biological sampling indicated as invaded during the study, but together only explained 6.6% of the variation in report accuracy (Nagelkerke R^2 = 0.066; Table 3.3).

How frequently an angler fishes (i.e., their anticipated days fishing per year) had a positive relationship with the odds of their Prussian carp report being in a HUC-8 indicated as invaded by the sampling distribution: on average, for every 10 days the angler anticipated to fish in 2019, the probability their report was corroborated by the sampling distribution increased by 13% (odds ratio= 1.13: 1.02-1.25; Table 3.3, Figure 3.6).

Whether or not they also reported another non-Prussian carp Carassius (in addition to their Prussian carp report), had a negative relationship with the odds of their Prussian carp report being in a HUC-8 indicated as invaded by the sampling distribution: on average, the angler reporting a non-Prussian carp Carassius decreases the probability of their Prussian carp report being corroborated by the sampling distribution by 75% (odds ratio= 0.25: 0.11-0.64; Table 3.3, Figure 3.6).

Finally, neither metrics of an angler's ability to identify fishes had significant relationships with the odds of their Prussian carp report being in a HUC-8 indicated as invaded by the sampling distribution: not their ability to correctly identify Prussian carp look-a-likes (odds ratio= 1.04: 0.76-1.39), nor their ability to identify Prussian carp as Prussian carp (odds ratio=1.01: 0.29 – 3.3.29; Table 3.3, Figure 3.6).

Discussion

Our study suggests that reports of Prussian carp by recreational anglers in Alberta can be a powerful tool for predicting the invasive species' actual distribution as indicated by biological sampling; for every report of Prussian carp a HUC-8 area received, the probability that area was confirmed as invaded by biological sampling increased by more than 10 times. Overall, 88% of Prussian carp reports from anglers were in agreement with the biological sampling distribution. Out of the 32 HUC-8s that biological sampling indicated were invaded, 28 were also indicated as invaded by angler reports of Prussian carp. While angler reports also indicated an extra 28 HUC-8s outside the biological sampling distribution as invaded, this over-estimated area drops to 6 HUC-8s if only areas with more than one report are considered (and the adjustment only adds 2 areas as missed to the original 4 HUC-8s missed in the un-adjusted report distribution; Figure 3.3).

We found that the greater the number of Prussian carp reports in a HUC-8 area, the higher the likelihood of that area being confirmed as invaded by biological sampling. However, this relationship was the opposite with the total number of goldfish/ other Carassius reports; our results suggest goldfish sightings tend to indicate Prussian carp are *not* in the area. Not only does this result fail to support our hypothesis, but it at first seems contrary to our result showing that those that indicated they saw a goldfish were more likely to also say they saw a Prussian carp. However, this inconsistency could be explained by our result suggesting Prussian carp reports by people that also identified goldfish in a certain area were more likely to be wrong about the Prussian carp they identified. In summary, many people identified Prussian carp in a variety of locations, but if they identified a goldfish in addition to a Prussian carp at a location, their Prussian carp sighting was more likely not confirmed by biological sampling. While locations (i.e., HUC-8 areas) with multiple Prussian carp reports are highly likely to actually be invaded, if sightings of goldfish accompany many of the Prussian carp reports, managers may consider this a reason to use biological sampling to confirm the invaded state of the area. Furthermore, a portion of the goldfish reports were of those in public parks and ornamental ponds, so future analysis should include the type of waterbody the sighting was located in to distinguish between the area invaded by wild goldfish and the distributions of such man-made (and more likely self-contained), waterbodies.

Another surprising result was that those with better fish identification abilities were *not* more likely to accurately identify Prussian carp (i.e., submit sightings within the sampling distribution), but they *were* more likely to report Prussian carp in the first place. This could suggest that an angler's ability to identify fish was associated with an angler's confidence in making the report in the first place. Alternatively, anglers who are better at identifying fish may be more specialized /invested in angling, which may be associated with other factors such as sight rate or willingness to participate in a reporting effort (Needham et al., 2009), serving to increase their overall report rate in this study. However, our dependent variable for this regression was a Prussian carp report's accuracy, as approximated by whether it reflected the sampling distribution – not whether it was *actually* an incorrect or correct identification. Even if the sampling distribution was completely accurate, that would only enable us to say that Prussian carp sightings outside the sampling distribution are incorrect, but not that those within the sampling distribution are all correct: photos of the sightings were not mandatory, and even if they were, genetic testing could still be required to differentiate between goldfish and Prussian carp. Future studies that better confirm the veracity of angler reports (via photos and/ or biological testing of specimens), may be better able to assess what factors affect the likelihood of a report being correct (Crall et al., 2011; Gallo & Waitt, 2011). Our results also suggest that fish identification skills should be promoted among anglers to increase reporting rates and reduce the mistaken removal of similar-looking native species.

Finally, fishing frequency had no effect on an angler's likelihood of reporting Prussian carp, failing to support the idea that more days fishing per year was providing significantly more opportunities to sight a Prussian carp. However, the more the angler fished, the greater the accuracy of any report of Prussian carp they did make (i.e., as compared to the sampling distribution). This could suggest that fishing frequency was acting as some sort of proxy for fish identification ability, but this would be suspect considering our actual measure of fish identification skills were not significant in that same model, nor were any of the metrics for fish identification ability related to anglers' days fishing per year. Alternatively, it could be that an angler with high fishing frequency had more opportunities to sight and confirm the identity of Prussian carp overall, and this ability led to increasing the likelihood that their identification of Prussian carp was correct, but verifying this would involve further study and information such as where the angler was fishing and how many times they sighted a Carassius in a spot before they decided to report it.

Several attributes of aquatic invasive species may influence their candidacy to be targeted in an angler report program. For an angler to report a fish somewhere, that location must first be fished often enough to see/ catch it. Prussian carp's known invaded area is concentrated in the south/central areas of Alberta – as is Alberta's human population, and these coinciding distributions could have lent themselves to a citizen science reporting program in a way AIS in the northern (more remote) areas of Alberta couldn't have. Other species attributes that could affect their likeliness to be caught, identified, and reported include how easily they can be told apart from native species, as well as if they regularly consume the sort of bait that facilitates angling. There should be further investigation into how distribution maps determined from angler reports of other species compare to those of Prussian carp, so to identify if there are species traits that are better suited to be incorporated into a reporting initiative. This could be an especially interesting comparison between invasive and non-invasive aquatic species, considering the threat AIS poses is suggested in the first Chapter to be important in an angler's willingness to report Prussian carp.

Interestingly, anglers in this study appear to be relatively more "invested in fishing" compared to the wider angling population: overall, licenced anglers in Alberta spend an average of 14.3 days fishing in 2010 (Zwickel, 2012) while the participants of this survey spent an average of 47.1 ($\pm$ 29 days)– more than three times as many days. The difference in fishing days between participants in this study and anglers at large could be a manifestation of the "non-response bias", where those that respond to the survey are not representative of the general population, and thus the sample is not actually random (Duda & Nobile, 2010). Perhaps if non-response bias is better accounted for and the survey were to reach a more representational portion of the angling population, the effects of variables that could be related to angler specialization or level of participation, such as angling frequency and fish identification skills (Needham et al., 2009) could be strengthened and made more detectable. This could be achieved by keeping the survey brief and as simple as possible, or by segmenting the survey samples by characteristics of concern such as demographics, distribution channel, etc. (Duda & Nobile, 2010). To get a more representative portion of Alberta's angling population, future studies should aim at getting less specialization, more casual anglers that fish less. For other study limitation regarding differences between the study sample and Alberta's angling population, see Chapter 2's discussion.

Two additional potential limitations of this study concern assessing the veracity of angler reports: one is that we do not currently know the distribution of goldfish, which means we could not account for their presence confusing those who identified Prussian carp outside of the sampling map, nor could we confirm the veracity of angler's goldfish sightings. The second limitation is that we do not have the exact locations for null reports (i.e., when respondents said they have not seen Prussian carp, we didn't ask them to tell us the locations of those non-sightings). This means we did not have a way of knowing what areas were "checked" for Prussian carp by reporters, and we could not acknowledge people correctly identifying fish as not Carassius. It is possible that the biological sampling is not completely accurate and missed certain waterbodies outside of the currently indicated range, so some reports of Prussian carp beyond the sampling distribution were correct. Having report photos be optional in this study allowed us to explore how well the report map was able to predict the sampling map without using methods to confirm the sightings, which would have reduced the total reports we collected. However, future studies should consider the inclusion of a way to confirm the accuracy of the reports, so the effects of variables such as fish identification skills can be clarified.

To further understand the dynamics that determine the efficacy of a reporting initiative by recreational anglers for aquatic invasive species, other covariates should be considered for incorporation into future studies. In particular, angler-specific characteristics, like the dimensions assessed in Chapter 2, could be considered (e.g., perspectives on the fishery, belonging to the angling community, etc.), along with more spatially- relevant variables. For example, having more detailed understanding of angler effort distribution (i.e., both where anglers are and how often they fish) would further elucidate the factors associated with sighting opportunity (and thus reporting opportunity). In addition, incorporating the distribution of Prussian carp look-a-like species such as quillback, lake whitefish, and goldeye in an analyses of report accuracy could help determine whether these species may be mistakenly reported as Prussian carp, and erroneously removed from waterbodies and/or fished without limit, thus becoming causalities in the war against Carassius.

Tables

Table 3.1 The tabulated results for the binary logistic model predicting whether an area is indicated to contain Prussian carp according to the sampling map, including the pseudo r-squared value (1-deviance/null deviance; R^2), the estimates (B), the estimates' standard error (SE B), the odds ratio, and the *P*-value for each variable.

	R^2	*B*	*SE B*	**Odds**	***P***
Full model	0.72				
constant		-4.2058	0.4179	0.0149	<2 e-16
Total Prussian carp sightings		2.3283	0.4845	10.2604	1.54e-6
Total sightings of non-Prussian carp Carassius		-1.1599	0.2770	0.3135	2.83e-5

Table 3.2 The tabulated results for the binary logistic model predicting whether an angler indicated they saw Prussian carp, including the pseudo r-squared value (1-deviance/null deviance; R^2), the estimates (B), the estimates' standard error (SE B), the odds ratio, and the P-value for each variable.

	R^2	B	SE B	Odds	P
Full model	0.23				
constant		-3.2622	0.2980	0.0383	< 2e-16
Distance between angler's residence and the sampling's map invaded area		-1.0709	0.1435	0.3427	8.58e-14
Whether the angler had also reported a goldfish		1.6815	0.1774	5.3736	< 2e-16
Anticipated days fishing in 2019		0.0016	0.0023	1.0016	0.4869
Ability to ID Prussian carp look-a-likes		0.2026	0.0657	1.2246	0.0021
Ability to ID Prussian carp as Prussian carp		0.4131	0.2356	1.5114	0.0795
Ability to ID Prussian carp as invasive		0.9243	0.2732	2.5201	0.0007

Table 3.3 The tabulated results for the binary logistic model predicting whether a report of Prussian carp is in agreement with the sampling map, including the pseudo r-squared value (1-deviance/null deviance; R^2), the estimates (B), the estimates' standard error (SE B), the odds ratio, and the P-value for each variable.

	R^2	B	SE B	Odds	P
Full model	0.06				
constant		1.4391	0.4966	4.2169	0.0038
Whether the angler had also reported a goldfish		-1.3745	0.4508	0.2530	0.0023
Anticipated days fishing in 2019		0.1211	0.0526	1.1287	0.0215
Ability to ID Prussian carp look-a-likes		0.0435	0.1525	1.0444	0.7755
Ability to ID Prussian carp as Prussian carp		0.0104	0.6102	1.0104	0.9864

Figures

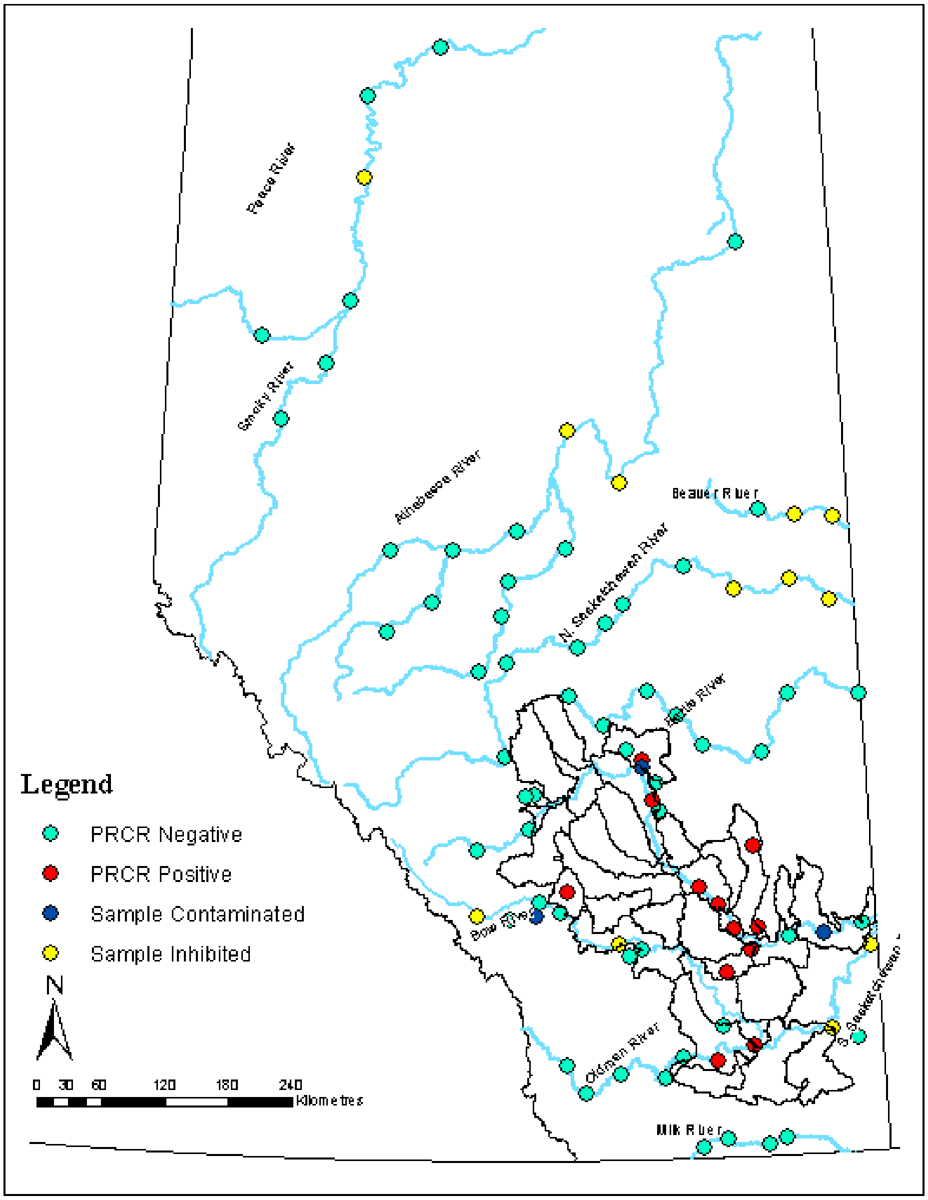

Figure 3.1 Locations of the 83 sites sampled for Prussian carp (PRCR) eDNA between 2018 and 2019 in Alberta, Canada, as well as the area indicated as invaded by Prussian carp from prior biological sampling (outlined in black).

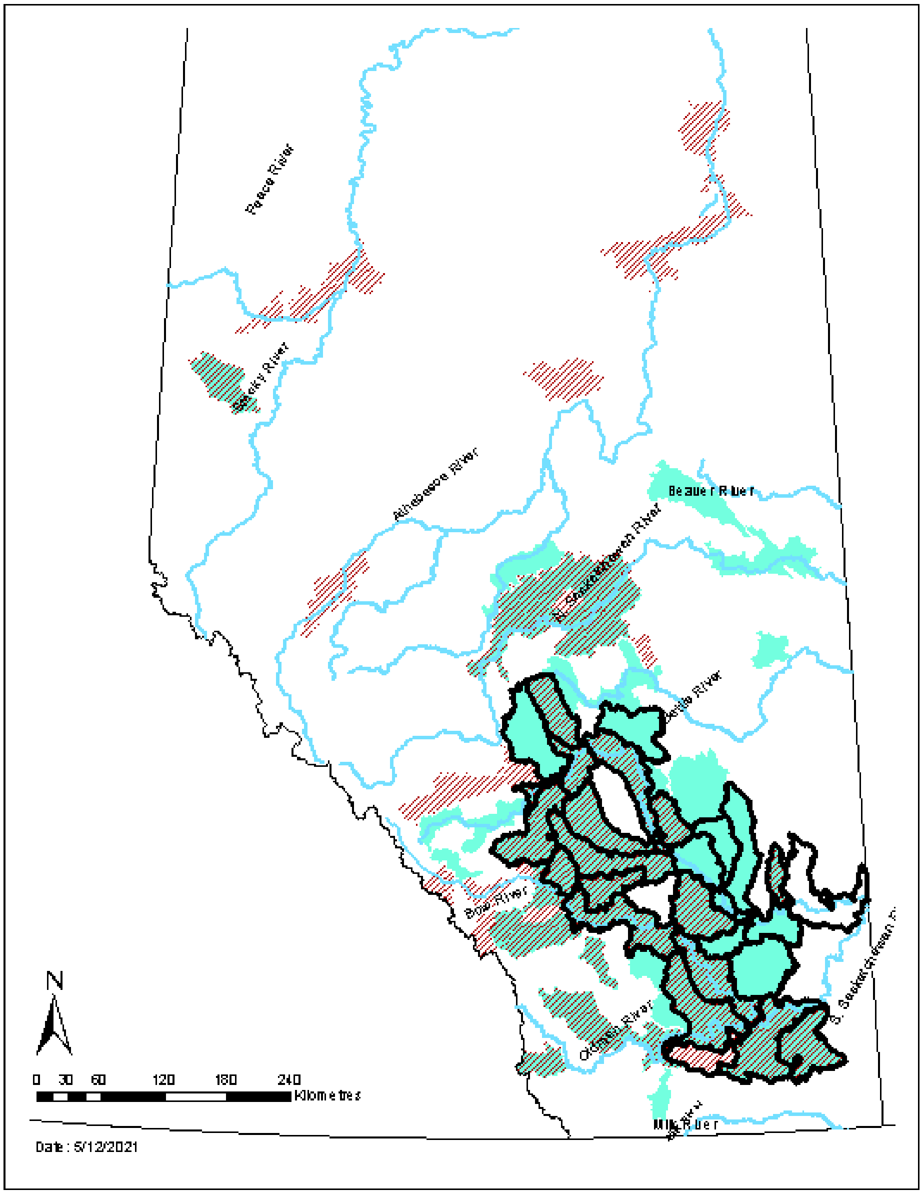

Figure 3.9 HUC-8s within Alberta's watersheds (Hydrological Unit Codes– with the 8th being the second finest level) that contain: 1) biological sampling results positive for Prussian carp (i.e., the sampling map; black outline), 2) angler reports of Carassius not specifically indicated as Prussian carp (red lines), and 3) angler reports of Prussian carp, Carassius gibelio (i.e., the report map; solid green).

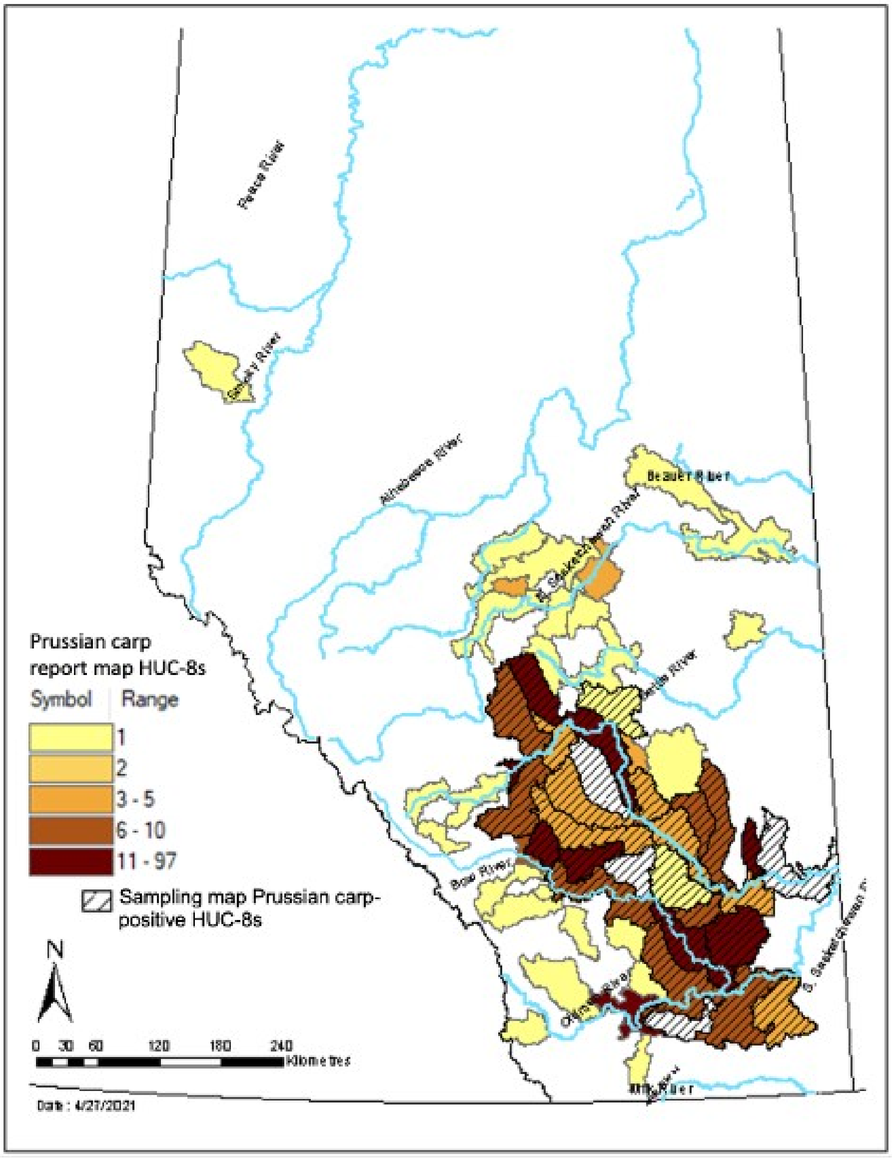

Figure 3.10 HUC-8s within Alberta's watersheds (Hydrological Unit Codes– with the 8th being the second finest level) that contain reports by recreational anglers of Prussian carp (Carassius gibelio) between July and December 2019 (i.e., the report map). Each HUC-8 is color-coded to indicate how many reports are contained within it: yellow =1, pale orange=2, orange = 3-5, medium brown= 6-10, and dark brown= 11-97. The HUC-8s that were indicated as invaded by biological sampling are indicated by black outline with lines (i.e., the sampling map).

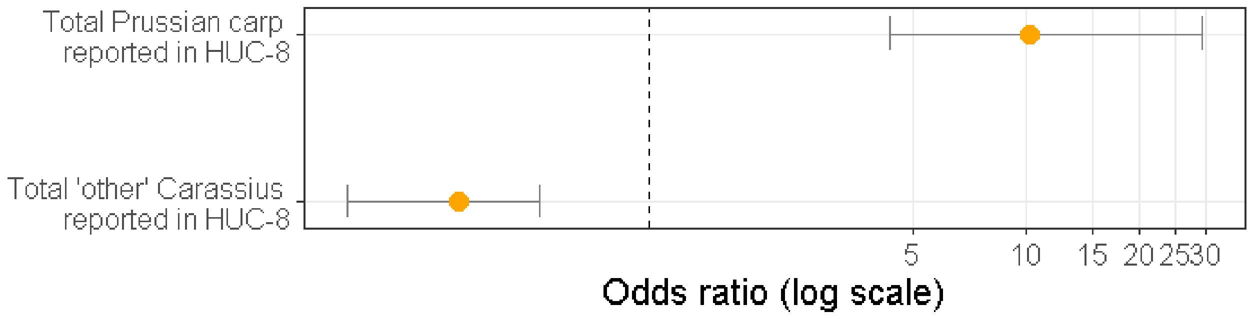

Figure 3.4 The mean odds ratios (95% ±C.I.), for the binary logistic regression model predicting whether a HUC-8 area (Albertan watersheds' "Hydrological Unit Codes"– with the 8^{th} being the second finest level) contains Prussian carp (*Carassius gibelio*), according to the biological sampling, as predicted by 1) the total number of Prussian carp that were reported within that HUC-8 by recreational anglers, and 2) the total number of Carassius that were not specifically indicated as Prussian carp reported within that HUC-8 by recreational anglers. Model $p<0.001$, and Nagelkerke $R^2 = 0.73$.

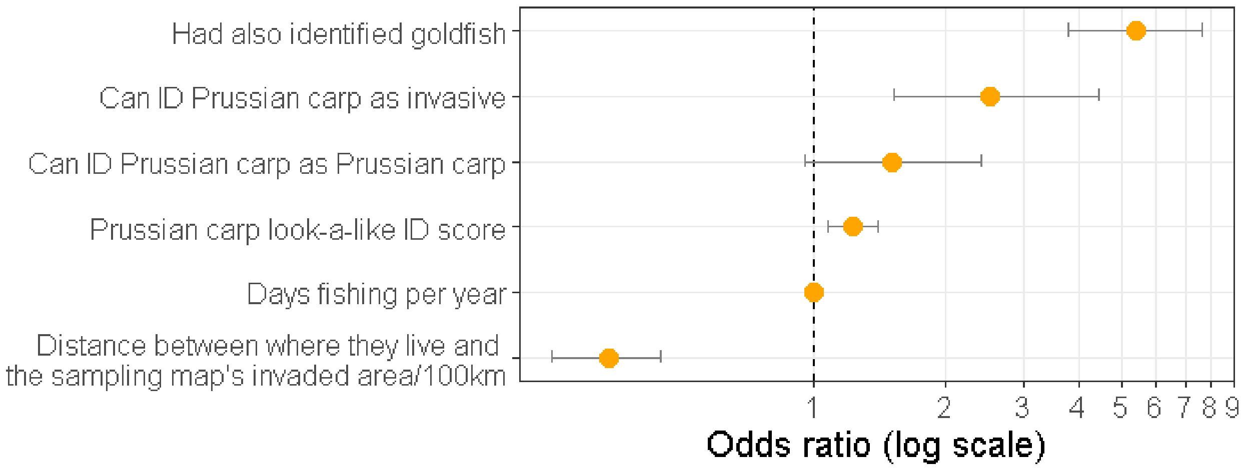

Figure 3.5 The mean odds ratios (95% ±C.I.), for the binary logistic regression model predicting whether a recreational Albertan angler indicated they saw a Prussian carp (Carassius gibelio), as predicted by 1) whether they also indicated they saw goldfish or another (non-Prussian carp) Carassius (binary; 0/1) , 2) their ability to ID Prussian carp as invasive (binary; 0/1), 3) their ability to ID Prussian carp as Prussian carp (binary; 0/1), 4) their ability to ID Prussian carp look-a-likes (score between 0 and 4), 5) their days fishing per year, and 6) the distance between where they live and the area indicated as invaded by the biological sampling (km /100, e.g., 200km= 2). Model $p<0.001$, and Nagelkerke $R^2 = 0.23$.

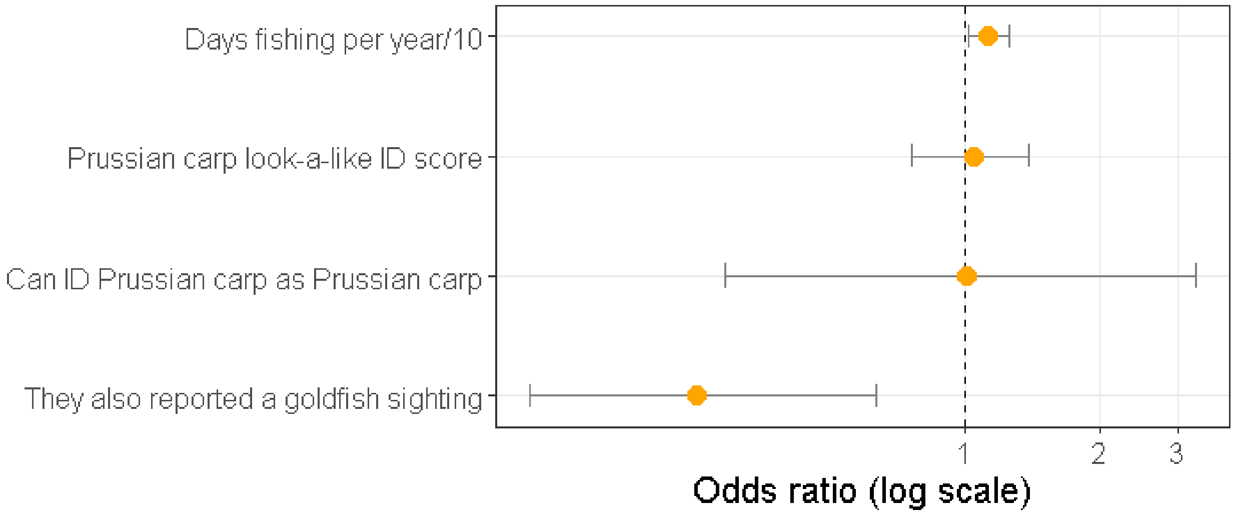

Figure 3.6 The mean odds ratios (95% ±C.I.), for the binary logistic regression model predicting whether an angler's report of Prussian carp (Carassius gibelio), is in an area indicated as invaded according to the results of biological sampling (i.e., is corroborated by the sampling map (Figure 3.2; 3.3)), as predicted by 1) the angler's days fishing per year, 2) their ability to ID Prussian carp look-a-likes (score between 0 and 4), 3) their ability to ID Prussian carp as Prussian carp (binary; 0/1), and 4) whether they also indicated they saw goldfish or another (non-Prussian carp) Carassius (binary; 0/1). Model p-0.004, and Nagelkerke $R^2 = 0.066$.

Appendix

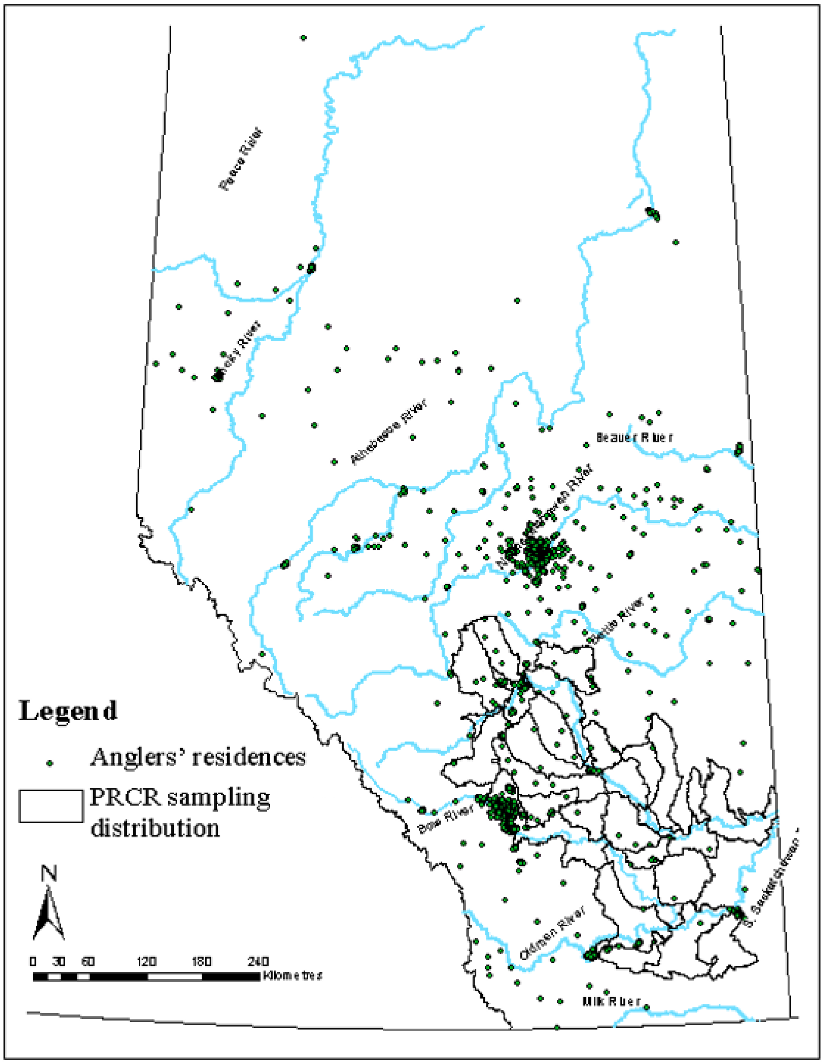

Figure A3.1 Locations of Albertan anglers' residences according to the centre of their FSA (Forward Sortation Area), represented by green dots. The black outline is the distribution of Prussian carp (PRCR), as determined by biological sampling.

Appendix: Methods excerpt from: ACA (Alberta Conservation Association), Project Description for 2019 - 2020

Section 3 – Methods

Distribution Map: We will identify sites from 2018-19 eDNA sampling where lab results indicated either contamination or inhibition. We will re-visit these sites in May 2019 and collect a second eDNA sample for lab analysis. At each site, three replicate samples and one control will be taken. The first sample will be collected at the most downstream end of the site location, with the other two sampled progressively upstream. Sampling will involve attaching a sterilized filter cup (250ml Thermo Scientific™ Nalgene™ Analytical; 0.45um pore size) to silicone tubing (Cole-Parmer mflex #24), loaded through a peristaltic pump (Geopump Series II, Geotech Environmental Equipment Inc., Denver, Colorado). Using a telescopic pole, the cup will be placed just below the surface of the water with the filter facing upstream and pump turned on. Once 1000ml of water is pumped through the filter, the cup will be removed from the water. Using forceps, the filter will be removed from the cup, folded, and placed into a labelled vial filled with anhydrous ethanol, then placed into an individual labelled plastic bag. Between replicate samples, forceps will be disinfected with a 50% bleach solution and rinsed twice in distilled water. The second sample will then be taken 10m upstream of the first, and the third another 10m upstream. Lastly, 250ml of distilled water will be passed through a filter as a control in order to test for contamination from the filter cups or forceps. After eDNA collection is complete, we will record temperature, dissolved oxygen (YSI Optical Pro DO), conductivity, pH, and total dissolved solids (Oakton PCTSTestr 50). Between sites, all eDNA collection equipment that came into contact with water will be treated with 50% bleach solution.

Additionally, whirling disease decontamination protocols (AEP 2017) will be followed according to the location of the sampling site within the designated risk zones (AEP 2018). Filters will be stored in a -20C freezer prior to extraction. All samples will be processed at the Department of Biological Sciences Molecular Biology Service Unit at the University of Alberta. Once results are obtained from the University of Alberta, we will finalise the current distribution map of Prussian carp in Alberta.

Population and Habitat Assessment: We will return to sites identified as Prussian carp positive in 2018 from June 29 to July 26, 2019, to determine population abundance/structure and habitat characteristics in these areas. Preliminary results from 2018 indicate 10 carp positive sites. Using single pass electrofishing, we will perform fish inventory surveys and retain any captured Prussian carp. Small streams will be sampled using protocols outlined in Standard for Sampling of Small Streams in Alberta (AEP 2013). River sites will be sampled for a minimum of 2,000 m, separated into 500 m reaches, with each reach alternating between left and right banks. Captured carp will be euthanized and biological data will be collected in the field including length, weight, and sex. Otoliths will be retained for lab analysis of age. We will also collect standard habitat data, including wetted and rooted widths, stream type composition, water temperature and dissolved oxygen (YSI Optical Pro DO), pH and conductivity (Oakton PCTSTestr 50), turbidity (Hanna Instruments 93703), maximum depth and velocity (Hach FH950) at each site. Collected data will be used to characterize the population of Prussian carp by constructing length at age distributions and determining sex ratios. Habitat data will be used to ground truth our occupancy model. Whirling disease decontamination protocols (AEP 2017) will be followed according to the location of the sampling site within the designated risk zones (AEP 2018).

CHAPTER 4: GENERAL CONCLUSION

Aquatic Invasive Species (AIS) affect the health of over 60% of endangered fish species in Canada, and just behind habitat loss and degradation are the second biggest threat to the country's freshwater fish (Dextrase & Mandrak, 2006). The recent invasion of the Prussian carp (*Carassius gibelio*) in Alberta and Saskatchewan threatens the provinces' native aquatic species and ecosystems (Docherty et al., 2017; Elgin et al., 2014). The fish's resilience and high rates of monozygotic reproduction pose challenges to their eradication, so the species distribution must be determined to allocate the population suppression and spread prevention efforts that remain a priority (Docherty et al., 2017; Green & Grosholz, 2021). If enough of Alberta's >280,000 anglers were able to report Prussian carp, such a force could have application as a cost-effective alternative to or complimentary tool for traditional population research and aquatic invasive species (AIS) early warning systems.

Our results suggest that Prussian carp reports by recreational anglers in Alberta can be a powerful tool as indicators of the invasive species' actual distribution as indicated by the biological sampling; for every report of Prussian carp a HUC-8 area received, the probability that area was confirmed as invaded by the sampling map increased by more than 10 times. This accuracy was surprising considering the lack of confirmation of reports – photos were not mandatory and were rarely provided.

Our results also suggest that anglers that are more personally attached to the fishery and perceive a greater need for action to protect the fishery are more willing to report sightings of Prussian carp during their fishing activities. This suggests that in addition to detailing the ecological impact of Aquatic Invasive Species (AIS), fisheries managers should encourage behaviours and programs that develop anglers' personal attachments to the fishery, and frame the threat of invasive species in ways that highlights their personal threat to the angler and that sense of attachment. Managers should also make clear the mechanism of how the threat operates and relate that explicitly to the action we are asking of the angler, so the efficacy of any proposed behaviour is understood. Anglers from Calgary were also significantly less willing to report Prussian carp, although the drivers behind this require further investigation.

Our study revealed a positive relationship between fish identification abilities and likelihood of reporting Prussian carp, despite having no discernible effect on the report's accuracy; thus, the role an angler's ability to identify fish plays in the accuracy of their reports of AIS such as Prussian carp should be further investigated with more sensitive metrics of both report accuracy and angler fish identification abilities (Crall et al., 2011). Anglers that fished more frequently were also more likely to have correctly identified Prussian carp, although the mechanism behind this relationship, be it sampling effort or angling specialization, is still unclear (Copeland et al., 2017a; Scott & Shafer, 2001). More comprehensive investigations into the theory of planned behaviour (including social norms), as it applies to willingness to report AIS could further elucidate the drivers behind such pro-conservation behaviours (Bamberg & Möser, 2007; Kan & Fabrigar, 2017; Rivis & Sheeran, 2003). In addition, potential barriers to reporting should also be investigated, such as the perceived difficulty or futility of reporting (i.e., defeatist attitudes; Armitage et al., 1999; Zanetell & Knuth, 2004).

The performance of this study's citizen science Prussian carp report efforts suggests the participation of recreational anglers in AIS citizen science reporting programs have potential as cost-effective AIS early warning systems or alternatives to traditional population research.

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