A socio-ecological risk assessment of the effects of recreational fishing on American Eel (*Anguilla rostrata*)

by

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Abstract

In the present thesis, I used human dimensions and ecological research techniques to investigate whether recreational fishing poses a threat to American Eel (*Anguilla rostrata*), an Endangered species in the Canadian province of Ontario and globally (IUCN Red Listed as Endangered). Specifically, in Chapter 2 I explored angler perspectives and behaviour towards the American Eel through interviews. In Chapter 3, I evaluated the effects of simulated catch-and-release angling on American Eel, in terms of mortality and injury over a seven-day holding period. Almost all anglers (90%) who had captured eels in the Ottawa River, Ontario, had released them (Chapter 2), and eels were found to be relatively resilient to catch-and-release events (Chapter 3). Overall, my results suggest that recreational fishing does not pose a threat to American Eel, however this research is only a preliminary assessment and not all variables involved in a true recreational fishing scenario were examined.

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Thesis Format and Co-authorship

While this research is my own, its undertaking was a collaborative effort with each co-author contributing to its completion. The roles of each co-author are outlined below.

Chapter 2: Anglers interactions with American Eel: Exploring human perspectives and behaviour toward an unloved but imperiled fish. M. Aline Litt, Nathan Young, Nicolas W.R. Lapointe, and Steven J. Cooke.

The project was conceived by Litt, Lapointe, and Cooke. Litt wrote the interview guide, with feedback from Young, Lapointe and Cooke. Fieldwork was conducted by Litt and field technicians, with logistical support from Cooke and Lapointe. Analyses were conducted by Litt with input from Young, Lapointe and Cooke. The manuscript was written by Litt, with feedback from Young, Lapointe and Cooke.

Chapter 3: Does catch-and-release angling pose a threat to American Eel? A hooking mortality experiment. M. Aline Litt, Brooke S. Etherington, Lee F.G. Gutowsky, Nicolas W.R. Lapointe, and Steven J. Cooke.

The project was conceived by Litt, Lapointe, and Cooke. Litt designed the experiment, with feedback from Gutowsky, Lapointe and Cooke, and final decisions were made in the field by Litt and Etherington. Fieldwork was conducted by Litt and Etherington, with logistical support from Cooke and Lapointe. Analyses were conducted by Litt with input from Gutowsky, Lapointe and Cooke. Manuscript preparation was conducted by Litt, with feedback from Lapointe and Cooke.

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Chapter 1 – General Introduction

The State of Freshwater Biodiversity

Less than 1% of water on Earth is fresh but despite its small expanse on Earth's surface, freshwater is home to a disproportionately high number of species (at least 126,000) (WWF 2018). In addition, many other bird, fish, amphibian and invertebrate species rely on freshwater at some point in their life history. Global indices reveal that the biodiversity crisis is most dire for species residing in freshwater ecosystems (IUCN 2018; WWF 2018), whose populations have declined in abundance by an average of 83% between 1970 and 2014 (WWF 2018). Dudgeon et al. (2016) identified overexploitation, water pollution, flow modification, habitat degradation, and species invasion as the five major types of threats to freshwater biodiversity. More recently, this list was expanded by Reid et al. (2018) to include climate change, microplastic pollution, freshwater salination, and nine other emerging threats. Many of these threats are unpredictable in terms of their effects on different species or regions. In part, this is due to the erratic nature of the threats, but a large part of the uncertainty is due to knowledge gaps (Dudgeon et al. 2006; Reid et al. 2018).

Threat Assessment for Imperiled Species

To address the biodiversity crisis at the species level, conservation biologists identify threats to a species, and then implement a recovery strategy to mitigate or eliminate the threat (Lawler et al. 2002; Kerr and Cihlar 2004; Rao et al. 2007). In practice, this process is more complex because most species face multiple threats, and conservation resources (e.g. money, time) are generally inadequate to address all potential perils. Therefore threats are often ranked to ensure that limited resources focus on priority species, threats and/or ecosystems (Master 1991). This process of prioritization requires at least a minimal understanding of the threats, but unfortunately there are major gaps in our knowledge of the status of imperiled species and the nature of threats facing these species (Lawler et al. 2002; Baillie et al. 2004). Moreover, it has been found that poorly understood threats are less often assigned recovery tasks, compared to well understood threats (Lawler et al. 2002). This could have major implications for the recovery of a species if an under-studied threat is in fact a driving factor of the species' decline. Thus, it is imperative to have at least a rudimentary understanding of all potential threats to an imperiled species.

Recreational Fishing

Freshwater ecosystems support thriving commercial, subsistence, and recreational fisheries. In terms of commercial and subsistence fisheries, freshwater and inland fisheries are an important global source of income and nutrition for millions of people (World Bank 2012). Though recreational fishers do not necessarily rely on their harvests for nourishment (Cooke et al. 2018), they derive pleasure and harvest some fish through recreational fishing activities (World Bank 2012). Between 220 million (World Bank 2012) and 700 million (Cooke and Cowx 2006) people participate in recreational fisheries around the world, capturing a wide range of species and using a variety of capture methods (e.g. angling, netting, spear fishing) (Arlinghaus and Cooke 2009). Valuation of recreational fisheries is estimated through expenditures by fishers and social benefits, given that there are no direct market transactions associated with recreational fishers' yields (Arlinghaus et al. 2002). For example, Canada's 2015 recreational fishery consisted of more than 3.2 million adult anglers who spent over $2.5 billion on transportation, lodging, travel packages, supplies, and services directly related to recreational fishing activities (Fisheries and Oceans Canada 2019).

A full perspective on recreational fishing must also consider its negative implications, which often pertain to the global biodiversity crisis. The effects of recreational fishing are often overlooked, or assumed to be minor compared to commercial fishing (Cooke and Cowx 2004), but are in fact substantial (Lewin et al. 2006). For example, four species (*Sander vitreus, Esox lucius, Oncorhynchus mykiss, Salvelinus namycush*) in Canada have shown steep declines over several decades and these declines have been correlated with their popularity as recreationally harvested gamefish species (Post et al. 2002). Aside from the direct threat of overharvesting, recreational angling may pose a threat to fishes through unintentional mortalities as a result of catch-and-release fishing (Cooke et al. 2016). Catch-and-release fishing is practiced for a variety of reasons: (1) captured fish are by-catch (i.e. undesirable in terms of species or size), (2) regulations require fish release for conservation reasons, (3) voluntary action due to ethical or conservation motives (Cooke and Wilde 2007). It is estimated that on a global scale, as much as 60% of recreationally-captured fishes are released (Cooke and Cowx 2004). This high proportion of releases is often fueled by an assumption that released fish survive the angling interaction, however mortality rates for fish species following catch-and-release are highly variable (Muoneke and Childress 1994), with factors such as fight time, hooking location, hook type, and duration of air exposure impacting species differently, based on their unique characteristics and sensitivities (Cooke and Suski 2005; Brownscombe et al. 2017). Thus, best practices for catch-and-release must be species-specific, rather than generalized for all fishes (Cooke and Suski 2005).

Despite growing research concerning recreational fisheries in general, its effects on imperiled and non-target species remain understudied. There is concern that recreational fishing activity may counteract conservation efforts, but in some contexts angling communities have been strong advocates for the conservation of endangered gamefish (Granek et al. 2008; Cooke et al. 2016). Angler involvement in conservation efforts is linked to their sense of stewardship (i.e. values obtained through personal experience or education), the size of the resource sector (i.e. there is a greater sense of responsibility for each angler in a smaller fishery), and the source of the impact (i.e. imperilment caused by recreational fisheries incites less angler involvement than if imperilment is attributed to external drivers) (Granek et al. 2008). Of course, angler lobbying for conservation can only be considered a beneficial conservation action if the effects of angling do not impede conservation efforts (Cooke and Suski 2005). The effects of recreational fishing are often discounted in risk assessments for imperiled species (Cooke et al. 2016). The level of threat posed by catch-and-release angling on an imperiled species can be evaluated using rapid assessment techniques (Bower et al. 2016). A catch-and-release rapid assessment involves consultation with all relevant parties to identify areas of the fishery in which to focus research efforts and research to test the lethal and sub-lethal effects of catch and release on the species (Bower et al. 2016). The results of the rapid assessment may indicate that the level of threat from the recreational fishery is minimal for that species, or alternatively, may indicate a need for further research and mitigation action.

Recreational Fisheries as Socio-Ecological Systems

One well known aspect of biodiversity decline is that anthropogenic factors underlie many of the prevalent threats (Kerr and Currie 1995; Forester and Machlist 1996; Davies et al. 2006), including those specifically affecting freshwater biodiversity (Reid et al. 2018). Recognition of the human-wildlife connection has led to increasing calls for examining conservation problems in a socio-ecological framework (Lotze-Campen et al. 2008; Ohl et al. 2010; Guerrero and Wilson 2017). In brief, this involves recognizing the complex interrelations between social and ecological systems and allocating equal emphasis to understanding the perspectives and needs of humans and the needs of other species and ecosystems. More critically, it entails an examination of the human system and ecosystem in association with each other, therefore illuminating feedback cycles and complex interrelations that might be missed if the two components were studied independently (Guerrero and Wilson 2017).

Recreational fisheries are socio-ecological systems in which resource availability, angler behaviour, and management decisions interact and result in different outcomes over temporal and spatial scales (Schlüter et al. 2012). The ecological components of recreational fisheries and effects of management have been studied for a long time (Johnson and Carpenter 1994; Hunt et al. 2013). More recently, it has been recognized that the angler component of fisheries is also an essential consideration (Johnson and Carpenter 1994; Hunt et al. 2013). Integration of the two components (social and ecological) is rare but vital. To create regulations that are beneficial to both anglers and fish, management must recognize the diversity of angler motivations and the drivers of their behaviour, while simultaneously understanding the state of the fish population and threats to its continued propagation (Schlüter et al. 2012; Hunt et al. 2013).

Study Species

The American Eel (*Anguilla rostrata*) is a member of the Anguillidae family. Anguillidae are facultative catadromous fishes with long narrow bodies, pectoral fins and fused dorsal, caudal, and anal fins (Tesch and Thorpe 2003). This family is known for their complex life histories. The American Eel and European Eel (*Anguilla anguilla*) spawn in separate areas of the Sargasso Sea (Atlantic Ocean) in species-wide panmictic spawning events (Tesch and Thorpe 2003). Following spawning, American Eel leptocephalus larvae drift with ocean currents towards continental waters ranging from Guyana as far northward as southern Greenland (Tesch and

Thorpe 2003). As they reach the continental shelf, the leaf-shaped larvae metamorphose into translucent 'glass' eels which then settle in coastal (marine and brackish) or inland (fresh) waters (Jessop 2010; Cairns et al. 2014). Once glass eels gain pigmentation, they are known as elvers (Facey and Van Den Avyle 1987). The pigmentation slowly acquires a green-yellow coloration, signifying the eels' longest life stage in which they are known as 'yellow eels'. As yellow eels, they feed at night and conceal themselves in substrate during the day (Cairns et al. 2014). After three to twenty years, eels begin their metamorphosis to 'silver eels', for their return migration to the Sargasso Sea. This metamorphosis involves a change in coloration to grey-silver pigmentation, gonadal development, enlargement of the eyes, and degeneration of the digestive tract (Facey and Van Den Avyle 1987; Cairns et al. 2014). The mean age of silvering ranges from 4.8 to 21.9 years and seems to be somewhat correlated with distance from spawning grounds (Cairns et al. 2014).

American Eel play an important ecological role in the freshwater ecosystems that they occupy. Prior to their population decline, eels were a considerable portion of the total biomass in the riverine and lacustrine freshwaters of Eastern North America (Smith and Saunders 1955; Ogden 1970). In the estuarine and freshwater habitats where they are found, American Eel are top predators that feed on invertebrates and small fishes (Ogden 1970; Schmidt et al. 2006; Eberhardt et al. 2015) and could be a potential predator for invasive species such as the Round Goby (*Neogobius melanostomus*) (MacGregor et al. 2013). They are also a host species for at least one freshwater mussel (*Elliptio complanata*) (Galbraith et al. 2018). Research conducted in the Hudson River and its tributaries suggests that eels are the keystone species in some rivers, determining the structure and energy dynamics of the entire fish community (Schmidt et al. 2006). Furthermore, American Eel are documented as a prey of birds (Willard 1977; McLean and Byrd 1991), whales (Hodson et al. 1994), and sharks (Béguer-Pon et al. 2012), among others. Finally, Anguillid eels are considered important vectors for the transport of nutrients, carbon, and other organic matter between marine and freshwater ecosystems (Laffaille et al. 2000; Schmidt et al. 2006).

Eels are also highly valued by humans. Anguillid eels are consumed globally, along with being used for medicinal and instrumental purposes (Tsukamoto and Kuroki 2013). In Canada, many Indigenous groups highly value the American Eel, including the Algonquins of Ontario who traditionally harvested the species for medicinal, nutritional, spiritual and material purposes (Algonquins of Ontario 2012, 2014a, 2014b). In terms of economics, estimates of the combined value of European and American Eel exceed $66 million in gross revenue (Pendleton et al. 2014). In Canada, the combined value of the silver eel and glass eel fisheries was $35.2 million in 2016 (Government of Canada 2018).

American Eel have exhibited drastic declines in recruitment (Castonguay et al. 1994; Casselman 2003) and are listed as Endangered on the IUCN red list (Jacoby et al. 2017), as well as in Ontario (Canada) (MacGregor et al. 2013). Archeological findings, traditional knowledge, and records from early European settlers indicate that the historical range of eels in Ontario was expansive, including most of the Ottawa River, St. Lawrence River and Lake Ontario watershed (MacGregor et al. 2013). On the Ottawa River, eels once migrated as far north as Lake Temiskaming (MacGregor et al. 2013), and modeling suggests that there were approximately 3,700 km^2 of suitable and accessible habitat for eels along the Ottawa River (MacGregor et al. 2015). The existing long-term data series of eel abundance indicate that recruitment of American Eel in Ontario has declined by more than 99% since the 1980s (Casselman 2003). Today, eels are extirpated from the upper reaches and tributaries of the Ottawa River (e.g. Lake Temiskaming, Algonquin Park) and long-time anglers in the middle reaches of the main stem (e.g. Lac Des Chats) report steep declines in catches (MacGregor et al. 2013). Historically, Ontario eels were almost exclusively female and were some of the largest and most fecund individuals in the species (Castonguay et al. 1994; Casselman 2003). Given their high fecundity, they are suspected of being disproportionately large contributors to the spawning biomass and therefore of particular concern for conservation, because their survival may be crucial for the resilience of the species beyond Ontario as well.

Ontario's *American Eel Recovery Strategy* outlines the primary threats to Ontario eels as: mortality due to hydro-electric turbines (during downstream migration); reduced habitat access due to barriers (during upstream migration); commercial harvesting outside Ontario; contaminants; and habitat degradation/destruction (MacGregor et al. 2013). Given that all fishing for eels is prohibited in Ontario, the recovery strategy assumes that there is no longer a threat from fishing. The document considers the impact of previous commercial fishing (and ongoing commercial fisheries outside Ontario), and briefly mentions Aboriginal fishing, yet it does not once acknowledge the potential impact from ongoing recreational fishing in which eels may still be captured as bycatch, even if they are not being directly targeted.

Research Objectives

The general objective of this thesis was to evaluate the effects of recreational fishing on American Eel *(Anguilla rostrata)* through a socio-ecological lens (Figure 1-1). Chapter 2 uses social science methods to explore recreational angler behaviour and perspectives towards American Eel to uncover any existing conflicts between anglers and eels, and to identify any threats from anglers that could impede the conservation of the species. I conducted interviews with Ottawa River anglers to learn about their fishing practices, knowledge of American Eel, experiences capturing eels, and their perceptions of the environment in general. Chapter 3 uses an experimental approach to evaluate the impact of catch-and-release angling on American Eel under controlled lab conditions. Specifically, I examined injury and post-release mortality of American Eel following simulated angling events in which either the hook was removed, or the fishing line was cut. Chapter 4 integrates the findings of Chapters 2 and 3 and discusses their implications, as well as future research opportunities on the topic.

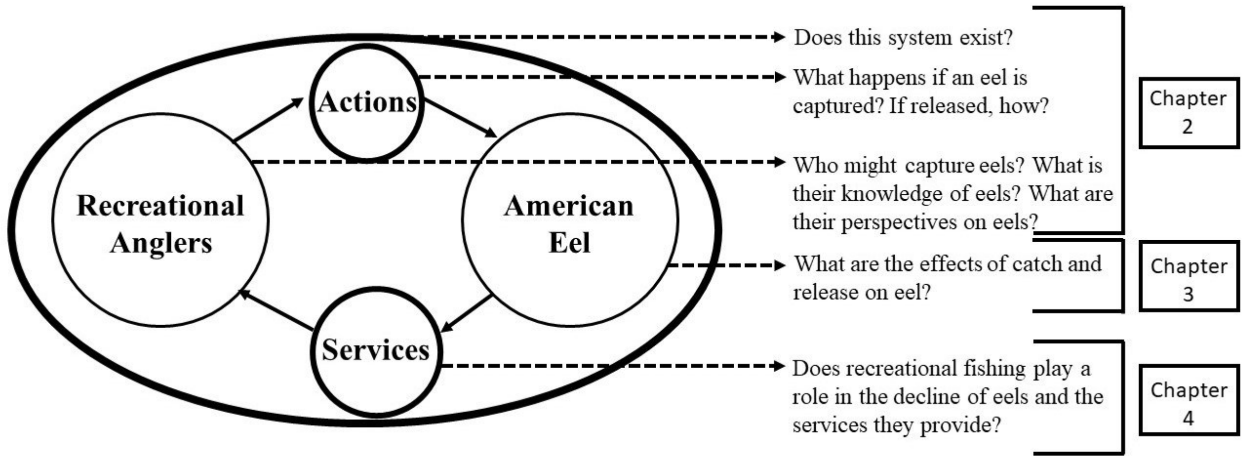

Figure 1-1. A socio-ecological framework of incidental capture of American Eel by recreational anglers. Dashed lines point toward research questions that develop from each component of the system, and boxes on the left indicate the corresponding chapters that address each question.

Chapter 2 – Angler interactions with American Eel: Exploring human perspectives and behaviour toward an unloved but imperiled fish.

Abstract

As aquatic biodiversity continues to decline, anglers are interacting more frequently with imperiled species. As a result, management strategies must be developed to balance recreational fisheries and conservation objectives. To fully understand the relationships between anglers and the species they encounter, both biological and sociological factors must be examined. To date, however, recreational fisheries research has focused primarily on the fish component of angler-fish interactions. Understanding the human dimension of these encounters is equally important, as the decisions made by anglers have a direct impact on the animals and their environments. Here, I explore angler perspectives and behaviour towards the American Eel (*Anguilla rostrata*), an unpopular and non-targeted species listed as Endangered in the Canadian province of Ontario and globally (IUCN Red Listed as Endangered). Interviews with 48 anglers revealed that almost half had captured an eel at some point in their angling history, but only 6% had killed eels (and all prior to the eel's Endangered status listing in Ontario). However, a large proportion of respondents (38%) were, or would be, uncomfortable handling eels if captured, and almost half of respondents (48%) declared a limited or lack of knowledge about the species. Furthermore, only 69% support current or future eel conservation efforts on the Ottawa River. These findings suggest discomfort around eels and lack of knowledge about the value of eels may contribute to poor public support for conservation of the species.

Introduction

Recreational angling is a popular activity around the globe (Arlinghaus and Cooke 2009) with fisheries managers and resource users working collaboratively to achieve diverse fisheries management objectives (e.g., creation of a trophy fishery, maximizing catch; Cowx 2002). Yet, as fish biodiversity continues to decline (Fu et al. 2003; Hutchings and Baum 2005; Jelks et al. 2008; Vasilakopoulos et al. 2014), recreational anglers are increasingly interacting with fish that are imperiled and for which reconciling conservation and recreational fisheries goals may be a challenge (Cowx et al. 2010; Cooke et al. 2016). To overcome this management challenge, recreational fisheries must be regarded as dynamic socio-ecological systems in which understanding angler behaviour, and the perspectives driving behaviour, are as critical for effective management as understanding fish biology (Hunt et al. 2013; Fenichel et al. 2013).

Human dimension studies of anglers have led to a broader understanding of recreational fisheries. For instance, researchers have uncovered behavioural and attitudinal subgroups within angling communities (Quinn 1992; Nguyen et al. 2013), identified angler knowledge gaps with implications for management (Gallagher et al. 2015), and assessed levels of support for new fish recovery techniques (Donaldson et al. 2013). Such human dimensions studies have also revealed that anglers can be valuable advocates for conservation of popular but imperiled species and their habitats (Granek et al. 2008; Cooke et al. 2016). This is not surprising, given that preserving the species they target is critical for an anglers' continued enjoyment of their pastime (Cowx et al. 2010). However, most studies of angler perspectives and behaviours have focused on popular gamefish species. This has left several important questions about these social-ecological systems unanswered. What are anglers' opinions and behaviour towards less desirable species? How do anglers behave when capturing non-target species, particularly when these are imperiled?

The American Eel (*Anguilla rostrata*) is an example of a non-target, imperiled species that may be affected by anglers though incidental capture (i.e. as bycatch). It is a semelparous, catadromous fish with a complicated life-history. After a panmictic spawning event in the Sargasso Sea, leptocephalus larvae develop as they drift with ocean currents, eventually reaching coastal waters and swimming up rivers ranging from Guyana to southern Greenland (Tesch and Thorpe 2003). The species has exhibited a drastic decline in recruitment (Castonguay et al. 1994; Casselman 2003) and is listed as Endangered on the IUCN Red List (Jacoby et al. 2017) and in the province of Ontario, Canada (MacGregor et al. 2013). The steep decline (of greater than 99% in Ontario since the 1980s) is primarily attributed to historical overfishing, barriers to migration (e.g. dams), entrainment in turbines, and habitat alteration (MacGregor et al. 2013). Although commercial and recreational fishing for the species is prohibited in Ontario, there is anecdotal evidence to suggest an angling impact on American Eel. A portion of anglers describe disliking or being uncomfortable handling eels, leading some to kill and discard incidentally captured eels despite their conservation status, while others choose to reduce handling by cutting the line as opposed to removing the hook (N. Lapointe, Canadian Wildlife Federation, personal communications). To explore the prevalence of this reported discomfort with eels and any threat it might pose from anglers to eels, I used interviews with anglers on the Ottawa River to examine knowledge and perspectives relating to American Eel, and to characterize angler behaviour during eel encounters. This research is exploratory, meaning that it is intended to uncover variables and potential associations for future investigation (Stebbins 2001). This research was conducted to assess the potential threat posed by anglers on incidentally captured American Eel and to identify any attitudinal barriers exhibited by anglers that could impede conservation of the species.

Methods

Face-to-face, semi-structured interviews were conducted between July and September 2018. To recruit participants, I used opportunistic sampling of anglers at public boat launches along the Ontario side of the Ottawa River within 70 kilometres (upstream and downstream) of the City of Ottawa, Ontario. On a given visit, I approached as many individuals as possible to ask if they fished. If a site was too busy to approach all individuals, I targeted anglers who were returning from their fishing trips or fishing from shore, because they were more likely to agree to an interview than anglers about to start fishing. Anglers were asked to participate in an interview about their fishing practices, knowledge of American Eel, experiences capturing eels, and their perceptions of the environment in general (see Appendix A for full interview). Audio recordings of interviews were made and later transcribed. Following transcription, answers were coded using a three step inductive process, as outlined by Thomas (2006). In brief, a close reading of the transcriptions led to the development of categories related to the objectives. Following the initial reading, categories were examined for overlap and, where appropriate, combined to create broader encompassing themes. Transcriptions were then re-read and coded to the themes. This qualitative inductive approach permitted text to be coded to multiple themes and not all text was assigned a theme. Once themes were defined, a coding guide was created to guide final coding. To ensure reliability, a second coder analyzed 19% of the texts using the coding guide. Inter-rater agreement percentage was calculated as:

$$\left(\frac{number\ of\ agreements\ for\ categories}{total\ number\ of\ categories}\right) \times 100\ \%$$

Inter-rater agreement ranged from 89-93% for the four open-ended questions.

Analyses were conducted using RStudio version 1.1.383 (R Studio Team 2014) running R (R Core Team 2017). Pearson's Chi-Squared Tests were used to examine correlations between: (1) prior experience catching eels and knowledge of eels, (2) prior experience catching eels and comfort handling eels, (3) knowledge of eels and comfort handling eels, (3) knowledge of eels and support for cutting the line if a scientific study recommended it, (4) knowledge of eels and support for eels conservation in general. (5) agreement with three environmental values statements and support for eel conservation. Anglers were asked to indicate agreement or disagreement for these environmental value statements: (1) *nature exists to meet the needs of humans;* (2) *recreational anglers cannot catch enough fish to affect a fish population, and;* (3) *anglers should be educated on fish species at risk and how to release them.* A fourth environmental values statement (*environmental degradation is a major problem facing humanity*) was presented, but it was dropped (i.e. not examined in terms of correlations with other variables) after respondents unanimously agreed. In any tests involving support for eel conservation or support for cutting the line if a scientific study recommended it, Monte Carlo simulations were used to create a reference distribution to compensate for the small sample sizes in some of the categories of responses (Hope 1968). In tests involving knowledge of eels, this was treated as a binary variable in which 'no knowledge' was assigned to anglers who self-attested as having little or no knowledge (even if they provided guesses about eels) and 'knowledge' was assigned to anglers who indicated knowledge of eels, without qualifying their statements in any way. All p-values were adjusted using Holm's correction for multiple comparisons.

This study was approved and conducted in accordance to the Carleton University Research Ethics Board (108960).

Results

Study Group - Of the 60 anglers approached, 48 consented to being interviewed. However, not all anglers responded to all interview questions, therefore not all findings are based on 48 respondents. Pairwise exclusion was used to maximize the use of available data. Median interview duration was 6 minutes (with a range of 3 to 21 minutes). In comparison to the national angler profile in Canada (Fisheries and Oceans Canada 2019), respondents in the present study was skewed towards more males (85% compared to 79% in national survey), younger anglers (with an average age of 39 years compared to 47 years in national survey), and anglers who fished more frequently (58.5% of respondents having fished more than 50 days per year compared to an average of 15 days, as reported by the national survey) (Table 2-1). Respondents in the present study were also relatively experienced anglers, given that 66.7% of respondents had fished for more than twenty years

Eel Capture - 46% of respondents had caught at least one eel at some point in their angling history. Reported eel captures had occurred between 1960 and 2018, with the majority being captured during the spring and summer. Most respondents who had captured eels were using live bait (worms and minnows) and targeting catfish (*Ictalurus punctatus*), walleye (*Sander vitreus*) or black bass *(Micropterus salmoides* and *M. dolomieu*). Estimates of eel size ranged from 30 – 120 centimetres. When asked about what had been done with captured eels, 90% respondents indicated they had released them. Of the respondents who released eels, 63% of releases involved removing the hook, 31.5% involved cutting the line, and one eel was described as having removed the hook on its own. Only three respondents mentioned killing eels, two of whom had done so for harvest, one who had killed and discarded eels. The respondent who had killed and discarded eels stated, "w*e used to just cut the head off"* and explained this by saying

"We were younger then… we were afraid. You know, thought it was just a giant snake." When asked about their comfort handling eels, 38% of all respondents indicated that they were, or would be, uncomfortable dealing with an incidentally captured eel. Twenty-eight respondents provided more detail in their answers and these responses frequently expressed disgust for handling eels (due to their slimy texture or the difficulty of holding them) (39%), as well as a preference for using tools (e.g. gloves) (46%) and for cutting the line when handling eels (25%). Respondents frequently expressed statements such as "*I don't handle those things. I just use the pliers and flip it off and away they go."* and "*…we hated touching them because they'd coil themselves around your wrist, we'd just cut the line and let it free."*

Knowledge of Eel **–** I asked respondents to tell me what they knew about the American Eel. Coding revealed the following seven themes, each followed by the percent of interviewed anglers that expressed such knowledge: (1) knowledge of eels in an angling context - 23% (e.g. *"when there's an eel around, the catfish won't bite"*), (2) knowledge of the species as food -10% (e.g. *"I think they make sushi out of it"*), (3) conservation status - 21% (e.g. *"you should not catch them and I think they're protected"*), (4) ecology - 25% (e.g. *"they're just very deep most of the time and they're always around logs… they'll only mostly come out to feed"*), (5) invasiveness - 6% (*"they eat our smaller fish… and they are invasive"*), (6) physical description - 35% (*"they're… long, almost snake-looking, but have the fins that kind of follow the body line"*), (7) vigor - 10% (e.g. *"They are vicious in the water… they're pretty strong - yeah, they definitely put up a fight"*). However, the overarching theme emerging from the answers was a confessed lack of knowledge (44%). Many respondents who expressed some knowledge qualified their answers with statements such as *"I don't know too much really about them, really and truly I don't."* Seven respondents provided no response other than expressing their lack of knowledge, for example, *"I know nothing about the American Eel… I didn't even know we had it in these waters"*. Most respondents (92%) did not think the American Eel was dangerous to humans, and the remainder were undecided. When asked if the eel population in the Ottawa River was increasing, decreasing or stable, 33% of respondents were undecided and 30% responded that the species was in decline (Figure 2-1). When told that eels were in decline, respondents were asked to speculate on primary causes for their decline. Only 6% of respondents (3 people) suggested dams as a possible cause for decline. Many respondents mentioned fishing pressure (36%) and pollution (43%) as possible causes for decline (Figure 2-2).

***Support for eel research & conservation* –** When asked if anglers would follow the advice of a scientific study if it showed that cutting the line increased survival of eels compared to removing the hook, 76% respondents said they would follow this advice, with the remainder saying they would not follow the advice (7%) or that it would depend on the lure they were using at the time (9%). Of the 45 respondents who were asked if they supported current and/or future efforts to increase the eel population in the Ottawa River, 69% answered yes, 11% answered no, 15% needed more information to decide whether they supported conservation efforts, and 5% of respondents thought that there was nothing left to support. Expanded answers from respondents who supported eel conservation efforts included statements such as *"I'm not a fan of them, but I don't want to see them go extinct"*. The five respondents who did not support eel conservation provided the following answers: (1) *"Because those fish are squirmy"*, (2) *"Because…they would eat a lot of minnows and other kind other kinds of little fishes…"*, (3) *"Because I don't think nature needs our support"*, (4) *"I don't see the benefit of it, in our lakes and as well as for fishermen. Nobody eats eel. It's not a delicacy here"*, (5) *"I don't like them"*. Respondents who said they needed more information to make a decision explained with answers such as *"If I knew* *the consequences of supporting it and not supporting it, if I had the facts, then I would. Especially what benefits the eel brings to the economy and the ecosystem and all that. But I have to be educated."* Finally, the responses from the two anglers who believed there was nothing left to support were *"You can't [support it]. You can't increase or decrease. It depends how many… come. You can't do nothing."* and *"How can you support the eels now [that] there's none? There used to be. But there's none… past Arnprior [a town upstream of Ottawa] there are a bunch of rivers, we used to catch eels there too but there's nothing now. And not even the small ones, I don't see them anymore."*

Influence Factors **–** There was no evidence to suggest that anglers with prior experience catching eels was correlated with having some knowledge of eels (χ^2=3.3, df = 1, P>0.05). Additionally, there was no evidence to suggest that previous capture or knowledge of eels increased comfort when handling eels (χ^2= 1.0×10^{-31}, df = 1, P>0.05, χ^2=0.59, df = 1, P>0.05). Knowledge of eels was not significantly correlated with support for line-cutting if a scientific study recommended the practice (χ^2=0.77, P>0.05), nor was it correlated with support for eel conservation in general (χ^2= 3.44, P>0.05). An angler's disagreement with the statement "nature exists to meet the needs of humans" was not correlated with their willingness to support eel conservation efforts on the Ottawa River (χ^2=9.84, P>0.05), nor was their agreement with the statement "anglers should be educated on fish species at risk and how to release them" (χ^2=12.27, P>0.05) or the statement "recreational anglers cannot catch enough fish to affect a fish population" (χ^2=4.23, P>0.05).

Discussion

Interviews suggest that angler behaviour when incidentally capturing American Eel is not a direct threat to the species. Although nearly half of respondents had captured eels at some point, only three anglers reported killing eels, either for harvest or discard. For the one report of killing eels for discard, the angler explained that this was done out of fear because of lack of knowledge about eels (i.e. they thought they were snakes). Overall, killing and discarding eels appears to be an infrequent occurrence, given that only one angler reported this action. All three incidents of killing eels (for harvest or discard) occurred prior to the listing of American Eel as Endangered in Ontario in 2008.

If anglers are not directly killing eels upon capture, the survival of an eel following incidental capture is primarily dependent on the handling practices used for its release. These interviews revealed that 38% of respondents were, or would be, uncomfortable handling eels. This is not surprising in the context of the literature; phobias of non-predatory animals (i.e. animals not likely to attack/harm humans) are not unusual (Davey 1994; Arrindell 2000; Batt 2009). Eels specifically have been ranked as anxiety or fear-provoking animals in social science surveys (Davey 1994; Batt 2009). One potential driver for this heightened anxiety or fear of animals like eels is disgust, which is often associated with sensory cues such as sliminess and with animal discharges like mucus and feces (Bennett-Levy and Marteau 1984; Davey 1994; Phillips et al. 1998; Curtis and Biran 2001; Prokop and Fančovičová 2010). In the present study, disgust is a plausible source of the discomfort expressed by anglers when handling eels, given that one third of respondents indicated that the eel's slimy texture and handling difficulty contributed to their discomfort. Additionally, a preference was revealed for the use of gloves and tools, which reduce the need for directly touching or handling an incidentally captured eel. These lines of evidence suggest that many anglers would prefer a release method that minimizes the need for directly touching eels. This is corroborated by the existing practice and identified preference for line cutting. Of anglers who had captured eels in the past, 31.5% had cut the line, and line cutting was identified as a theme in 25% of the responses to the question about comfort handling eels. Line cutting is a quick method for releasing a fish and it requires little handling (Fobert et al. 2009). As such, it is a viable option for releasing incidentally captured eels with only a limited amount of handling required, given that eels exhibit high survival and hook-shedding rates following line cutting (Chapter 2).

Our interviews suggest that knowledge of eels and their decline has not been effectively transferred to the public. Anglers are presumably one of the most well-informed segments of the population regarding fish and the threats facing fish and, as revealed by the demographics of the respondents, these interviews captured a highly experienced portion of the angling population. More than two thirds of respondents were fishing prior to the closure of the recreational eel fishery in Ontario and nearly thirty percent had been fishing since the 1980s, prior to the drastic decline of the eel population. Yet, a large proportion of anglers were uncertain in their knowledge of American Eel and unaware of the species' current status and the reasons for its decline. For instance, only 6% of respondents (3 people) suggested dams as a possible contributor to the species' decline, despite all interviews being conducted within 40 km of one or more major river-spanning dams. In contrast, it is well recognized within the scientific community that riverine barriers such as dams are a primary factor contributing to the decline of eels everywhere (MacGregor et al. 2013), including on the Ottawa River where turbine mortality for eels in the upper reaches is modelled to be as high as 97.2% (MacGregor et al. 2015). Indeed, Macgregor et al. (2008) cited eels as a nonrecreational fisheries example of the invisible collapse facing many popular gamefish species. Since then, considerable attention has been focused on the species from science and management (see 148th Annual Meeting of the American Fisheries Society 2018, for example), however these interviews indicate that the decline of eels remains largely invisible to the public.

Anglers who supported eel conservation efforts on the Ottawa River explained their stance with statements about the intrinsic value of nature and an inherent importance of conserving species at risk. In contrast, almost a third of respondents were undecided or did not support eel conservation and among these, several questioned the instrumental value of eels (i.e. the tangible benefits of eels for the environment, anglers, and economy). This lack of knowledge about the instrumental value of eels was corroborated by responses to other questions in the interview: Only 10% of respondents mentioned eels as a food source when asked about their knowledge of eels. None mentioned the species' economic value, which totaled $35.2 million in Canada in 2016 (Government of Canada 2018). It has previously been suggested that buy-in to conservation action may be best achieved through promotion of instrumental rather than intrinsic value (Justus et al. 2009). In this circumstance, it appears that gaining support for eel conservation may require a variety of approaches – whereas some anglers are led to support eel conservation through an intrinsic value of biodiversity, others may require more tangible valuations of eels (e.g. economical or specific ecological benefits).

The discomfort of Ottawa River anglers towards the American Eel is not extraordinary in comparison to global perspectives on freshwater eels, however other cultures that interact with eels generally also have a valued connection to the species, whether it be for nutritional, medicinal, material, or spiritual purposes. In Ireland, European Eels (*Anguilla anguilla*) have a negative image in folklore and popular culture, however eels have still been harvested for centuries and, more recently, eel conservation has drawn public awareness to the fascinating life history of eels (McCarthy 2014). In France, many sayings employ similes to eels to express sneakiness and surreptitious behaviour (Feunteun and Robinet 2014). However the species is still economically valued, commonly eaten, and the subject of an extensive recreational fishery (Baisez and Laffaille 2008; Dorow and Arlinghaus 2011). There, anglers who recognize the current decline of eels are willing, under certain circumstances, to commit to stricter regulations for eel conservation than currently exist (Dorow et al. 2009). In Polynesia, the inhabitants of Tikopia were documented as being disgusted at the appearance and squirminess of eels, however they simultaneously considered eels as sacred (Firth 1930). In Japan, the existence of over one hundred names for eels is an indication of their importance to Japanese culture and cuisine, yet eels are also feared because of their mysterious behaviour and resemblance to snakes (Kuroki et al. 2014). More locally, the Algonquins of Ontario have put forth several calls for further conservation of American Eel and have emphasized the importance of these efforts by describing the species' value for medicinal, nutritional, spiritual and material purposes (Algonquins of Ontario 2012, 2014a, 2014b). This brief overview of varied cultural perspectives on freshwater eels emphasizes the global relationships between humans and eels, in which the complex and unique life history of eels elicits both mystery and fascination. The respect and value allotted to eels by other cultural groups suggests that if sought, support for eel conservation by Ottawa River anglers is possible to achieve.

Discomfort and lack of knowledge do not seem to cause a significant direct threat to eels from anglers but may have implications for the conservation of the species. Conservation support has been linked to societal attention and species charisma, with most research and effort focused on popular and attractive species (Bonnet et al. 2002; Clark and May 2002; Jarić et al. 2019).

Additionally, conservation case studies suggest that knowledge can improve public attitudes towards species' conservation (Tisdell and Wilson 2004; Ploeg et al. 2011; O'Bryhim and Parsons 2015). Thus, for a species with a discomfort-inducing nature and a lack of public knowledge about it, conservation prospects may be particularly dire. However, if increased support for conservation is desired, this situation can be improved - 15% of respondents expressed a need for more information to decide if they supported eel conservation efforts. This indicates that there is an opportunity to increase angler knowledge of eels.

Table 2-1. Demographics and general fishing practices of the angler interview respondents on the Ottawa River.

Demographic/Question and Categories of Responses	Number of Respondents	Percentage (%)
Gender	**48**	
Female	7	14.6
Male	41	85.4
Age	**48**	
<20 yrs	5	10.4
20-29 yrs	7	14.6
30-39 yrs	16	33.3
40-49 yrs	6	12.5
50-59 yrs	9	18.8
60-69 yrs	5	10.4
How many years have you been fishing?	**48**	
<10	6	12.5
10-19	10	20.8
20-29	12	25.0
30-39	6	12.5
40-49	8	16.7
>49	6	12.5
Approx. how many days per year do you fish?	**41**	
<10	1	2.4
10-19	7	17.1
20-29	3	7.3
30-39	3	7.3
40-49	3	7.3
>50	24	58.5
Do you practice catch & release or catch & keep?	**47**	
Catch & Release	24	51.1
Catch & Release and Catch & Keep	23	48.9

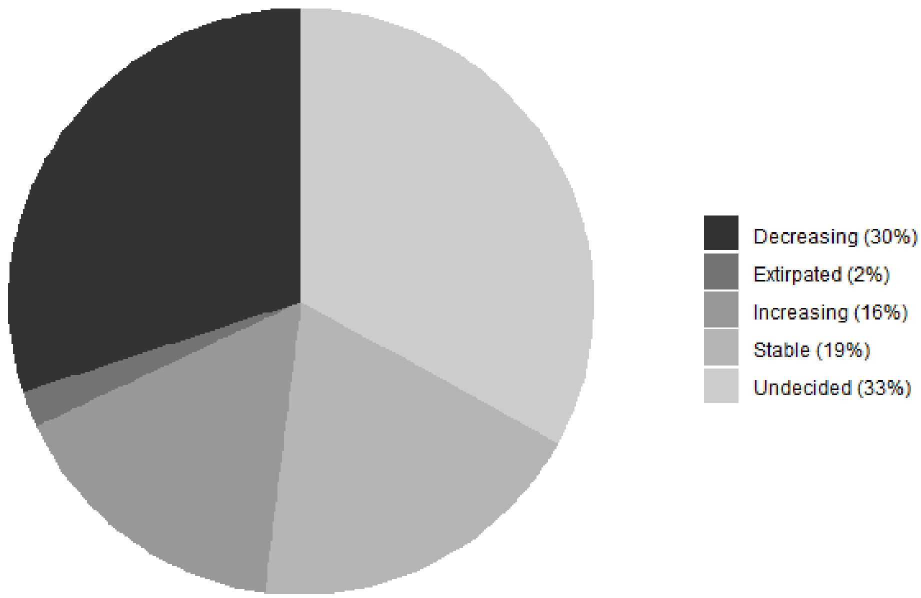

Figure 2-1. Angler responses to the question: Based on what you know, is the American Eel population in the Ottawa River increasing or decreasing or neither?

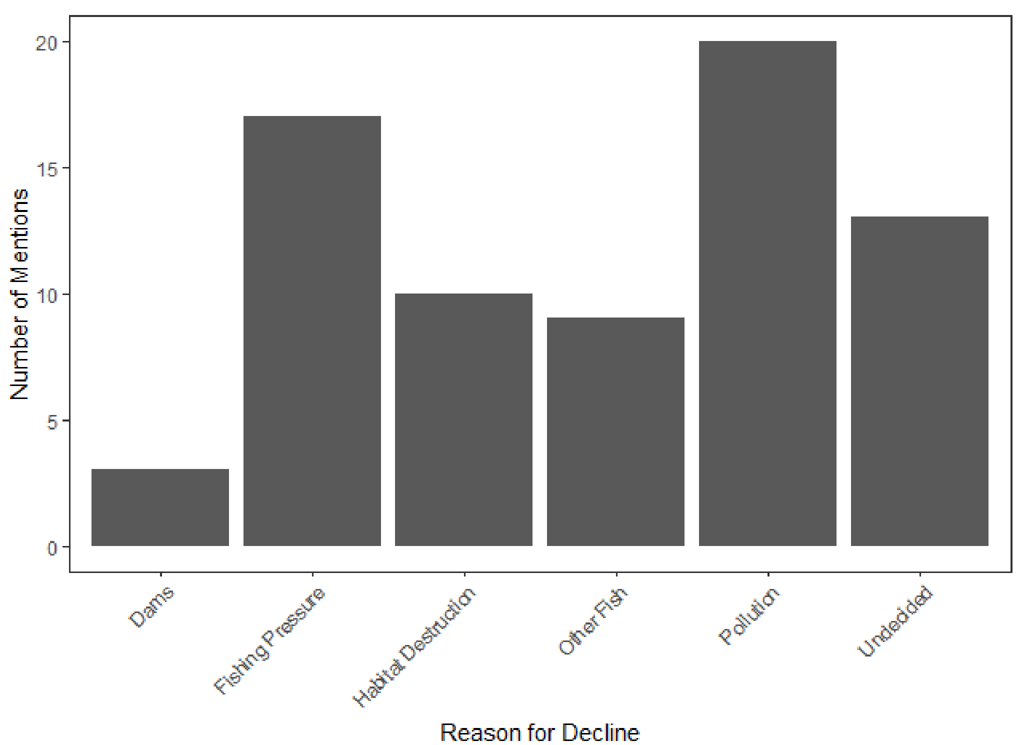

Figure 2-2. Potential reasons provided by respondents for the decline of American Eel and the number of mentions by anglers for each reason.

Appendix 2-A – Angler Interview Guide

Part 1: <u>Fishing Practices</u>

1. How many years have you been fishing?
2. Approximately how many days per year do you fish?
3. Do you practice catch-and-release and/or harvest the fish that you catch?

Part 2: <u>Knowledge of American Eel & Capture Experiences</u>

4. Have you ever caught an eel while angling on the Ottawa River?
    a. ***If yes:*** How many eels have you caught on the Ottawa River?
    b. ***If yes:*** Do you feel comfortable handling an eel?
    c. ***If no:*** Would you feel comfortable handling an eel if you caught one?

If no, then skip questions 5-10. Proceed to #11. If caught many eels, answer questions for the most recent capture of an eel.

5. In what year and season did you catch an eel?
6. What were you targeting when you caught the eel?
    d. **If respondent can't remember**: what do you commonly target on the Ottawa River?
7. What bait or lure were you using when you caught the eel?
    e. **If respondent can't remember**: what bait or lure do you commonly use as bait/lure when fishing on the Ottawa River?
8. Approximately how big was the eel that you caught?
9. Did you have any difficulty handling the eel?
10. What did you do with the eel that you caught?
    c. **If eel was released:** Did you release it after removing the hook or cutting the line?
    d. Why did you choose this action?
11. Can you tell me what you know about the American Eel?
    a. In your opinion, are eels dangerous to humans?
        i. ***If yes:*** what type of danger do eels pose to humans?
12. Based on what you know, is the American Eel population in the Ottawa River increasing or decreasing or neither?
        i. ***If decreasing:*** what is causing the decrease in eel populations?
13. In your opinion, is there an abundant or depleted eel population in the Ottawa River?
14. Do you think the Eel population pose a threat to other species in the Ottawa River?
15. If I told you that the American Eel population in Ontario was decreasing, what do you think the primary reason for the decrease would be?
    a. What about more broadly in the St. Lawrence watershed?
16. If scientific studies showed that cutting the line as opposed to removing the hook increased survival of eels, would you follow this advice if you caught an eel?

Part 3: <u>Demographic Information</u>

17. In what year were you born?

Part 4: <u>Environmental Values & Recreational Fishing Beliefs</u>

18. I am going to read you some statements about the environment, and I'd like you to tell me your level of agreement with them, and why.
    a. Nature exists to meet the needs of humans.
       -select agree/disagree based on explanation, not initial yes/no due to misunderstanding wording of question
        i. *Probe for why*
    b. Recreational anglers cannot catch enough fish to affect a fish population.
        i. ***Probe for why***
    c. Environmental degradation is a major problem facing humanity.
        i. ***Probe for why***
    d. Anglers should be educated on fish species at risk and how to release them.
        i. ***Probe for why***
19. Do you support current and/or future efforts to increase the eel population in the Ottawa River?

Chapter 3 – Does catch-and-release angling pose a threat to American Eel? A hooking mortality experiment.

Abstract

When anglers incidentally capture a protected fish species, many jurisdictions require that it be released immediately to ensure the fish's survival, however few imperiled species have been studied in terms of their post-release survival. The American Eel (*Anguilla rostrata*) is an example of an imperiled species which may be caught as bycatch by recreational anglers, but for which the threat of catch and release is unknown. The present study examines the short-term mortality and injury of American Eel following simulated catch-and-release scenarios. Specifically, I compared the effects of cutting the line versus removing the hook, as well as shallow versus deep hooking. No mortalities occurred in any of the groups during a seven-day monitoring period and most eels exhibited little or mild injury. Furthermore, a high degree of hook shedding occurred in the line-cut groups, with some evidence to suggest an impact of hook depth on hook shedding; 93.7% of hooks were shed in the shallow-hook–line-cut group compared to 71.8% of hooks shed in the deep-hook–line-cut group. The results suggest that eels are relatively resilient to catch and release, however validation of results in a field setting is recommended.

Introduction

Recreational fishing is a popular activity, with estimates of 220 million (World Bank 2012) to 700 million (Cooke and Cowx 2004) people participating on a global scale. Despite the prevalence of recreational fishing, its implications for fish stocks are often entirely overlooked (Post et al. 2002) or assumed to be minimal compared to the effects of commercial fishing

(Cooke and Cowx 2004, 2006; Lewin et al. 2006). This is particularly true for recreational catch-and-release angling because if a fish is not harvested, it is often assumed to survive the angling interaction (Muoneke and Childress 1994; Cooke and Schramm 2007). Several hundred catch-and-release studies have revealed that the survival of fish following catch and release is highly variable among species and contexts (Muoneke and Childress 1994), and that even when a fish survives, significant sub-lethal impairments (e.g. behavioural, physiological) can occur (Arlinghaus et al. 2007).

Catch-and-release research has identified a wide range of variables influencing survival and fitness of released fishes (see Brownscombe et al. 2017 for a full review). Hook location is considered a key factor in determining the outcome of released fishes, with deep hooking being a predominant cause of mortality (Muoneke and Childress 1994; Bartholomew and Bohnsack 2005; Cooke and Wilde 2007). For many species, cutting the line rather than removing the hook increases survival of deeply hooked fish (Tsuboi et al. 2006; Fobert et al. 2009). For example, hook removal attempts for deeply hooked European Eel (*Anguilla anguilla*) resulted in higher mortality (64.4%) compared to line cutting (25.1% mortality) (Weltersbach et al. 2018). Line cutting is effective because it prevents further injury associated with fish struggle during hook removal, but it also reduces the length of air exposure, another key factor influencing survival in catch-and-release angling. Air exposure has been shown to have various lethal and sub-lethal effects on a variety of fish species (Ferguson and Tufts 1992; Arlinghaus and Hallermann 2007) and catch-and-release principles recommend limiting air exposure as much as possible (Pelletier et al. 2007; Cook et al. 2015).

Much of the catch-and-release research to date has focused on the most popular game fish species (see Cooke and Suski 2005) with comparatively less research on rare or imperiled species. Although fisheries closures are generally implemented to protect imperiled species from targeted angling and harvest, it is often impossible to avoid their incidental capture as bycatch when anglers are targeting other species. To understand the effects of these events on imperiled species, it is crucial to conduct at minimum a rapid assessment evaluating the species' resilience to catch-and-release practices (Cooke et al. 2016, Bower et al. 2016).

Catch-and-release risk has not been assessed for the American Eel (*Anguilla rostrata*). This catadromous fish has exhibited drastic declines in recruitment in many parts of its range (Castonguay et al. 1994; Casselman 2003). American Eel are listed as Endangered on the IUCN red list (Jacoby et al. 2017), as well as in Ontario (Canada) where recruitment has declined by more than 99% since the early 1980s (Casselman 2003; MacGregor et al. 2013). In Ontario, the Upper St. Lawrence-Lake Ontario (USLR-LO) river system and the Ottawa river system both contain American Eel. The eels in these drainage systems are almost exclusively females, with a larger body size and higher fecundity than elsewhere in the species' range (Castonguay et al. 1994; Casselman 2003). Consequently, it is believed that these females are significant contributors to the spawning biomass for the entire species, and their decline is of concern for conservation.

The potential effects of incidental capture via recreational fishing on American Eel is not considered in the Ontario Recovery Strategy for the American Eel (MacGregor et al. 2013). Under the Ontario *Endangered Species Act* (2007), all fishing for eels is prohibited, and any incidentally captured eels must be released. However, there are anecdotal reports of angler discomfort with the handling of eels, leading some anglers to cut the line rather than remove the hook. The sub-lethal and lethal effects on American Eel from cutting the line rather than removing the hook, as well as from catch and release in general, remain unknown. The objective of this study was to evaluate risk posed by catch-and-release angling to American Eel. I used a controlled experiment to quantify injury and mortality of eels following simulated catch-and-release scenarios (cutting the line and removing the hook). For this investigation, I tested the null hypothesis that catch and release of eels does not cause post-release mortality from injuries during hook removal. I predicted that hook removal would cause higher mortality rates than cutting the fishing line. This prediction is based on the wealth of catch-and-release research on other species, which indicates that line cutting reduces mortality, especially for deeply hooked fish.

Methods

Two hundred and seven American Eel were obtained from a commercial fyke net fishery in French Lake, NB (45°55' N, 66°17' W) in June 2018 and transported to Mactaquac Biodiversity Facility, NB in an aerated tank. At the facility, eels were held in tanks (91x457x46 cm) with gravel substrate and short lengths of pipes for shelter. Tanks were supplied with ambient temperature (10-16 °C), flow-through water from the St. John River.

After a 24 h holding period, eels were netted and randomly assigned to one of four groups (Figure 3-1). (1) Control group eels were transferred directly to the experimental holding tanks with minimal air exposure. Non-control groups were anaesthetized using clove oil (200 ppm), tagged with anchor tags, and measured for total length and weight. (2) Sham group eels were then transferred to recovery tanks. (3) Shallow-hooked eels were hooked in the lips or jaw and (4) deep-hooked eels were hooked in the throat at the base of the tongue using pliers. All hooks were size #2 offset baitholder style with a turned down eye and barbed shank and hook. Anaesthetized eels were individually held in 25-L recovery tanks for at least 20 min and until they recovered equilibrium and resumed normal swimming behaviour. This recovery time is five times longer than was found necessary for Longfinned Eel (*Anguilla reinhardtii*) under similar temperature and induction times and with a dose of 120 ppm clove oil (Walsh and Pease 2002). Anaesthesia and simulated hooking were necessary for this experiment because the eels would not feed in captivity, so a true angling event was not possible. The control group allowed the confounding effects of tagging to be distinguished from the effects of the experimental treatments, while the sham group functioned in the same way for any confounding effects of anaesthesia.

After at least 20 minutes and when regular activity resumed, sham eels were released into the experimental holding tanks. Shallow-hooked and deep-hooked eels were randomly assigned to two simulated catch-and-release treatments: (A) line cut or (B) hook removal. For both scenarios, the eel was removed from the recovery tank by the line and handling time was measured from when the eel was lifted by the line until it was placed in the holding tank. The line-cut treatment involved using a pair of scissors to cut the line within 4 cm of the hook's eye. The hook-removal treatment required the mock angler to remove the hook from the eel, regardless of handling time or number of times the fish was dropped. Mock anglers could use a pair of fisherman's longnose hemostats to assist with hook removal. Once the catch-and-release scenario was complete, eels were released into the experimental holding tanks. All eels were monitored for seven days post-processing with regular tank checks for mortalities.

After seven days, eels were euthanized (a requirement of the scientific permit for biosecurity reasons). All previously hooked eels were examined for injury at the hooking site. Injuries were classified into four levels; (0) no sign of injury, (1) a slight tear/scar but no blood, (2) a small amount of blood but no swelling, (3) significant blood, clot, or swelling. All line-cut eels were checked for hook retention. If the hook was not visible at the hooking site, the eel was dissected to confirm whether it was ingested. All experimental manipulations were conducted in accordance with the Canadian Council on Animal Care.

Analyses were conducted using RStudio version 1.1.383 (R Studio Team 2014) running R (R Core Team 2017). A Pearson's Chi Squared Test, with a Monte Carlo simulation due to small sample size, was used to examine the effect of experimental group on injury score. A Pearson's Chi-Squared Test was used to investigate the effect of hook depth on hook shedding. A Kruskal Wallis (KW) rank-sum test was used to examine the effect of experimental group (i.e. not including control or sham groups) on handling time. In this case, KW test was used due to highly different variances in handling time among groups. Dunn's test was used to conduct multiple comparisons. Finally, to confirm the homogeneity of the groups (control, sham, deep-hook–line-cut, deep-hook–hook-removal, shallow-hook–line-cut, and shallow-hook–hook-removal) in terms of length and mass, ANOVA tests were performed, followed by Tukey's Honest Significant Difference (HSD) test for multiple comparisons. P-values for all tests involving experimental group as a dependent variable were adjusted using a Holm's correction for multiple comparisons.

Results

There were no mortalities in any of the groups over the seven-day holding period. Following euthanasia, eel necropsies revealed only minor scarring or no sign of meaningful injury in 87.4% of fish and there was no evidence to suggest an impact of treatment on injury score (χ^2=5.2, P>0.05). After the seven-day holding period, 82.8% of the eels in the line-cut groups had shed the hook. There was evidence of an effect of hook depth on hook shedding (χ^2=4.0, df = 1, P<0.05) whereby fish hooked in more shallow locations had a greater tendency (93.7%) to shed hooks than those hooked in deep locations (71.8%). No ingested hooks were found during the dissections of the line-cut eels with missing hooks. There was a significant difference in handling time among groups (χ^2=24.9, df=3, P<0.05). Multiple comparisons indicated that handling the deep-hook–hook-removal group took significantly longer than handling any of the other groups (see Table 3-2).

Despite allocating fish to treatments randomly, there was a significant difference (F=3.6, df = 5, P<0.05) in total length among treatment groups. Specifically, Tukey's HSD test revealed that fish in the control group were smaller than in the sham and the deep-hook–hook-removal fish groups. However, there was no evidence to suggest a difference in fish mass among groups (F=1.8, df = 5, P>0.05), which indicates that overall body size was generally consistent among groups.

Discussion

Overall, this research provided little evidence to suggest that catch-and-release angling poses a significant threat to American Eel, however it is acknowledged that this experiment is only a preliminary investigation and many other variables exist in true angling scenarios. No mortalities occurred during the catch-and-release experiment and injury score did not suggest a difference in outcome between cutting the line and removing the hook. Additionally, 82.8% of the line-cut eels shed their hooks within 7 days. Based on current results, either method of releasing eels (cutting the line or removing the hook) is acceptable in terms of mortality outcomes. These results are highly relevant to Ontario, where the release of incidentally captured eels is mandatory under the *Endangered Species Act,* however the findings are also relevant for anglers elsewhere who are releasing eels as unwanted bycatch.

This is the first study to examine the effects of catch and release on American Eel. I originally predicted higher mortality and increased injury in hook-removal groups because I anticipated that they would have extended handling times (and therefore increased air exposure). Hook removal did indeed take longer (72s) than cutting the line (31s), for both shallow and deep-hook fish, but handling time was only statistically significantly longer for deep-hook fish. However, this did not translate to a difference in short-term mortality or injury. This is not overly surprising because it has been previously shown that American Eel exhibit a high tolerance to prolonged air exposure and hypoxemia (Hyde et al. 1987). Furthermore, the present experiment's 0% mortality rate is consistent with the short-term (≤72h) mortality that Weltersbach et al. (2018) found for European Eel (the most closely related species to *A. rostrata*) that had been hooked in the lips, jaws or oral cavity with a similar hook (size #1 J-hook). Weltersbach et al. (2018) found longer-term (43-64 day) adjusted mortality for the same treatment (hook-removed) to be 8.4%. This suggests that some mortality may have been observed if the holding period was extended beyond seven days.

In this study, deep hooking refers to the base of the tongue. While this is consistent with some of the literature on catch and release (Siewert and Cave 1990; Meka 2004), other studies employ more extreme definitions of deep hooking including fish hooked in the gills, gastrointestinal tract, or esophagus (Fobert et al. 2009; Pullen et al. 2017; Weltersbach et al. 2018). Here, a less extreme definition was used because I wanted to examine differences between line cutting and hook removal and Weltersbach et al. (2018) found that hook removal was not possible in 90.9% of eels hooked in the gills or gastrointestinal tract by a large hook. The same study found that

34.2% of European eels angled using large J-hooks (in true fishing events) were hooked in the gills or gastrointestinal track. Thus, my definition of deep hooking enabled comparison of the two treatments (line-cut and hook-removal), but it does not fully address a portion of angling scenarios in which eels swallow the hook. Future work exploring the effects of other deep hooking locations (e.g. gills, esophagus, gastrointestinal tract) is required to capture all relevant catch-and-release scenarios.

These results revealed a high level (82.8%) of hook shedding within seven days following release. The high amount of short-term hook shedding is consistent with findings in other species (71.4% over 10 days in bluegill, Fobert et al. 2009; 46% over 14 days in bonefish, Stein et al. 2012). In European Eel, hook shedding rates ranged from 0-41.2% depending on hook size, however these percentages are for eels hooked in the gills or gastrointestinal tract (Weltersbach et al. 2016, 2018). The higher level of hook shedding from the present experiment compared to the European Eel studies is presumably partly attributable to the shallower placement of hooks, as is the finding of a 0% ingestion rate (though the latter may also be affected by the fact that the eels were not feeding during the holding period). Indeed, the present work did identify some evidence to suggest that hook depth impacts hook shedding ability.

These findings contribute to a growing body of literature regarding the conservation of American Eel by addressing the previously overlooked possibility of a threat from recreational catch-and-release angling. Future research is recommended to further evaluate the topic, including the undertaking of field studies to verify these results in non-simulated scenarios. This research suggests that incidental capture by anglers does not pose a major threat to American Eel as long as eels are released, whether it be by removing the hook or cutting the line.

Table 3-1. Characteristics including mean total length (TL in cm) ± standard deviation, mean weight (g) ± standard deviation, handling time (s) ± standard deviation and number of eels (n). Characteristics are listed for the control group, the sham group and for the four groups divided by hook depth (shallow or deep) and treatment (hook-removal or line-cut).

Group	Mean TL (cm) ± SD	Mean weight (g) ± SD	Handling Time (s)	n
Control	50.3 ± 6.4	235.0 ± 101.9	NA	48
Sham	55.1 ± 6.1	287.0 ± 112.9	NA	32
Deep-hook–line-cut	53.7 ± 6.5	263.5 ± 109.9	31.6 ± 18.3	32
Deep-hook–hook-removed	54.7 ± 7.1	271.2 ± 93.9	96.6 ± 86.5	31
Shallow-hook–line-cut	53.8 ± 5.8	256.3 ± 96.2	30.7 ± 13.8	32
Shallow-hook–hook-removed	51.4 ± 5.5	225.2 ± 83.8	47.5 ± 34.1	32

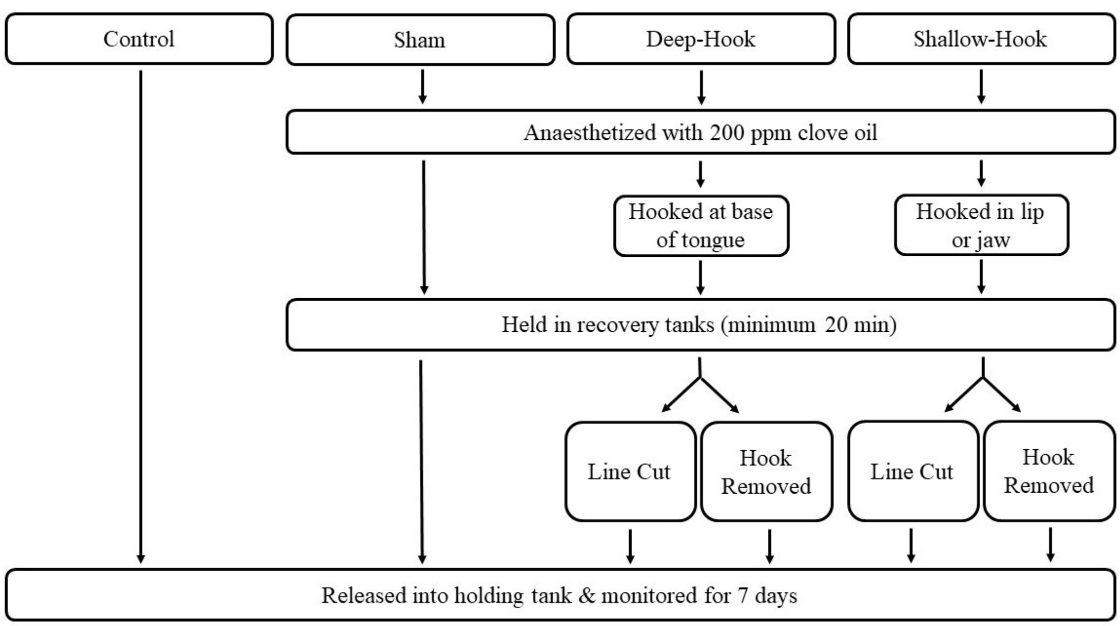

Figure 3-1. Schematic of the experimental protocol. The top row indicates group names. Note that the deep-hooked and shallow-hooked eels were subdivided into line-cut and hook-removal treatments, resulting in six final groups: control; sham; deep-hooked, line-cut; deep-hooked, hook-removal; shallow-hooked, line-cut; shallow-hooked, hook-removal.

Chapter 4 – General Discussion

Summary of Findings

This thesis assessed the effects of recreational fishing on American Eel (*Anguilla rostrata*), an Endangered species in Ontario and one listed as globally Endangered by the IUCN.

In Chapter 2, I conducted interviews with 48 anglers along the Ottawa River to explore their knowledge and perspectives, and behaviour towards eels, as well as to gauge their support for eel conservation. Specifically, I asked respondents about their fishing experience, knowledge of eels, any experiences capturing eels, and their environmental values. I found that only a low proportion of interviewed anglers had ever killed eels, and that all incidents of this occurred prior to the eels' listing as Endangered in Ontario. However, nearly half (48%) of respondents had caught an eel at some point. A considerable portion (38%) of respondents were, or would be, uncomfortable handling eels; exploration of this topic uncovered themes relating to dislike of eel texture (i.e. sliminess) when handling, and a preference for tools and line cutting. Furthermore, 44% of respondents declared a limited or entire lack of knowledge about eels. Finally, almost one third of anglers (31%) did not support eel conservation efforts on the Ottawa River, either because they did not know enough about eels, or they did not perceive any benefits to conserving the species.

In Chapter 3, I conducted a controlled tank experiment to determine American Eel mortality and injury following catch and release to determine if catch-and-release angling poses a threat to the species. I simulated an angling interaction by hooking anaesthetized eels, then attempting to cut the line or remove the hook following the eels' recovery. I monitored eels for seven days following the angling scenario, making daily observations for mortality. After seven days, eels were euthanized, scored for injury level associated with hooking, and line-cut eels were checked to see if the hook was shed. The catch-and-release experiment yielded no mortalities and only little or mild injury in 87.4% of the fish. I documented a high degree (82.8%) of hook shedding over the seven-day holding period, and hook shedding ability was significantly higher for shallow-hooked eels than for deep-hooked eels (χ^2=4.0, df = 1, P<0.05). Lastly, the angling scenarios revealed a significant difference in handling time based on treatment (χ^2=24.9, df=3, P<0.05), whereby hook removal of deep-hook eels took far longer (96.6 ± 86.5 seconds) than any of the other treatments (30.7 ± 13.8 – 47.5 ± 34.1 s).

Synthesis and implications

Together, these chapters present a socio-ecological risk assessment of recreational fishing for American Eel. Through angler interviews, areas of concern relating to the capture and release of American Eel as bycatch were identified. The concerns relating to post-release mortality and injury of eels were examined through simulated angling scenarios. Thus, a rapid assessment was used to generate an integrated knowledge about the level of threat that recreational fishing poses to eels. If a further reduction of the threat is deemed necessary, the findings of this assessment could be used to address the areas of concern relating to angler knowledge and perspectives about eels by conducting outreach about eel life history, and by spreading best practices release of incidentally captured eels.

The combined results of this thesis' data chapters suggest that mortality and injury of eels from incidental capture in recreational fisheries along the Ottawa River is minimal, bearing in mind that the study and experiment conducted here do not capture the full spectrum of perspectives and variables that play roles in this socio-ecological system. Angler interviews revealed that direct killing of eels was uncommon, with all the reported years of these occurrences being prior to 2008, when eels were listed as Endangered in Ontario. Indirect mortality following catch-and-release is also suspected to be low, given that the simulated catch-and-release scenarios resulted in no mortalities over the seven-day holding period. The low impact of recreational fishing on eels is also substantiated by the low percent (12.6%) of moderate to severe injuries found in the catch-and-release experiments, as well as the lack of evidence to suggest an effect of treatment on injury score. These findings suggest that recreational fishing is not a threat for Endangered eels in the Ottawa River. That said, it must be acknowledged that the effects of recreational fishing on American Eel may vary regionally based on differing regulations or other spatially influenced factors (see future directions). Given this, the present thesis can be considered a preliminary indication of the species' resilience to catch and release. However, it does provide a framework for future socio-ecological assessments of the effects of recreational fishing on eels in other regions.

My research suggests that cutting the line is a viable recommendation for releasing incidentally captured eels, both in terms of angler approval and eel survival. Angler interviews revealed that approximately one third (31.5%) of respondents who had captured eels had cut the line. When asked if they were or would be comfortable handling eels, 25% of responses mentioned a preference for cutting the line if they caught an eel and 46% of responses described a disgust for handling eels. When asked whether they would follow the advice of a scientific study that recommended cutting the line as opposed to removing the hook, 76% of respondents stated that they would. This indicates that anglers are open to cutting the line. When release methods were compared in the catch-and-release experiment, it was revealed that there was no difference in outcomes (mortality, injury score) between cutting the line and removing the hook and most eels (83%) in the line-cut treatment shed their hook within the seven-day holding period.

Additionally, it was found that cutting the line for deep-hooked eels was significantly faster than attempting to remove the hook. Based on these results, either method of release (cutting the line or removing the hook) is an acceptable action for anglers who have incidentally captured the species – indeed, it is possible that line cutting may be better for deep-hooked eels (in terms of sub-lethal effects), given its lower handling time. In instances of deeper hooking than what was tested in Chapter 3, line cutting may be the only course of action, as was found to be the case in European Eel (Weltersbach et al. 2018). This finding has the potential to reduce a source of angler discomfort by endorsing their pre-established preference to cut the line, thereby reducing handling of eels. Furthermore, the dissemination of the findings related to high hook-shedding rates and high handling times associated with hook removal of deep-hooked fish may allay any angler concerns about the eels' survival if the hook is not removed. On a broader scale, this work contributes to a growing body of research that suggests that, under certain circumstances (e.g. if the fish is deeply hooked), line cutting may be an equally good, or better, option for releasing fish (Tsuboi et al. 2006; Wilde and Sawynok 2009; Fobert et al. 2009).

Increased recognition of the role of humans in many conservation problems has led to the adoption of interviews and other social science research techniques by many ecologists who do not necessarily have the expertise to create and apply robust social science methodology (St. John et al. 2014; Young et al. 2018). In terms of the present work, the exploratory interviews in Chapter 2 provide valuable information about the perspectives and behaviour of anglers along the Ottawa River, however several limitations must be considered when interpreting the findings from this research. Firstly, the validity of any self-report may be compromised by various response biases, including social desirability bias (i.e. a respondent's tendency to provide answers that are favorable) (Nederhof 1985; Furnham 1986). Among other possibilities, this bias may have led to reduced reports of illegal activity (i.e. killing eels), or increased reports of support for eel conservation. Another limitation of Chapter 2 is that selection of respondents was not random. While the demographics of the respondents indicate that a large range of anglers (in terms of age and fishing experience) were interviewed, only anglers who use public boat launches on the Ontario side of the river were approached. As a result, the views and knowledge of anglers who fish from their own property, as well as anglers on the Quebec side of the Ottawa River, were not captured. Part of this targeted approach was intentional: since eels are not listed as Endangered in Quebec, the anglers on that side of the river do not have the same legal requirement to release incidentally captured eels. Further challenges of the study design employed in Chapter 2 serve as excellent lessons for the application of social science methods by other ecologists. To obtain useable data from interviews, questions should be directed and specific so that respondents will provide comparable answers. For example, the question "Can you tell me what you know about the American Eel?" was too vague. To be able to quantify knowledge, a better question would have been: "Tell me everything that you know about the American Eel". Or, to gain insight about a specific aspect of knowledge about eels, one could break down the question into multiple parts: "What does the American Eel look like?", "What is the conservation status of the American Eel", "What habitat does an American Eel occupy?", et cetera. In conclusion, there is significant value to applying social science research methods to conservation problems, however guidance from social science researchers (including methodology papers such as Young et al. 2018) is crucial to creating robust study designs and generating useable data.

This study is the first to examine the effects of recreational fishing on American Eel, and one of few studies examining recreational fishing impacts on Anguillid species in general. By conducting this work, I have addressed the previously overlooked potential threat of recreational fishing on American Eel and have identified promising areas for improving angler-eel interactions (through increased knowledge of eels and best practices for their release). Furthermore, I have demonstrated the effective use of a socio-ecological rapid assessment to address potential threats for species at risk. This work demonstrates how the combination of human dimensions exploratory research and controlled experimentation can be used to develop a holistic understanding of a threat (Figure 4-1). By examining the human and ecological systems in conjunction with each other, the research was able to be directed toward the most relevant factors affecting both components. For example, this thesis contains a focused discussion on line cutting as a means of release because it was revealed to be a favourable option for both anglers and eels. If the human and ecological systems had been studied separately, line cutting versus hook removal may have been debated, however its importance would not have been emphasized as clearly as in the present approach. A socio-ecological framework such as the one used here could be applied to exploration of recreational fishing impact on other fishes, or it could be adapted to address other types of threats for a broad range of species.

By considering the effects of recreational fishing on a non-target species, this thesis also contributes a new dimension to the debate of whether recreational fishing promotes conservation through angler advocacy or impedes conservation by negatively impacting fish stocks. For American Eel, recreational fishing does not appear to be a conservation problem, however anglers do not consider eels a target species and therefore are not incentivized to promote conservation of eels either. Granek et al. (2008) identified degree of stewardship, size of user group and source of threat as the factors affecting the likelihood of angler involvement in conservation efforts for target species. Here, angler interviews demonstrate that for non-target species, only degree of stewardship (i.e. environmental values) plays a role in determining conservation support, because there is not a strong user group that instrumentally values eel. The potential to change this perception (through angler education) remains unknown (see future directions).

Future directions

There are further avenues of research to contribute to this topic.

The present findings relate primarily to anglers on the Ottawa River (Ontario) and eels from the St. John River (New Brunswick). I recognize that there is spatial variation in both angler and eel behaviour, so my findings may not be representative of angler-eel interactions at large. For example, direct mortality rates may be higher in areas of Ontario where the range of Endangered American Eel overlaps with the range of invasive Sea Lamprey (*Petromyzon marinus*). Like eels, Sea Lamprey have elongated bodies, and are described as "eel-like" in news articles (e.g. CBC News 2012), educational web pages (e.g. OFAH/OMNRF Invading Species Awareness Program 2012), and academic literature (Hubbs and Pope 1937). Ontario's Ministry of Natural Resources and Forestry and Fisheries and Oceans Canada both advise not returning lamprey to water if found (Fisheries and Oceans Canada 2018; Ministry of Natural Resources 2019). If anglers elsewhere in Ontario are as uncertain in their knowledge of eels as Ottawa River respondents were found to be, it is possible that they may mistake eels for lamprey and unintentionally kill an Endangered species. This example of why the level of threat from recreational fishing may vary over the range of American Eel demonstrates the need for caution when extrapolating the findings of the present study to angler-eel interactions elsewhere in the species' range.

The catch-and-release experiment primarily addressed one recurring theme identified in the angler interviews – line cutting, but other potential variables were uncovered in the interviews that have not been addressed. For example, respondents frequently mentioned a preference for using tools such as towels and gloves if they captured an eel. This finding reveals a variable that was overlooked in the catch-and-release experiment; specifically, what are the effects of handling American Eel using gloves and towels on long-term survival? Use of abrasive materials during fish handling (especially for a fish as vigorous as an eel), can contribute to significant mucus loss, leading to infection and disease (Barthel et al. 2003; Colotelo & Cooke, 2010). Further investigations could include handling material (towels or gloves versus bare hands) as a variable in analyses.

While simulated angling events allow researchers to separate confounding factors from independent variables, field validation is essential to ensure that the simulations are representative of true angling events (Cooke et al. 2013a). Field validation of this thesis' results – i.e. tracking eels in their natural habitat following capture in true angling events – would be beneficial to explore the full range of variables relating to catch and release of eels. Firstly, this would reveal the normal hooking depth of incidentally captured eels. Additionally, tracking eels post-release using telemetry could provide longer term mortality data, thereby identifying any latent factors from the experiment in Chapter 3 (e.g. infection due to mucus loss from extended handling times).

If a further threat reduction from anglers towards American Eel is sought, this research identified opportunities for improved outreach in the angling community about Endangered American Eel and what to do if one is incidentally captured. A considerable portion of interviewed anglers (44%) declared a limited or lack of knowledge about eels and about one third did not fully support eel conservation. Educating anglers on the best practices for release of eels could increase their preparedness for the potential of capturing an eel. In this way, the threat from recreational angling toward incidentally captured eels could be further reduced, if deemed necessary. Angler education programs and the establishment of informal institutions (i.e. rules or regulations) hold promise as effective means of inciting voluntary behaviour changes by anglers (Cooke et al. 2013b). Such outreach would present a novel opportunity to evaluate the effectiveness of angler education regarding the conservation of a non-target species.

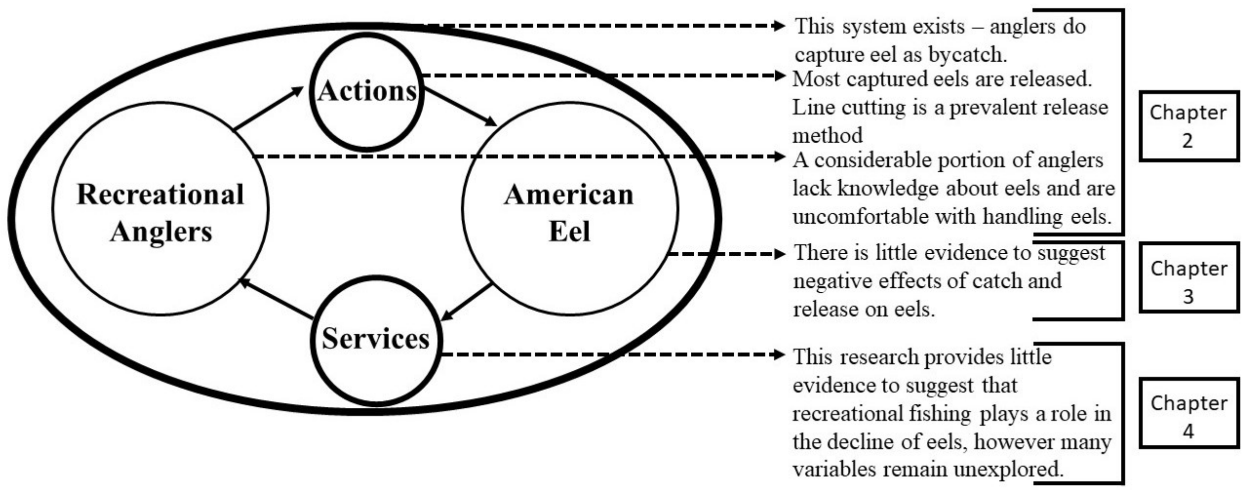

Figure 4-1. A socio-ecological framework of incidental capture of American Eel by recreational anglers. Dashed lines point toward research results that developed from each component of the system, and boxes on the left indicate the corresponding chapters that address each question.

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