Mitigation of freshwater turtle bycatch and mortality associated with inland commercial fyke-net fisheries

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Dedication

I dedicate this work to my mother, my father and my wife for always supporting me.

Abstract

Accidental capture and drowning in entrapment-style fishing gear is a known source of mortality for freshwater turtles. Bycatch reduction devices (BRDs) reduce accidental capture by using size, shape and behavioural differences between target and bycatch species to increase gear selectivity. Behavioural observations from arena and field trials were used to inform the development of BRDs for fyke nets. Trials were conducted in the context of a fishery with a diverse target and bycatch community that complicates BRD development. To compensate, several devices were developed. A 5 cm exclusion ring reduced captures of three turtle species by > 90% but also reduced target fish captures by > 20%. An internal escape grid reliably released smaller turtles and had no major effect on target fish retention. These BRDs can be used individually or together, depending on the community and conditions, and the development method presented can be modified for other diverse fisheries.

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Co-authorship

Chapter 1: Refinement of bycatch reduction devices to exclude freshwater turtles from commercial fishing nets. N. A. Cairns, L. J. Stoot, G. Blouin-Demers, and S. J. Cooke.

While this study is my own, the research was undertaken as part of a collaborative effort and each co-author played a valuable role in its completion. The project was conceived by Cairns, Stoot, Cooke, and Blouin-Demers. Field work was conducted by Cairns and Stoot. All writing and analysis was conducted by Cairns. All co-authors provided comments and feedback on the manuscript. This manuscript will be submitted to *Aquatic Conservation*.

Chapter 2: Using behavioral observations to develop escape devices for freshwater turtles entrapped in fishing nets. N. A. Cairns, L. J. Stoot, G. Blouin-Demers, and S. J. Cooke.

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Chapter 1: General Introduction

While targeting economically valuable species using imperfectly selective gear, fishers often capture sympatric non-target organisms (Abbott and Wilen, 2009). These incidental captures are collectively referred to as bycatch (Alverson *et al.*, 1994). Depending on the fishery, bycatch can span a wide variety of taxa and trophic levels, from non-optimal size classes of the target fish species, to mammals, birds and reptiles (Davies *et al.*, 2009; Hall 1996). Inland fisheries bycatch pose a real risk to freshwater turtles (Bishop 1983; Lowry *et al.*, 2005; Bury 2011; Raby *et al.*, 2011; Larocque *et al.*, 2012a). Freshwater turtles can overlap in habitat with target fish species, and represent a large portion of the biomass in many freshwater ecosystems (Congdon *et al.*, 1986). During the active season, turtles require access to atmospheric oxygen and, therefore, forced submergence represents a source of additional mortality (Ultsch *et al.*, 1984; Barko *et al.*, 2004).

Fishery-induced mortality of incidentally captured freshwater turtles has been noted in a number of studies looking at fisheries (Sullivan and Gale, 1999; Michaletz and Sullivan, 2002), turtle/fishery interactions (Bishop, 1983; Barko *et al.*, 2004; Fratto *et al.*, 2008a;b) and those investigating turtle ecology (Horne *et al.*, 2003; Carrière, 2007). Barko *et al.* (2004) noted that passive fishing nets set for 24 hours resulted in the deaths of ~10% of all turtles captured, and notably 29% of captured snapping turtles (*Chelydra serpentina*). Bishop (1983) also recorded a net-capture mortality of ~10% in the diamondback terrapin (*Malaclemys terrapin*). Fratto *et al.* (2008b) reported mortality in 61% of bycatch turtles in 48 hour net sets, with mortality increasing with increasing water temperature. Incidental turtle captures in nets set by fisheries biologists in Missouri for 72 hours resulted in nearly 100% mortality for all species (Barko *et al.*, 2004). Roosenberg *et al.* (1997) estimated that between 15% and 78% of the diamondback terrapin population in their study died annually in a local crabpot fishery, with even the minimum estimate being far beyond a sustainable rate of adult mortality (Congdon *et al.*, 1993; 1994). Freshwater turtle life histories are typified by naturally high juvenile mortality and delayed sexual maturity; turtles compensate for this with low adult mortality, negligible senescence and extreme iteroparity (Congdon *et al.*, 1993; 1994; Miller 2001). As such, turtle populations are very sensitive to increased rates of adult mortality (Brooks *et al.*, 1991).

Turtles are regularly collected as bycatch in a small-scale fyke-net fishery that operates on lakes and large rivers in eastern Ontario, Canada (Burns, 2007; Larocque *et al.*, 2012a). This fishery targets fish species that vary in size and ecology. Small panfish such as sunfish (*Lepomis* spp.) and yellow perch (*Perca flavescens*) are primary targets, while larger species like bullheads (*Ameiurus* spp.) and common carp (*Cyprinus carpio*) are also targeted. The local turtle community also varies in size and ecology. Turtle bycatch is composed primarily of four species: painted (*Chrysemys picta*), northern map (*Graptemys geographica*), snapping (*Chelydra serpentina*) and musk turtles (*Sternotherus odoratus*) (Larocque *et al.*, 2012a; Nguyen *et al.*, In Review). This fishery presents an ideal opportunity to develop a bycatch reduction program (BRP), which can be used as a case study for inland fisheries as a whole as well as to protect local biodiversity and socioeconomic interests.

Bycatch reduction devices (BRDs) are key components of most bycatch reduction programs (BRPs) in larger fisheries (Hall, 2000). BRDs are modifications or additions made to gear to improve selectivity and avoid incidental captures, ideally without increasing effort and with minimal effect on target landing (Hall, 2000). BRDs function by using differences in behaviour or morphology between target and bycatch species as selective criteria (Broadhurst, 2000). Recently, the development of BRDs to avoid freshwater turtle bycatch in entrapment-style gear has gained attention and several designs have been proposed (reviewed in Bury *et al.*, 2011). BRDs can be grouped in two categories: those that prevent initial capture (exclusion) and those that allow captured individuals to escape (escape) (Fratto *et al.*, 2008b). Although behaviour (i.e., anecdotal evidence) has been used as the basis for many of these BRDs, few studies have expressly looked at freshwater turtle behavior in the context of BRD interaction. The use of behaviour to inform conservation is, in general, an underutilized tool but can be particularly helpful as these observations inform at the scale of the individual and can provide novel insight (Sutherland, 1998). My aim was to use quantitative and qualitative behavioural observations in combination with size selective criteria to develop a suite of BRDs based on the unique characteristics of the community affected by the eastern Ontario panfish fishery.

Research Objectives

The overall objective of my thesis was to design effective exclusion and escape BRDs for a fishery with diverse target and bycatch assemblages, specifically the commercial panfish fishery in eastern Ontario, Canada. To do this, I used behavioural observations to document bycatch interactions with the net. In chapter two, I focused on selective criteria that would reduce the risk of initial capture by excluding turtles. I observed turtle behaviour around the mouth of the net to determine if there was variation in the rate of interaction between turtle species. These observations helped to determine the differential risk of entrapment between species and the effective positioning of devices. I also used controlled arena trials to determine the effectiveness of exclusion devices with selection constrictions based on turtle carapace width as compared with carapace height. I then used field trials and autonomous cameras to compare two styles of devices. Finally, field implementation was conducted in a period of high turtle and fish activity to determine overall efficacy of the BRD in real fishing conditions. In chapter three, I addressed in-net behaviour and attributes that can be used to allow turtles to free themselves from entrapment gear. I used arena trials to determine species-specific patterns of activity and areas of high-use in the net. These can be used to determine where an effective escape BRD placement might be and which species are likely to use it. Using these observations, I designed an escape BRD and then field tested it along with a previously designed escape BRD.

Chapter 2: Refinement of bycatch reduction devices to exclude freshwater turtles from commercial fishing nets

Abstract

The capture of non-target species is a conservation issue in many commercial fisheries. Bycatch reduction devices (BRDs) are commonly used as mitigation tools to improve selectivity of fishing gear and thus reduce bycatch. The aim of this paper was to refine a simple BRD to exclude four species of freshwater turtles from commercial fyke-nets in a fishery in eastern Ontario that targets a variety of fish species. I tested the efficacy of modified exclusion devices (vertical slots and constriction rings) using an adaptive approach including *in situ* observations, controlled behavioural experiments, and field trials. *In situ* observations made by camera were used to estimate turtle catchability and to document turtle behaviour during net interactions, which was used to inform BRD design and placement. In controlled behavioural experiments, the passage rates of target fish (i.e., sunfish), bycatch fish (e.g., game fish), and turtles across a modified net throat suggested that a 5 cm exclusion ring should be suitable for reducing bycatch in this fishery; turtles readily turned sideways to pass through larger openings. Paired field trials indicated that a 5 cm constriction ring reduced the number of turtle captures for all 4 species considered. The constriction ring also reduced captures of non-target game fish. In controlled behavioural experiments there was little evidence of a reduction in catches of target sunfish, however, in paired field trials there was a 23.4% reduction in sunfish catches. In light of these results, I recommend the use of a 5 cm constriction ring for fisheries targeting sunfish in areas where freshwater turtles are present.

Introduction

Bycatch is the inadvertent capture of non-target species and is a major issue in commercial fisheries in marine and freshwater environments around the globe (Saila, 1983; Alverson *et al.*, 1994; Raby *et al.*, 2011). Bycatch occurs as a result of overlap in spatial distribution between target and non-target species, and the use of gear lacking the selectivity to differentiate between the two. Bycatch reduction devices (BRDs) are modifications to fishing gear that improve selectivity by allowing bycatch species to be excluded or to be freed (Broadhurst, 2000). BRDs designed to exclude bycatch species typically exploit size or behavioural differences between bycatch and target species (Broadhurst, 2000; Roosenburg and Green, 2000). Size selectivity functions simply by physically limiting those individuals that are too large or of the incorrect shape to pass through the BRD (Broadhurst, 2000). Behavioural differences can also be exploited to improve selectivity. For example, observations of behaviour around nets can be used for BRD design and placement (Watson, 1989; Broadhurst, 2000; Harden and Willard, 2012). In addition, the propensity of a bycatch species to change its orientation when interacting with a BRD may affect the performance of the BRD. Information on size and behaviour can be combined to determine where overlap between target and non-target species is incomplete, and to create a device that capitalizes on that difference to avoid bycatch (Broadhurst, 2000).

Many species of freshwater turtles overlap in habitat with fish that are the target of commercial fisheries, which puts these turtles at risk of incidental capture and associated mortality (Barko *et al.*, 2004; Carrière *et al.*, 2007; McClellan and Read, 2009; Larocque *et al.*, 2012a; Drake and Mandrak, *In Press*). The need for atmospheric oxygen makes most turtles unable to tolerate prolonged submergence in warm water. Delayed sexual maturity and naturally high mortality at early life stages limit the ability of most turtle species to buffer the loss of fecund individuals (Brooks *et al.*, 1991; Congdon *et al.*, 1993, 1994; Bulté *et al.*, 2010). Turtles have been the benefactors of several BRDs, in both freshwater and marine systems (Broadhurst, 2000; Lowry *et al.*, 2005; Fratto *et al.*, 2008a,b; Bury, 2011; Larocque *et al.*, 2012b). The development of turtle excluder devices (TEDs) for commercial marine trawl fisheries is one of the better known and successful examples (Crowder *et al.*, 1995; Broadhurst, 2000; Epperly, 2003). A simpler TED has been implemented for commercial and recreational blue crab (*Callinectes sapidus*) fisheries to reduce incidental capture of diamondback terrapins (*Malaclemys terrapin*; Bishop, 1983, Wood, 1997; Roosenburg and Green, 2000; Hart and Crowder; 2011). Most TEDs rely on the fact that there is a size or shape difference between target and bycatch species. In many freshwater fisheries, target fish and bycatch turtles may be more similar in size than in marine fisheries (Fratto *et al*., 2008a), making it more difficult to develop effective TEDs. Thus, behavioural differences between fish and turtles should be exploited in BRD development for freshwater fisheries, but very few efforts have been made to observe and quantify freshwater turtle interactions with fishing gear.

In eastern Ontario, Canada, a small-scale fyke-net fishery operates in freshwater lakes and large rivers (Burns, 2007; Larocque *et al.*, 2012a). Fyke-nets are passive entrapment nets in which fish movements are obstructed by a long lead line that directs them into a trap (Hubert, 1996). The eastern Ontario fishery targets several fish species that vary in size and ecology: small panfish such as sunfish (*Lepomis* spp.) and yellow perch (*Perca flavescens*) are primary targets, but larger bullheads (*Ameiurus* spp.) and common carp (*Cyprinus carpio*) are also targeted. The local turtle community likewise varies in size and ecology. For example, the mass of a snapping turtle (*Chelydra serpentina*) can be 300 times that of a musk turtle (*Sternotherus odoratus*). Intermediate in size are the northern map turtle (*Graptemys geographica*) and the painted turtle (*Chrysemys picta*). These four turtle species have habitat preferences that put them at risk of capture in areas of eastern Ontario where fyke-nets are deployed (Larocque *et al.*, 2012a).

Previous studies investigating bycatch reduction in the eastern Ontario commercial fishery left several questions unanswered. Larocque *et al.* (2012b) found that an exclusion BRD with an 8 cm spacing still allowed the capture of large map turtles (with carapace widths larger than 8 cm), while it reduced the capture of small musk turtles (with carapace widths less than 8 cm; Larocque *et al.*, 2012b). Could differences in behaviour between the two species be responsible for this unexpected result? Can behavioural information inform conservation (i.e., “conservation behaviour”; Sutherland, 1998) through improvements in BRD design?

The aim of this paper is to use an adaptive approach to refine a simple exclusion BRD for commercial fyke-nets and to evaluate its effectiveness at reducing captures of four species of freshwater turtles. First, turtle behaviour when interacting with nets was documented *in situ*. Then, controlled behavioural experiments were used to determine the willingness of target and bycatch species to pass through the BRDs under controlled conditions. Finally, the efficacy of the refined design was tested using paired field trials under realistic commercial fishing conditions.

Methods

Study area

The study was conducted on Lake Opinicon and at the Queen’s University Biological Station (44° 34 N, 76° 19 W) approximately 100 km southwest of Ottawa, Ontario, Canada. Lake Opinicon is a shallow (mean depth of 2.8 m) mesotrophic lake with a surface area of 780 ha (Agbeti *et al.*, 1997).

Nets

Nets and net set methods used in this study were the same as those presented in Larocque *et al.* (2012a) and mimic those used by commercial fishers in eastern Ontario. Briefly, I used fyke-nets constructed of 7 structural rings each with a diameter of 0.91 m attached together with #15 knotted nylon, 2.54 cm square mesh (5.08 cm stretch; Christiansen's Nets Company, Duluth, Minnesota, USA). On the second and forth rings there is a throat that directs organisms into the cod end of the net and minimize escape. These nets were set in pairs connected mouth to mouth by a lead net 10.7 m long and 0.91 m tall, and each net also had 4.6 m long wings set at ~45° angle all made of the same material. The nets were set near shore in shallow water (1 m to 2.5 m deep) and left to fish for approximately 24 hours.

Evaluating turtle-net interactions in situ

GoPro Hero cameras (Woodman Labs, San Mateo, California, USA) pointing out towards the mouth were deployed inside 98 fyke-nets (Figure 1) from 12 June 2011 to 20 June 2012 and programmed to take one high resolution photo every 5 seconds for approximately 3.5 hours. I reviewed the photos to record the number of interactions for each species of turtle. The interaction rates (per hour soak) were then compared to the capture rates (per hour soak) of the same net over the total soak time. Qualitative observations were also made on how turtles approach the nets and on how they move around the mouth of the net to inform BRD design and refinement.

Evaluating constriction BRDs using controlled behavioural experiments

To refine the BRDs used by Larocque *et al.* (2012b) and determine how turtles were still able to enter modified fyke-nets, a behavioural arena was developed to test model exclusion devices by conducting controlled behavioural experiments. The arena was 2 m long by 60 cm wide and bisected by a net throat with or without a BRD (Figure 2). The arena was situated outdoors and was filled with enough lake water (at ambient temperature) to cover the throat and BRD completely. Preliminary behavioural experiments conducted in 2011 were used to ensure the willingness of turtles to pass through a funnel without incentive. During these preliminary trials, cameras (as above) were used to gather behavioural information on turtles interacting with BRDs.

Controlled behavioural experiments were conducted from 5 May to 22 June 2012 at water temperatures from 13 to 21°C for turtles and 15 to 24°C for fish. Both turtles and fish were collected using unmodified fyke-nets. Fish trials were run on the day of capture. Turtles were held in open air ~700 L fibreglass flow-through tanks for 1 to 5 days before trials. Each turtle or fish was placed in the trial arena for 10 minutes and its behaviour was observed from a distance and recorded. Preliminary trials indicated that single *Lepomis* were unlikely to move during a ten minute trial, so four were added per trial and exclusion was recorded as a proportion. No stimulus or bait was used to guide the individuals through the throat or BRDs, relying instead on unsolicited movement in a confined space.

Three treatments were compared using repeated measures on the same individual: painted copper piping constriction rings with measurements of 22.5 by 5 cm, 22.5 by 8 cm, and an unobstructed throat. Individual order of treatment was randomized. Between treatments, the individuals were placed in a 60 L cooler. Each species was exposed to each order of treatments twice for a total of 12 trials per species. Trials were conducted using target fish (sunfish and bullhead) and bycatch fish (largemouth bass, *M. salmoides*), as well as painted, musk, and map turtles. All turtles and fish had dimensions that would allow them to pass though a 5 cm spacing.

Only male turtles were used in an effort to minimize stress on females during the critical spring reproductive season.

Evaluating constriction BRDs with paired field trials

BRDs with a spacing of 5 cm were affixed to standard fyke-nets that were set with floats in the cod end to provide access to air. Nets were set from 7 to 24 September 2011 in water temperatures of 17 to 21.5°C. The first BRD was vertically oriented “bars” attached across the mouth of the net with a spacing of 5 cm. The second device was the 5 cm constriction ring attached on the inside of the first throat. Both devices were constructed from 1.27 cm metal tubing. Nine groups of three nets (2 treatments and a control) were set together for roughly 24 hours. Cameras were used to monitor the qualitative aspects of turtle/exclusion device interactions using the same methods as the *in situ* turtle/net interactions but with cameras facing towards the throat (Figure 1). Pairs of similarly modified nets were fished together connected by a lead net and the order of treatment rotated for each set. Upon net retrieval, target and bycatch were identified to species, measured and counted. All organisms were returned to the site of capture.

Further field trials were conducted from 29 April to 21 June 2012 with water temperatures from 9.5 to 26°C. The same methods were used as in 2011, but the exclusion bars treatment was eliminated. A total of 22 groups (unmodified controls set with a 5 cm constriction ring) were set in 11 sites. Each site was fished twice with treatment order reversed. At least one week was given between sets at a site.

Statistical analyses

All statistical analyses were conducted using R statistical software (R Development Core Team, 2012) unless otherwise mentioned. A $p < 0.05$ was selected as significant.

In the controlled behavioural experiments, the passage rates of individuals through 8 cm and 5 cm exclusion devices were compared to the control. Individuals that failed to pass through the control were excluded. The successful passages were summed by species and treatment and compared to control values using Fisher's Exact Test for count data.

For the observation of turtle/net interactions *in situ* and paired field trials, I first compared treatment and control capture rates for each species using pair-wise tests, followed by a comparison of haul composition and indicator species analysis while controlling for site. Capture per unit effort (CPUE) for all species remained non-normal despite transformations and was therefore compared using Wilcoxon signed rank tests. A Wilcoxon rank sum test was used to test for species differences in carapace height (CH; turtles) and total length (TL; fish) between treatments. Fish with a TL less than 190 mm were excluded from comparisons as this size class is not targeted and can account for only 10% of a fisher’s landings (Ontario Ministry of Natural Resources, 2013). To determine differences in catch composition between treatment and controls, a blocked multi-response permutated procedure (MRBP) and indicator species analysis (ISA) were conducted using PC-ORD (Dufrêne and Legendre, 1997; McCune and Mefford, 2006). The MRBP used CPUE for each species to test for differences in species composition while controlling for between-site variation. If a difference in overall composition was determined, ISA was used *post hoc* to indicate which species differed.

Results and Discussion

Evaluating turtle-net interactions in situ

All turtle species combined, camera observations per unit effort (OPUE) were significantly higher than catch per unit effort (CPUE; Figure 3; $V = 2403$, $p < 0.001$, $r = 0.38$). Wilcoxon signed rank tests indicated that painted turtles ($V = 516$, $p = 0.01$, $r = 0.25$; Figure 3) and particularly map turtles ($V = 580$, $p < 0.001$, $r = 0.35$; Figure 3) were observed more frequently than they were captured. However, no such differences were observed for musk (V = 855, p = 0.34, r = 0.10; Figure 3) and snapping turtles (V = 45, p = 0.32, r = 0.10; Figure 3), although in the case of the latter this may be related to smaller sample size. Species composition differed significantly between observation and capture (Figure 3; A = 0.03, p < 0.001) which suggests that species differ from each other in the rate at which they are captured. However, no single species appeared to be the main driver of this overall difference. Although all species exhibited higher OPUE that CPUE, the magnitude of the difference varied by species, which suggests some differences in catchability between species.

Catchability is the relationship between the abundance of a species and the efficiency with which a capture method collects that species (Arreguín-Sánchez, 1996). The difference between observation (a proxy for abundance) and capture rates for each species is an indication of the likelihood of an individual of that species actually getting caught when interacting with a net. This proportion of captured to observed individuals is deemed the catchability coefficient (q; Arreguín-Sánchez, 1996). The rate of capture per interaction and the nature of these interactions may provide further insight into the design of BRDs (Bardach and Magnuson, 1980). For instance, the abundance and catchability of species may point to species that are most at risk of entering nets and allow focused efforts towards these species in particular. Information on the way turtles approach a net may also inform the type and placement of the BRD.

Our observations suggest that the four turtle species in Lake Opinicon approach and interact with fyke-nets differently. Painted turtles were regularly observed interacting with the nets, but few interactions resulted in capture, suggesting a low catchability (q = 0.3; Figure 3). Painted turtles typically approached along the lead net, swimming above the vegetation. Painted turtles appeared deliberate, swimming directly into the cod end or exiting quickly with minimal contact with the net. Painted turtles often avoided prolonged interactions with nets, turning around upon reaching the mouth of the net or transiting across the mouth to depart on the other side of the lead.

Map turtles had an OPUE nearly five times higher than their CPUE, suggesting the lowest catchability of the four species ($q = 0.2$; Figure 3). The behaviour of this species when approaching or interacting with the nets was similar to that of painted turtles, but map turtles tended to approach the net from higher in the water column. Transiting across the mouth of the net was particularly common in map turtles. This may be the cause of the relatively high rates of map turtle captures in nets equipped with 8 cm exclusion bars (Larocque *et al.*, 2012b). By design these bars impede turtle movement into the mouth of the net, but this has the unintended consequence of making movement around the lead more difficult compared to an unobstructed net, potentially increasing catchability of those turtles able to pass through the BRD. Map turtles that pass through the exclusion device once, in order to transit across the mouth, may then take the path of least resistance and proceed into the cod end of the net instead of passing through the BRD a second time.

Musk turtles had observation rates similar to their capture rates, suggesting higher catchability than map or painted turtles ($q = 0.44$; Figure 3). Behavioural observations suggest that musk turtles readily entered the mouth of the net. Musk turtles typically approached along the substrate following the lead or wing nets.

Very few snapping turtles were observed or captured during this portion of the study so an estimate of catchability is preliminary. For snapping turtles, OPUE and CPUE were very similar ($q = 0.95$; Figure 3). Snapping turtles were only observed twice and in both cases they interacted with the wings of the net in the water column above the macrophytes.

This is, to our knowledge, the first attempt to determine catchability for a community of turtles in the context of bycatch. Catchability has been used in management of fisheries for target species, but should also be used to quantify the differential risk of capture posed by unmodified commercial fishing gear to different bycatch species (Arreguín-Sánchez, 1996). Catchability and behavioural observations can be combined with other measures associated with risk of entrapment, like spatial overlap with target species, to inform mitigation efforts and BRD design (Harden and Willard, 2012).

Evaluating constriction BRDs using controlled behavioural experiments

Preliminary trials indicated that a model net throat without a BRD did not restrict the passage of turtles over a 10 minute period. Video observations revealed that turtles of all four species readily turn on their sides to pass through vertically oriented exclusion devices.

The Fisher's Exact Test revealed differences in the rates of exclusion where the more restrictive 5 cm device appeared to exclude more turtles than the 8 cm BRD. The 8 cm constriction device did not significantly affect the passage rates of any turtle species (painted: $p = 1$, power = 0.001; map: $p = 1$, power = 0; musk: $p = 0.21$ power = 0.15; Figure 4), bycatch fish (largemouth bass: $p = 1$, power > 0.001; Figure 4) or target fish (bullhead: $p = 0.2$, power = 0.14; sunfish: $p = 0.476$, power = 0.04; Figure 4). Reductions generated by the 5 cm device were significant or approached significance for all turtles despite relatively low power (painted: $p = 0.03$, power = 0.64; map: $p = 0.09$, power = 0.37; $p = 0.09$, power = 0.37; Figure 4). The 5 cm spacing significantly impeded largemouth bass passage rate ($p < 0.001$, power = 1; Figure 4), reductions in passage were nearly significant for bullhead ($p = 0.08$, power = 0.36; Figure 4), but there was no effect on passage for sunfish ($p = 1$, power = 0; Figure 4).

The lack of significant exclusion with the 8 cm device was unsurprising for painted or map turtles as both have been observed passing through this spacing in previous studies, but the lack of significant exclusion for musk turtles was unexpected. Larocque *et al.* (2012b) found that the overall capture of painted turtles was unaffected by the addition of an 8 cm vertically oriented constriction ring. In the same study, map turtles were collected equally by control and a bar style BRD with a spacing of 8 cm. However, Larocque *et al.* (2012b) found a 73% reduction in musk turtle captures using an 8 cm vertically oriented constriction ring. This suggests that there is a behavioural component to exclusion with this type of BRD, at least with musk turtles, as the vast majority of musk turtles have a carapace width smaller than 8 cm. The behavioural nature of this selectivity is further supported by our observation that all species tested readily turn on their side to pass through BRDs. This change in orientation results in essentially no size selectivity for musk turtles with an 8 cm BRD. Thus, any observable reductions in the capture of small turtles with an 8 cm spacing are likely the result of behavioural rather than physical exclusion.

The observed reductions in passage with the 5 cm constriction device may arise from an inability (physical) or unwillingness (behavioural) to pass through the smaller constriction, or a combination of the two. Although all individuals were able to fit through the 5 cm ring, the angle at which they approached may have limited the passage of some individuals. The closer the device gets to the minimum diameter of an individual, the more likely this individual will be excluded. In general, passage rates were lower for the 5 cm ring than for the 8 cm ring (Figure 4).

Sunfish did not appear to be deterred by the addition of a BRD with at least one sunfish passing through the 5 cm device in all trials. The bullheads, however, appeared to be more averse to passing through BRDs. Of the 7 largemouth bass that passed through the control, 6 also passed through the 8 cm ring, but none passed through the 5 cm ring. Bullheads and largemouth bass appear to be increasingly excluded by decreased spacing of the exclusion device, but BRDs seem to have little effect on sunfish passage (Figure 4).

Previous successes in excluding smaller turtles from nets using exclusion devices based on carapace width were likely due to behaviour (Larocque *et al.*, 2012b). Not all species were excluded, however, as painted (8 cm ring) and map turtles (8 cm bars) were collected at similar rates between modified and unmodified nets (Larocque *et al.*, 2012b). The willingness of all turtle species investigated to turn on their sides to traverse a BRD limits the efficacy of vertically oriented BRDs with large spaces and suggests that a design based on minimum diameter of turtles, such as carapace height, may be more appropriate. Using carapace height as a selective criterion, only snapping turtles and large female map turtles could be reliably excluded with an 8 cm device (Figure 5). The percentages (for adult males and females, respectively) of the Lake Opinicon turtles that can be excluded using a 5 cm device based on carapace height are 9% and 92 % for painted, 2% and 97% for map, 2% and 7% for musk turtles, and 100% for snapping turtles (Figure 5). These data, along with the minimal apparent effect to the main target species (sunfish), suggest that the 5 cm exclusion ring may be the most effective BRD to reduce turtle captures while still allowing the capture of target fish.

Evaluating constriction BRDs with paired field trials

In fall 2011, 9 paired net sets (for a total of 18 nets of each treatment) resulted in the capture of 224 fish and 11 turtles in unmodified nets while 109 fish and 3 turtles were captured in nets modified with 5 cm vertical bars, and 144 fish and 4 turtles were captured in nets modified with a 5 cm constriction ring. Both net modifications, bars ($V = 3$, $p = 0.08$, $r = 0.38$)

and ring (*V* = 3, *p* = 0.08, *r* = 0.3), tended to reduce turtle captures, but the differences were not statistically significant. Bycatch of game fish also tended to be reduced, but again the differences were not statistically significant for ring (*V* = 31, *p* = 0.19, *r* = 0.28) or bars (*V* = 30, *p* = 0.30, *r* = 0.29). The collection of target fish did not appear to be to be affected by the ring (*V* = 61, *p* = 0.30, *r* = 0.23), but the bars tended to diminish captures, albeit not in a statistically significant manner (*V* = 31, *p* = 0.06, *r* = 0.37). The difference in species diversity collected by control and modified nets was not statistically significant for the bar device (A = 0.02, *p* = 0.06) or the ring (A = 0.01, *p* = 0.17). In total, the control nets collected 8 target fish species, 2 bycatch fish species, and 2 turtle species while the modified nets collected 5 target fish species, 2 bycatch fish species, and 2 turtle species.

Cameras recorded several interactions where both devices excluded or failed to exclude painted and musk turtles. No turtle that passed through a BRD was observed escaping. Map or snapping turtles were not observed during this portion of the study. Similar to the observations made during the arena trials, both painted and musk turtles were seen turning on their sides to pass through the BRDs.

The most obvious difference between the two styles of BRD was the ease of use during net deployment and retrieval. The vertically oriented bars were more cumbersome, increasing the time required to set the net. Bars also limited access to the mouth of the net, hindering removal of tangled fish. Conversely, the constriction ring had little influence on ease of net use. Because of the important role of user friendliness for fisher adoption of BRDs (Campbell and Cornwell, 2008), the prevention of turtles from transiting across the mouth of the net, and the apparent reduced captures of target fish, I abandoned the use of the vertical bar BRD.

In spring 2012, 22 paired net sets (for a total of 44 nets of each treatment) resulted in the capture of 1143 fish and 129 turtles in unmodified nets, and 688 fish and 35 turtles in nets modified with a 5 cm constriction ring. The CPUE for all groups (turtles, bycatch fish and target fish) was reduced by the 5 cm exclusion device (Table 1), but some species were more affected than others. The composition of landings varied significantly between control and modified nets (A = 0.03, $p < 0.001$): there were stronger reductions in CPUE for painted (IV = 55.1, $p < 0.001$) and map turtles (IV = 36.1, $p < 0.001$) as well as largemouth bass (IV = 67.6, $p < 0.001$) and brown bullheads (IV = 53.5, $p < 0.001$). In total, the control nets collected 7 target fish species, 2 bycatch fish species, and 4 turtle species while the modified nets collected 6 target fish species, 2 bycatch fish species, and 3 turtle species.

The turtle species had varying responses to the BRD. Painted turtles displayed a 92.5% reduction in CPUE between unmodified and modified nets (Table 1) and those captured had significantly smaller carapace height (Table 1). The reduction in CPUE was higher than expected from carapace height alone and likely represents some behavioural exclusion in addition to physical exclusion. CPUE of map turtles was reduced by 92.6% (Table 1), but there was no difference in carapace height of individuals captured in modified and control nets (Table 1), which was surprising given that the means are noticeably different (68.2 ± 3.56 and 42 ± 0 mm for control and treatment, respectively). The device did not appear to have a significant effect on the CPUE for musk turtles even though a 38.3% reduction was observed (Table 1) and the turtles collected were significantly smaller (Table 1). This high capture rate for musk turtles is unexpected based on the success Larocque *et al.*, (2012b) had with 8 cm devices, and is concerning despite the better tolerance of submergence by this species (Stoot *et al.*, *In Press*). Only two snapping turtles were collected, both in unmodified nets. Based on carapace height of snapping turtles, it can be assumed that a 5 cm constriction device would exclude the majority, if not all adults of this species.

For largemouth bass, both CPUE and total length (TL; Table 1) were significantly reduced by the use of a 5 cm constriction ring compared to an unmodified net, which was not the case for northern pike CPUE and TL (Table 1).

The CPUE of target pumpkinseed sunfish was reduced by 22.6% by the 5 cm ring compared to an unmodified net, but TL did not differ significantly (Table 1). Bluegill sunfish displayed similar reductions in CUPE (22.7%) in the modified net, but the difference was not significant (Table 1). Bluegill collected in the modified net were significantly larger (Table 1). Black crappie and yellow bullheads tended to have lower CPUE with the 5 cm ring, but the differences were not statistically significant and there appeared to be little effect on the size of the individuals captured (Table 1). Brown bullheads were the only target species with a significant reduction for both CPUE and TL (Table 1). Rock bass CPUE and size were unaffected by the presence of the 5 cm ring (Table 1). A 93.4% reduction in bullhead landings is concerning for fishers as this is an important target species. These ictalurids possess sensitive barbels that may limit their willingness to pass through confined spaces (Ogawa *et al.*, 1997). The use of metal as a BRD in this study may have reduced the capture of bullheads as the electrosensitivity of these species may reduce passage rates through conductive BRDs (Parker and van Heusen, 1917; Peters and Bretschneider, 1972). The use of a plastic device of the same dimensions may minimize this effect, but further study is needed to address this possibility.

Conclusion

Each species in the freshwater turtle community displayed differences in behaviour and catchability, but there were similarities that can be exploited to improve BRD design. Three of the species readily turn on their sides when confronted with a narrow space, suggesting that carapace height is preferable to carapace width when trying to predict which turtles can be physically excluded with a given BRD. Because turtle height is less than turtle width, this will result in BRDs with smaller openings which, in turn, may diminish captures of target fish.

This study determined that an 8 cm BRD is too wide to exclude the majority of the turtles in eastern Ontario. Based on carapace height, a 5 cm BRD will exclude the majority of the adult female turtles, with the exception of musk turtles. Vertical bars make the net more cumbersome to use, so I support the use of a constriction ring. The reduction of bycatch fish, particularly largemouth bass, in addition to turtles is an added benefit of the 5 cm ring BRD. The capture rate of target fish was affected by our 5 cm constriction ring, but species differed in their response; sunfish were still collected in large numbers, bullheads were not. The use of plastic non-conductive materials in BRD construction may help capture more bullheads. In areas where larger fish are targeted, the implementation of a 5 cm ring BRD will likely lead to reductions in captures similar to largemouth bass. The 5 cm constriction ring did not eliminate turtle captures completely; to reduce turtle mortality further, this exclusion device should be paired with the provision of an air space (e.g., a float or setting net with top exposed to air; Larocque *et al.*, 2012c) or with an effective escape device (Larocque *et al.*, 2012b).

Tables

Table 1: Number, percent of landing, mean size and catch per unit effort (CPUE with SE) along with the corresponding Wilcoxon rank-sum test and signed-rank test statistics and the relative effect size (*r*) for each species collected using unmodified fyke-nets and those modified with a 5 cm constriction ring affixed to the first throat. A total 44 nets of each treatment were set in Lake Opinicon, Ontario, Canada form 29 April to 21 June 2012.

Species	Treatment	N	Percent	Mean Size (TL or CH)	*W*	*p*	*r*	CPUE (± SE)	*V*	*p*	*r*
Rock bass	Control	28	2.20	217.96	365	0.40	0.20	0.04±0.01	153	0.66	0.07
	Ring	31	4.29	225.97				0.03±0.01			
Black crappie	Control	34	2.67	247.18	256	0.69	0.06	0.03±0.01	166	0.08	0.26
	Ring	14	1.94	238.86				0.01±0.00			
Bluegill	Control	248	19.50	197.59	20932	0.02	0.12	0.26±0.05	570	0.14	0.22
	Ring	195	26.97	199.72				0.20±0.05			
Pumpkinseed	Control	479	37.66	208.26	92019	0.13	0.05	0.48±0.05	630	0.03	0.34
	Ring	362	50.07	207.00				0.37±0.06			
Yellow bullhead	Control	29	2.28	272.24	215.5	0.24	0.18	0.03±0.01	124	0.10	0.25
	Ring	12	1.66	264.50				0.01±0.01			
Brown bullhead	Control	106	8.33	299.15	547.5	0.03	0.20	0.11±0.03	319	< 0.001	0.63
	Ring	7	0.97	281.57				0.01±0.00			
Largemouth bass	Control	202	15.88	342.41	8772.5	< 0.001	0.31	0.21±0.03	789	< 0.001	0.64
	Ring	61	8.44	301.49				0.06±0.01			
Northern pike	Control	16	1.26	515.50	67	0.18	0.28	0.02±0.01	90	0.09	0.25
	Ring	6	0.83	476.50				0.01±0.00			
Painted turtle	Control	53	4.17	48.98	185	0.01	0.33	0.05±0.01	366	< 0.001	0.64
	Ring	4	0.55	43.00				0.00±0.00			
Musk turtle	Control	47	3.69	44.23	989.5	< 0.001	0.38	0.05±0.01	164	0.22	0.18
	Ring	29	4.01	40.24				0.03±0.01			
Map turtle	Control	27	2.12	68.19	46	0.11	0.30	0.03±0.01	164	< 0.001	0.51
	Ring	2	0.28	41.00				0.00±0.00			
Snapping turtle	Control	2	0.16	144.50	NA	NA	NA	0.00±0.00	NA	NA	NA
	Ring	0	0.00	0.00				0.00±0.00			

Total turtles	Control	129	10.14	NA	NA	NA	NA	0.13±0.02	614	<0.001	0.60
	Ring	35	4.84					0.03±0.01			
Total target species	Control	925	72.72	NA	NA	NA	NA	0.95±0.10	770	<0.001	0.50
	Ring	621	85.89					0.64±0.11			
Total fish bycatch	Control	218	17.14	NA	NA	NA	NA	0.22±0.03	820	<0.001	0.63
	Ring	67	9.27					0.07±0.01			

Figures

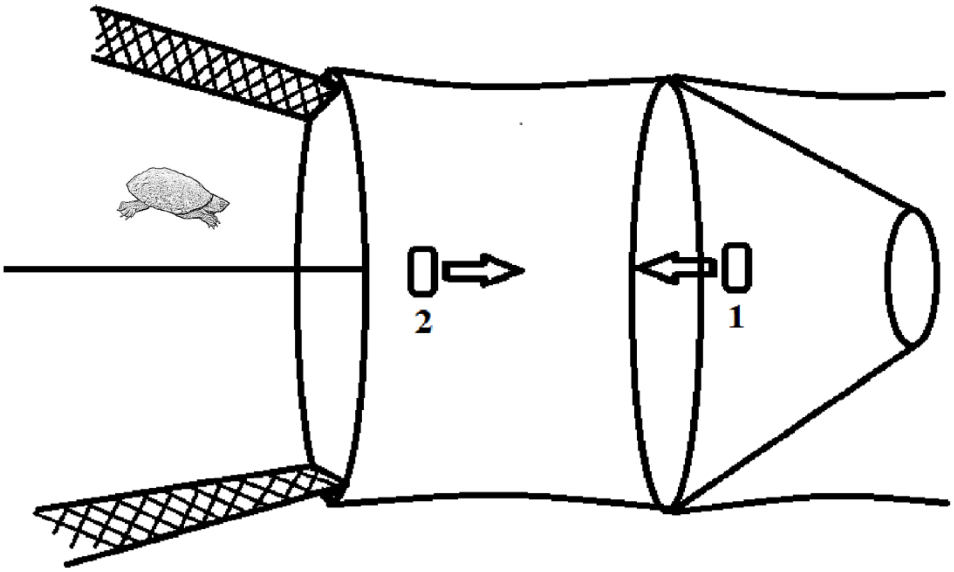

Figure 1: The mouth of a fyke/hoop-net as seen from above showing camera placement for: 1. Observing pre-capture net-turtle interactions and 2. Observing turtles interacting with the BRD affixed to the first throat in Lake Opinicon, Ontario, Canada.

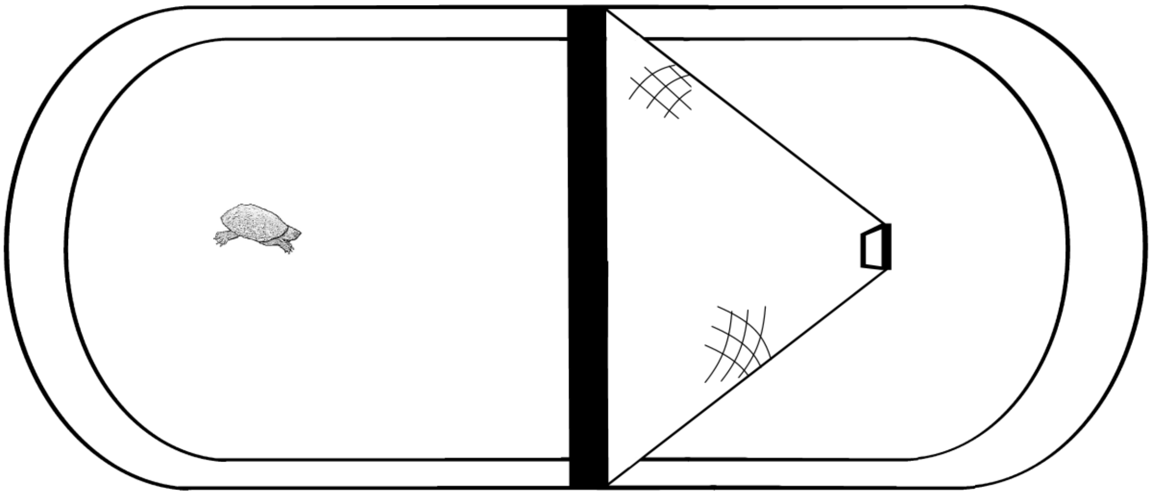

Figure 2: The arena (as seen from above) used during controlled behavioural experiments to evaluate the effect constriction BRDs of different diameters had on passage rate of representative target and bycatch species present in Lake Opinicon, Ontario, Canada. The arena measures 200 by 60 cm with a water depth of approximately 60 cm bisected by a replica fyke-net throat with or without a BRD. The BRDs used where constriction rings measuring 5 X 22.5 cm or 8 X 22.5 cm.

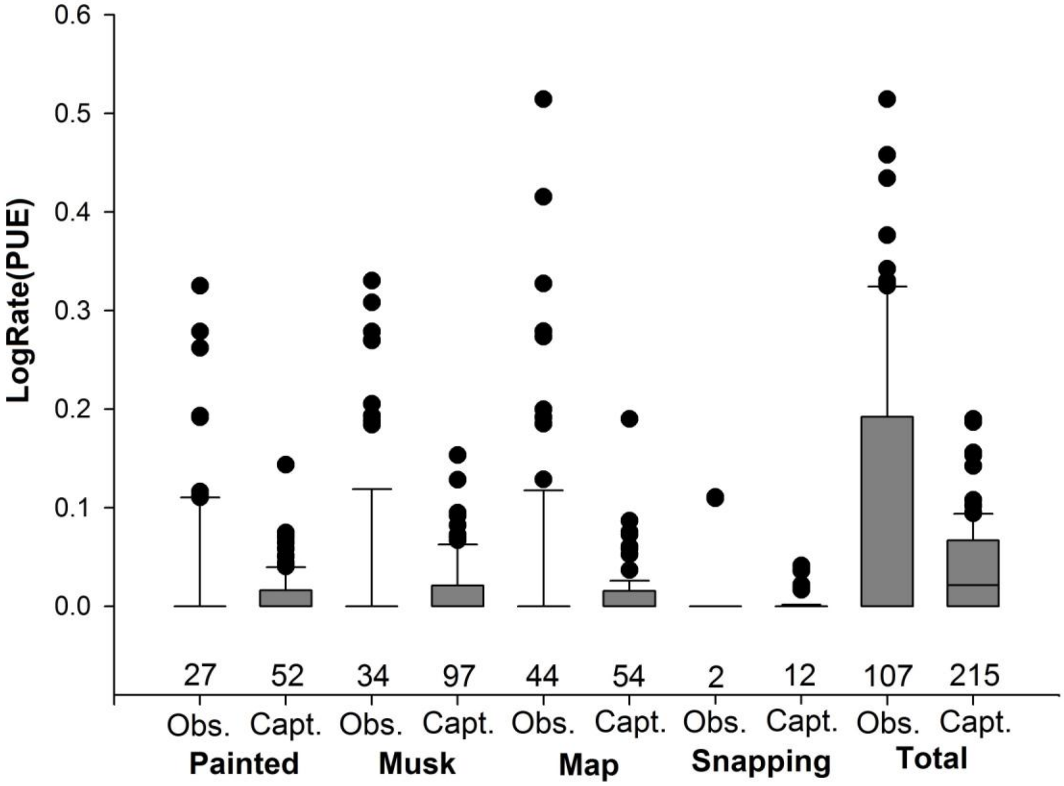

Figure 3: Logarithmically transformed turtle-net interaction observation (Obs.) per unit effort (PUE) rate using net mounted autonomous cameras and capture (Capt.) (PUE) rates for the same nets along with sample sizes for each method. The differences between these metrics point to the inter-specific variation of catchability within the turtle community of Lake Opinicon, Ontario, Canada. Boxes represent 25 and 75th percent of the population with whiskers the 5 and 95th percentiles. Data outside of these ranges are represented by dots.

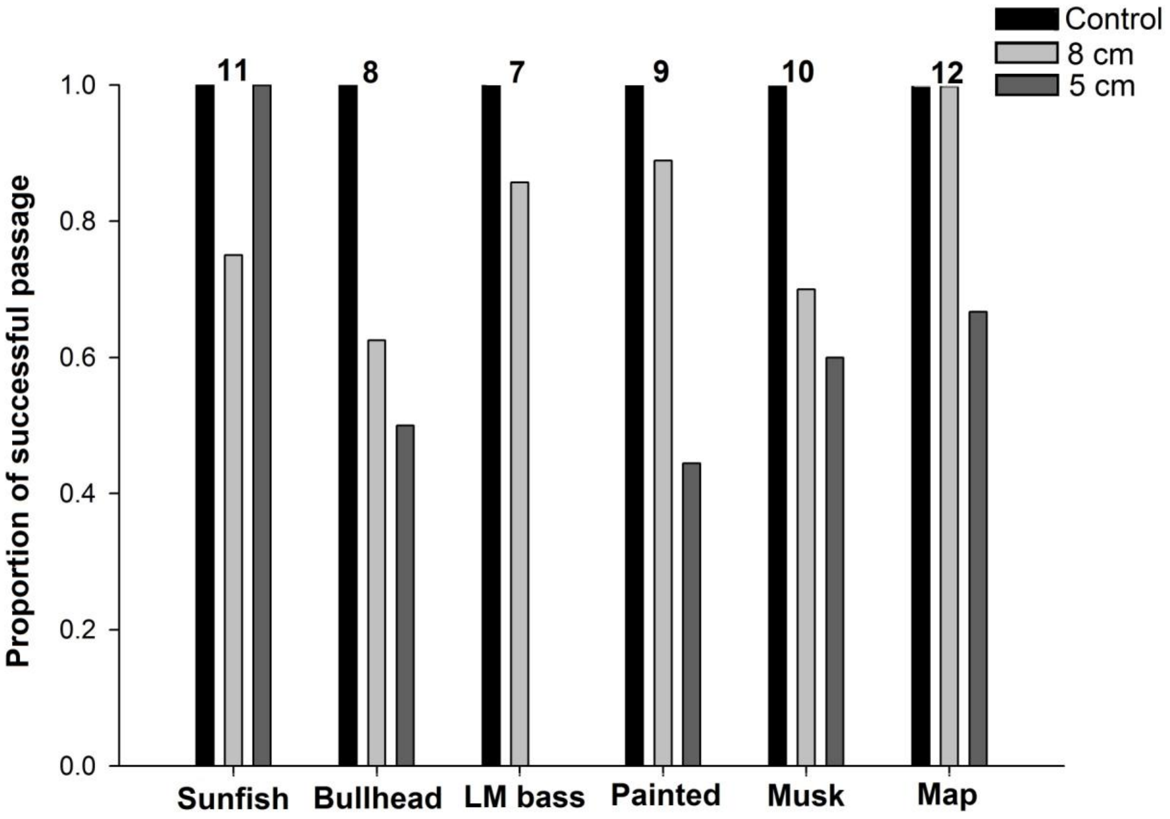

Figure 4: Successful passage rate through 8 and 5 cm constriction devices as a proportion of those individuals which successfully passed through a control in the form of an unconstricted funnel. The numbers above the histogram represent the sample size of individuals that passed their respective controls.

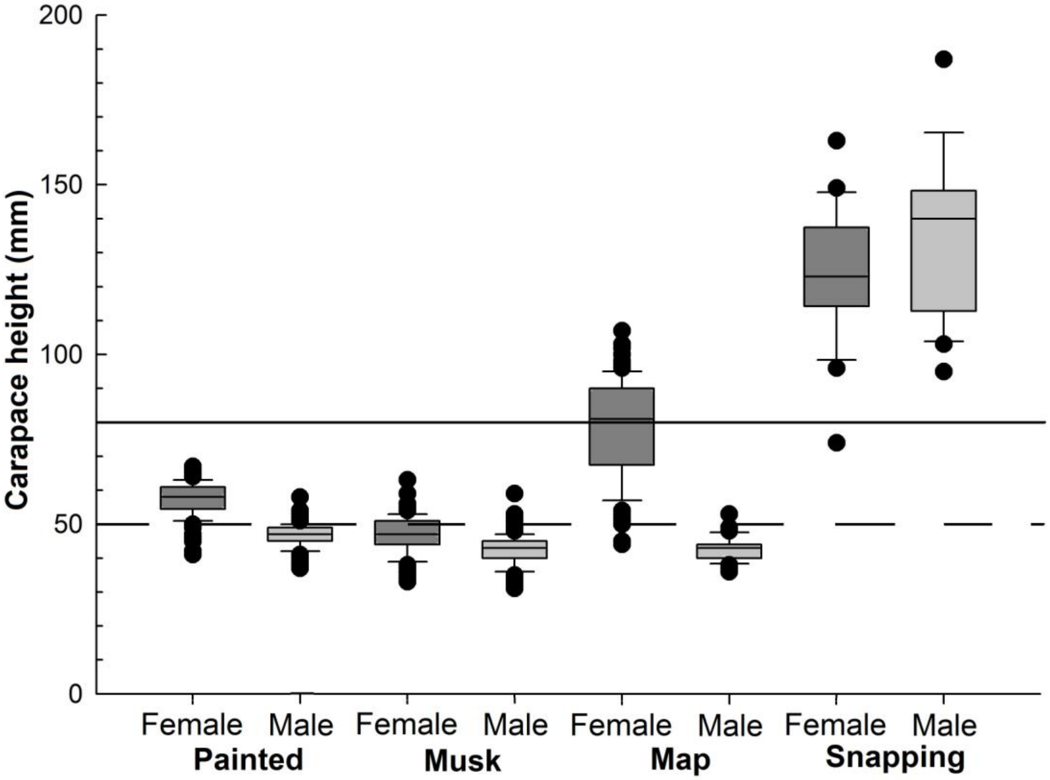

Figure 5: The minimum diameter (carapace height) of the common turtle species from the Lake Opinicon community and the subsections which can be excluded by rigid BRDs of different spacings. The dashed line represents a BRD spacing of 5 cm and the solid line one of 8 cm. A turtle with a carapace height greater than the spacing would not be physically able to pass through the BRD. Note the increased proportion of the community that would be predictably excluded by a 5 cm BRD. Boxes represent 25 and 75th percent of the population with whiskers the 5 and 95th percentiles. Data outside of these ranges are represented by dots.

Chapter 3: Using behavioral observations to develop escape devices for freshwater turtles entrapped in fishing nets

Abstract

The drowning of freshwater turtles following incidental capture in fishing gear can cause population declines. Four turtle species are captured incidentally in a small-scale commercial panfish fishery in eastern Ontario, Canada. The fyke-nets used in this fishery collect turtles alive which would allow for turtles to be freed with bycatch reduction devices (BRDs). I used quantitative and qualitative behavioral observations (with underwater cameras) in conjunction with controlled experiments and field trials to quantify the rates of locomotor activity and identify the areas of high use in the net by four turtle species. I then used these observations to inform the development of a new escape BRD (grid) and test a previous design (chimney). These devices were then field tested and held promise to help turtles evade fyke nets, although the reductions in turtle captures were not statistically significant. Target fish retention was not significantly affected by the BRDs. The escape devices I developed in this study can be used in the local fishery or modified for other fisheries. Escape devices can be used as components of a bycatch reduction program with exclusion devices, education, and effort management. If used with a simple exclusion device, the grid BRD has the potential to end turtle bycatch in this fyke net fishery. Moreover, this study demonstrates the value of underwater behavioural observations for the refinement of BRDs.

Introduction

Entrapment style fishing gear intercepts mobile fish and retains them until they are collected by fishers (Hubert, 1996). In some inland fisheries, entrapment gear incidentally captures freshwater turtles as bycatch (Bishop, 1983; Lowry *et al.,* 2005; Bury, 2011; Raby *et al.,* 2011, Larocque *et al.,* 2012a). Although entrapment gear tends not to injure turtles, forced submergence can lead to physiological disturbances, behavioral impairments, and drowning (Barko *et al.,* 2004; Stoot *et al.,* In Press). Turtle populations are sensitive to increased rates of adult mortality; with life histories typified by naturally high juvenile mortality and delayed sexual maturity, turtles rely on low adult mortality, negligible senescence, and extreme iteroparity to maintain populations (Brooks *et al.,* 1991; Congdon *et al.,*1993, 1994; Miller, 2001). Due to the threat that fisheries pose to freshwater turtles, a number of bycatch reduction devices (BRDs) have been developed to improve gear selectivity and to avoid incidental capture (Wood 1997; Bury, 2011; Larocque *et al.,* 2012b,c).

The avoidance of bycatch through BRDs often focuses on devices that prevent the capture of an individual, referred to as exclusion BRDs. Exclusion devices typically use rigid grids, bars, or rings to physically limit the size or shape of organisms that can enter the net (Bury 2011). Exclusion BRDs are particularly effective when bycatch species are larger than the target species (Hall *et al.,* 2000; Broadhurst, 2000). In fisheries where target and bycatch species are diverse, or broadly overlap in size, exclusion can be incomplete (Fratto *et al.,* 2008a). If this is the case, smaller individuals and species can still be collected and potentially result in demographic, population, and community shifts (Hall *et al.,* 2000; Dorcas *et al.,* 2007; Wolak *et al.,* 2010). In the case of passive entrapment gear, however, escape bycatch reduction devices can be used in addition to or instead of exclusion BRDs.

Differences in behavior while in the net and disparity in size between target and bycatch species can be determined and used as selective criteria in the development of exclusion and escape BRDs. Unlike entanglement gear or hooks (e.g., drum lines), turtles captured by entrapment typically remain mobile and unharmed (Hubert, 1996) at least for the period shortly (hours) after capture. As entrapment gear is passive, any escape device must allow a turtle to escape under its own volition and power, before the effects of forced submergence lead to behavioral or physiological impairments or death. Thus, an effective escape BRD implies a simple, well-positioned device that takes advantage of behavioral and size variation between target and bycatch species. Although many turtles can survive prolonged submergence, most active turtles become behaviorally or physiologically impaired in a relatively short period of time once deprived of air (Ultsch *et al.,* 1984; Stoot *et al.,* In Press). A physiological disturbance, like exhaustion, often manifests itself behaviorally and may lead to repetitive traits which can be used as selective criteria for BRD development. However, behavioral observations of entrapped freshwater turtles in the net are few. Measurement of animal behavior as well as the application of behavioral principles is an underutilized tool in conservation biology (Caro, 1998; Sutherland, 1998; Broadhurst, 2000). Behavioral observations (e.g., underwater video or time-lapse imagery) of entrapped turtles can potentially be used to improve the effectiveness of a BRD because the mechanisms of escape can be observed and quantified (Renchen *et al.*, 2012; Favaro *et al.,* 2012).

A small scale commercial fishery in eastern Ontario, Canada, provides an ideal case study for freshwater turtle bycatch in entrapment nets. The fishers use fyke-nets to collect a variety of panfish (*Lepomis* spp*.*, *Pomoxis nigromaculatus*, *Perca flavescens*) along with larger species like bullhead (*Ameiurus* spp.), suckers (*Catostomus* spp**.**), and carp (*Cyprinus carpio*).

Sympatric turtles are regularly collected as bycatch and with maximum allowable soak times for fyke-nets ranging between 2 and 7 days (Ontario Ministry of Natural Resources 2013) these individuals are at risk or drowning (Larocque *et al.*, 2012a). The four most commonly collected species are the painted turtle (*Chrysemys picta*), the northern map turtle (*Graptemys geographica*), the eastern musk turtle (*Sternotherus odoratus*), and the snapping turtle (*Chelydra serpentina*). Interviews with local fishers suggest that most are not fond of turtle BRDs, and particularly of escape devices. Escape BRDs are perceived as making nets difficult to store on deck and between seasons, more labour intensive to set and limiting in terms of depth. As such, most fishers do not view current BRDs as applicable to commercial fisheries (Nguyen *et al.*, In Review).

Our aim was to design an escape BRD that would be effective for all 4 species of bycatch turtles as well as address some of the concerns of local fishers. High resolution underwater video and time-lapse cameras were used to record behavior of entrapped turtles in controlled trials, and their most frequent location within the cod-end of a fyke-net. Behavior and location for each of the four turtle species were then used to guide the development of an escape BRD. The escape BRD I designed (an escape grid) was then field tested, along with a previous design (an escape chimney) that had only been tested on painted turtles. During the field trials, underwater cameras were deployed to observe the interactions of animals with BRDs.

Study Area

The study was conducted on Lake Opinicon and at the Queen's University Biological Station (44° 34N, 76° 19W) approximately 100 km southwest of Ottawa, Ontario, Canada. Lake Opinicon is a shallow (mean depth of 2.8 m), mesotrophic lake with a surface area of 780 ha (Agbeti *et al.*, 1997). This lake is part of the jurisdiction of a small-scale fyke-net fishery operating on freshwater lakes and large rivers in eastern Ontario (Burns, 2007; Larocque *et al.*, 2012a).

Methods

Nets

The fyke-nets used in this study were constructed of 7 structural hoops each with a diameter of 0.91 m attached together with #15 knotted nylon, 2.54 cm square mesh (5.08 cm stretch) (Christiansen's Nets Company, Duluth, Minnesota). Throats on the second and fourth hoops direct organisms into the cod-end of the net and minimize escape. Nets were set in pairs, connected mouth to mouth by a lead net 10.7 m long and 0.91 m tall. Each net had 4.6 meter-long wing nets made of the same material set at a ~45° angle from the lead. The nets were set in shallow water (<1 m to 2.5 m) and left for approximately 24 hours (see Larocque *et al.*, 2012a for details).

Documenting in-net behavior and activity

To document behavior, a controlled experiment was conducted using a completely submerged net and underwater video recording. In-net position and activity were observed and compared for the four species of turtles. Trials were conducted from 18 May to 20 June 2011 at water temperatures from 16.5 to 24.5°C. Male turtles (to avoid potentially harming reproductive females) were collected using unmodified fyke-nets and then held in open air ~700 L fibreglass flow-through tanks with access to basking platforms for a minimum of 24 hours before trials. Each turtle was placed in the mouth of a sealed net and its behavior recorded and observed on a live feed for three hours using three underwater cameras (Figure 6). From the video generated, I scored turtle activity and position in the net every five minutes. After an hour had elapsed, if a turtle was not observed moving for 15 minutes, or if it appeared to be in acute distress, the trial was ended and the turtle was removed. The cod-end of the net was divided into quadrants (along the x/y axis as viewed in profile) in order to determine if turtles spend more time near the top of the net or near the substrate as well as in the anterior or posterior portions of the net (Figure 6). Observations were made every 5 minutes and the quadrant occupied by the turtle at the beginning of the observation noted.

Preliminary trials with the escape grid

Controlled trials were conducted to determine the effectiveness a new escape BRD design (an escape grid) before it was tested in the field. These preliminary tests were conducted using the same methods as the in-net behavioral observations explained above. BRD interactions were recorded until escape and time at escape was noted.

Field trials with the escape chimney and the escape grid

To test the effectiveness of two escape BRDs at facilitating the escape of turtles while retaining target fish, the devices were affixed to standard fyke-nets and fished mimicking the commercial fishery. Nets were set in 2012 from 3 to 12 July in water temperatures of 23 to 29°C. The first BRD was a chimney-style device used successfully in controlled trials on painted turtles by Larocque *et al.,* (2012b). This device consisted of a tube of fine mesh reinforced with rigid wire to prevent collapse. The mesh tube was attached to the cod-end of the net just anterior to the final structural ring (Figure 6). A floating ring constructed of PVC plastic was used to maintain contact with the water surface while a gap between the float and the mesh was designed to allow turtles to escape (see Larocque *et al.,* 2012b). The second device was a grid inside the net positioned over the second funnel in the terminal compartment of the net (Figure 6 and Figure 7). The grid operated as a horizontally-oriented exclusion device to take advantage of the dorsoventrally flattened shape of most turtles. Bars spaced every 8 cm limited the size of the organism that could pass through the grid. Tarred twine was stretched diagonally across each gap to provide a barrier for fish smaller than 8 cm in height (Figure 7 and Figure 8). The use of an 8 cm spacing was based on the size of exclusion style BRDs effective at reducing turtle captures in this community (Larocque *et al.*, 2012b). The grid was constructed of 0.64 mm steel rods welded into the shape of a crescent with the points attached to the structural hoops of the net with a hinge that allowed the device to collapse for storage (Figure 7). When deployed, the grid sat at a ~ 45 degree angle to the orientation of the hoops and held open an escape hatch constructed of a 0.64 mm stainless steel rod bent into a rectangle 22.5 X 10 cm and affixed with a hinge to the structural hoop (Figure 7 and Figure 9). Both grid and escape hatch were woven into the mesh of the net.

Modified and unmodified nets were fished together connected by a lead net. Net pairs were set together for ca. 4 hours. The restricted soak time used in this study is not typical of this fishery, but was chosen to minimize the risk of turtles drowning (Barko *et al.*, 2004). GoPro cameras programmed to take one still photo every 5 seconds for approximately 3.5 hours were mounted inside the nets to monitor escape and turtle interactions with the devices (Woodman Labs, San Mateo, California, USA). Upon retrieval, target and bycatch individuals were identified to species and measured. Fish with a total length < 190 mm were excluded from comparisons as this size class is not targeted and accounts for only 10% of landings (Ontario Ministry of Natural Resources 2013). All organisms were returned to the site of capture immediately.

Statistical analyses

All statistical analyses were conducted using R statistical software (R Development Core Team, 2012) unless otherwise mentioned. I set alpha at 0.05. Due to the unidirectional nature of hoop nets and the reduced activity of most species beyond two hours, in-net behavioral analysis was limited to position in the terminal cod-end of the net between 5 and 120 minutes.

Documenting in-net behavior and activity

The occupancy of the four cod-end quadrants were compared using a chi-squared goodness-of-fit test for each species and the four combined. The first and second hours were tested separately to determine if occupancy for each species varied between the two time periods. For activity, 30 seconds of observation was completed every 5 minutes. If the test subject was active (crawling, swimming, or pulling on the netting) it was assigned a value of 1; if an individual was not active (sitting on the bottom or clinging to the netting without pulling) it was assigned a value of 0. Binary logistic regression was used to determine the relationship between activity and time for each species.

Field trials with the escape chimney and the escape grid

To determine the effectiveness of escape devices *in situ*, I compared catch composition between treatments and controls using a blocked multi-response permutated procedure (MRBP) and indicator species analysis (ISA) using PC-ORD (Dufrêne and Legendre, 1997; McCune and Mefford, 2006). I used catch per unit effort (CPUE) for each species to test for differences in species composition while controlling for between-site variation. If a difference in overall composition was determined, ISA was used *post hoc* to indicate which species differed. CPUE values remained non-normal after transformations; therefore pair wise comparisons were conducted using a Wilcoxon signed rank test with a continuity correction. A Wilcoxon rank sum test with a continuity correction was used to test for species differences in carapace height (CH; turtles) and total length (TL; fish) between treatments.

Results

Documenting in-net behavior

There was a significant difference between the number of observations per quadrant and the expected even distribution of net occupancy for all species combined ($\chi^2(3)=8.42$, $R^2= 0.02$, $p= 0.04$), musk turtles ($\chi^2(3)= 17.71$, $R^2= 0.03$, $p<0.001$), and snapping turtles ($\chi^2(3)= 27.65$, $R^2= 0.06$, $p<0.001$; Figure 10). In general, turtles were observed more often in quadrant A, then in section B; musk turtles favored section B followed by A, and snapping turtles favored section A. No significant difference in the occupancy of between sections was found for painted turtles ($\chi^2(3) = 3.73$, $R^2 = 0.01$, $p = 0.29$) or map turtles ($\chi^2(3) = 4.29$, $R^2 = 0.01$, $p = 0.23$; Figure 10). There was no significant difference in net occupancy found for any test group between the first and the second hour of submergence ($\chi^2(3) = 4.4$, $R^2 = 0.002$, $p = 0.22$; Figure 10). My qualitative observations indicated that turtles spend more time in the areas of the net with acute angles, such as the seam between the throat and the structural hoop of the net as well as in the terminal portion of the net where the mesh is pulled into a tight cone.

Documenting in-net activity

Logistic regression revealed that there was a significant interaction between the effect of time and the effect of species on the probability of being active ($\chi^2(3)=22.20$, $p=<0.001$) suggesting that all species did not react the same way to prolonged submergence. When each species' activity was compared individually to submergence time, painted, map and snapping turtles were significantly less active after two hours of submergence (Figure 11). Musk turtle activity however, was unaffected by submergence time under two hours (Figure 11).

Preliminary trials using the escape grid

Using the occupancy trends and the observed tendency of turtles to follow the seams of the net I determined that quadrant “A” would be an effective area for a BRD (Figure 6 and Figure 10). I developed an escape grid with an 8 cm spacing for this placement which would provide mechanical selectivity. A total of 14 painted, 11 map and 7 musk turtles were used to test the effectiveness of the prototype escape grid BRD. All but one painted turtle was able to escape, resulting in a success rate of 94% for this species. All individuals that successfully passed did so in under an hour, with escape time ranging from 0.9 to 57.1 minutes (means: painted: 14.6 ± 4.0; map: 9.9 ± 2.4; musk: 12.4 ± 2.5). Turtles appeared to readily pass through the device. Some individuals were observed passing through the device, only to return to the cod-end of the net without escaping. The escape hatch seemed well-positioned as most individuals escaped shortly after passing through the grid.

Field trials with the escape chimney

Analysis of catch composition using MRBP did not indicate a difference between nets modified with a chimney and unmodified controls but appeared to trend that direction (A = 0.01, *p* = 0.07) as a precaution ISA were conducted. No species was determined to be a significant indicator of differences in composition of total landings. The three species with the highest indicator values (IV) were map turtles (IV = 22.9, *p* = 0.08), which were collected most often in the control net, and the two species of sunfish (bluegill IV = 24.2, *p* = 0.12; pumpkinseed IV = 43.9, *p* = 0.24), which were collected most often by the modified nets.

A total of 20 turtles of three species were collected, 14 from control nets and 6 from nets modified with a chimney, a decrease of 57% from control to treatment. Comparisons between control and treatments revealed no significant difference in CPUE or carapace height (CH) for any individual turtle species (Table 2) or for all species combined ($V = 51$, $p = 0.12$, $r = 0.32$; Figure 12).

A total of 109 target fish of 5 species were collected, 46 from control nets and 63 from nets modified with an escape chimney, an increase of 27% from control to treatment. Capture rates did not differ significantly between control and treatment nets for all species combined (CPUE: $V = 73$, $p = 0.14$, $r = 0.3$; Table 2 and Figure 12) or for sunfish, which made up the majority of target landings (control: 91%; chimney: 87%; Table 2 and Table 3). Rates of game fish bycatch were not significantly different in control and modified nets, making up 18% of control and 10% of treatment landings, and the fish did not differ significantly in size (Table 2 and Figure 12).

Field trials with the escape grid

MRBP analysis did not identify any difference in total (target and bycatch) capture composition between nets modified with a grid and their controls ($A = 0.01$, $p = 0.18$). Over 23 paired trials, the nets modified with a grid device collected 2 map turtles while control nets collected 12 individuals representing 4 species. Despite this difference in captures, no significant difference was found for CPUE of any species (Table 3 and Figure 13). Both map turtles collected in the modified nets had CH > 80 mm. Four additional turtles (2 painted and 2 musk turtles) were recorded inside the modified nets using GoPro cameras, but were absent from the nets when they were retrieved. All turtles were observed using the escape device, accounting for their absence at the end of the trial. The *in situ* use of the BRD by painted and musk turtles mirrored the observations made in controlled trials, although *in situ* escape took longer than the mean escape time of controlled trials in all cases.

A total of 99 individual target fish of five species were collected; 57 from control nets and 42 from nets modified with an escape grid, a reduction of 26% from control to treatment. The CPUE for all species combined did not differ significantly between control and treatment nets ($V = 166$, $p = 0.21$, $r = 0.26$; Table 3 and Figure 13) or for sunfish, which were the most common species collected (control: 94.73%; grid: 87.71%; Table 3 and Figure 13). Largemouth bass were the only bycatch fish species collected, representing 15% of control and 5% of grid fish landings. This species had marginally higher capture rates in control nets but no difference in total length was observed (Table 3 and Figure 13).

Discussion

I found that musk and snapping turtles preferentially occupy the anterior part of the cod-end. Painted and map turtles occupy this area as often as any other portion of the net, suggesting that this should be a good area for BRD placement. The escape grid I designed to take advantage of this high-occupancy area functioned well, successfully freeing turtles in controlled and field trials.

I used behavioral observations while designing and testing our BRD prototypes. Exploiting the observed behaviors of target species has been successfully employed in fisheries to increase harvest; therefore, the behavior of bycatch species can be used to improve gear selectivity and help design more efficient BRDs (Nomura, 1980; Broadhurst, 2000; Wang *et al.*, 2007). Our study is one of very few to use quantified behavior in BRD development, but a number of BRDs targeting freshwater turtles have taken advantage of the expected behavior of trapped turtles in order to free them or to keep them alive.

Based on the assumption that the surface of the water presents a barrier to fish movement, but not to turtle movement, a number of escape devices have been designed to free turtles from entrapment gear. Most of these modifications are chimney-style devices, where a tube of mesh joins the cod-end of the net to the surface of the water allowing the amphibious turtles to escape while fish are retained (Fratto *et al.*, 2008b; Bury, 2011, Larocque *et al.*, 2012b). These devices have proven effective in a number of studies, but their efficacy at freeing several sympatric species of turtles has rarely been documented. Other designs have been developed using physical differences between fish and turtles to reduce reliance on the water surface as a barrier.

Fratto *et al.,* (2008b) used a panel of mesh with a loose weave that in theory would allow the more dextrous turtles to negotiate their way through, while retaining the target catfish. This design was successful at reducing turtle captures but had target retention issues. Lowry *et al.,* (2005) designed a platform-type device that successfully guided turtles towards an escape hole while blocking the hole for target carp. Lowry *et al.,* (2005) also used qualitative video observations to determine if turtles followed an expected path to escape.

In our study, qualitative and quantitative behavioral observations were used to plan and confirm the effectiveness of the BRDs tested. The chimney device used in the field trial was developed by Larocque *et al.,* (2012b) and tested by controlled trials using painted turtles. The positioning of the escape device was based on the literature and the assumption that turtles exhibited surface-searching behavior. I have shown, however, that different turtle species occupy each part of the net differentially, likely resulting in varied rates of interaction with the BRD. During our field trials, the chimney functioned relatively well. Despite being placed in the least occupied section of the net (Figure 1) it reduced overall turtle captures by >50% and retained target fish well. It is likely that turtle escape could be improved by moving the chimney to quadrant “A” above the throat of the net (Figure 1).

The grid device was devised under a series of constraints generated from the concerns of fishers, and the local diversity of turtles and fish. Fishers do not like chimney-style escape devices because they are not user friendly in a commercial sense and limit the depths at which nets can be set (Nguyen *et al.,* In Review). I therefore decided that a new escape device that would function within the confines of the net was required. Because the main target species of this fishery are small, laterally compressed sunfish compared to the generally dorsoventrally flattened turtles, using differences in shape to free turtles may be possible. It seems unlikely that an escape device that would free a very large snapping turtle (up to 17 kg in our sample) would retain target fish. Large turtles, however, are easily excluded with a BRD (Larocque *et al.*, 2012b). Thus, if paired with an exclusion BRD, our escape BRD would only be required to free small to medium turtles. To ensure that a turtle that is able to pass through the exclusion device can subsequently free itself, the escape BRD should have a spacing equal to or greater than the exclusion BRD.

The area of the net directly above the throat was determined to be the best placement for an escape device, accounting for 40% of all observations (33% excluding snapping turtles). The area under the throat was also used, but it seemed less probable that an escape device on the bottom would be effective as the bottom of the net rests on the substrate. The observation that turtles regularly occupied areas with seams was helpful in further refining the escape grid and its placement.

Field tests of the grid device indicated a 93.9% reduction in turtle captures. Those turtles that were retained had carapace heights > 80 mm and were therefore unable to pass through the BRD. This issue could easily be solved by the addition of an exclusion BRD. The 26% reduction in target fish captures, although not statistically significant, seems high but is similar to the difference between the chimney and its control so may represent normal variability in catches. Fish were observed passing thought the escape device but it is difficult to ascertain if these individuals would have met the 190 mm minimum TL mandated by this fishery. Further trials are needed to determine the long-term retention of fish in nets modified with an escape grid.

Management implications

In a freshwater commercial fishery in eastern Ontario, painted turtles represented 43%, musk turtles represented 41%, map turtles represented 9%, and snapping turtles represented 7% of turtle bycatch. Based on carapace height, an exclusion device with a spacing of 5 cm would exclude the most adult female turtles (92 % of painted, 7% of musk, 97% of map, and 100% of snapping turtles), but would retain males of several species as well as juveniles of all species. Therefore, there is a need for an escape BRD in addition to the exclusion BRDs I have already tested. Musk turtle in particular as the smallest species are still at risk but I have demonstrated through behavioral trials that this species is well suited to extraction from entrapment nets using escape BRDs. Musk turtles do not tire easily, occupy a predictable area of the cod-end and readily use the grid device suggesting this may be an effective part of a bycatch mitigation strategy for this species. Broadly the escape grid BRD I tested was effective at freeing turtles and its use in conjunction with an exclusion BRD could reduce incidental turtle captures to nearly zero.

Inexpensive commercially-available underwater cameras capable of obtaining time-lapse imagery or video are a powerful tool for understanding and addressing bycatch-related management problems in areas with sufficient water clarity. Behavioural information (i.e., conservation behaviour; Caro, 1998; Sutherland, 1998) has much to offer to development and refinement of BRDs for incidentally captured animals.

Small-scale and subsistence fisheries are key sources of protein for much of the human population, particularly in the developing world (Berkes *et al.,* 2001). Without management, these fisheries can be destructive to local ecosystems and with increasing human populations the need for simple management tools is acute in many areas (Berkes *et al.*, 2001). The eastern Ontario fyke-net fishery is a well known, organized and regulated fishery that can serve as a case study for the development of effective bycatch reduction strategies, including the development of BRDs. The escape devices I tested can be modified to fit other communities and conditions. Simple BRDs can provide important reductions in bycatch, thus rendering small-scale and subsistence fisheries more sustainable.

Tables

Table 2: Number, percent of landing, mean size (with SE) and catch per unit effort (CPUE with SE) along with the corresponding Wilcoxon rank-sum test and signed-rank test statistics and the relative effect size (*r*) for each key target and bycatch species collected using unmodified fyke-nets and those modified with a chimney style BRD. A total 23 nets of each treatment were set in Lake Opinicon, Ontario, Canada from3 to 12 July, 2012 in water temperatures of 23 to 29°C.

Species	**Treatment**	**N**	**Percent**	**Mean Size (TL or CH)**	***W***	***p***	***r***	**CPUE (± SE)**	***V***	***p***	***r***
Bluegill	Control	5	7.14	206.33±10.62	38.5	0.611	0.36	0.049±0.032	13	0.286	0.22
	Chimney	12	15.79	195±1.35				0.112±0.039			
Pumpkinseed	Control	37	52.85	207.94±1.36	843.5	0.338	0.677	0.377±0.117	74	0.255	0.237
	Chimney	43	56.57	207.07±2.27				0.0429±.0.071			
Largemouth bass	Control	9	12.86	340.11±33.58	61	0.077	1.249	0.087±0.047	22	0.624	0.102
	Chimney	7	9.21	242.78±10.38				00.075±0.033			
Painted turtle	Control	3	4.29	59±3.21	6	0.2	0.906	0.031±0.017	8	0.361	0.19
	Chimney	2	2.63	48.5±3.5				0.019±0.016			
Musk turtle	Control	3	4.29	48.33±2.33	5	1	0	0.032±0.017	9	0.787	0.056
	Chimney	3	3.94	48±2.65				0.029±0.016			
Map turtle	Control	8	11.43	73.78±6.56	7	0.4849	0.494	0.078±0.034	23	0.151	0.3
	Chimney	1	1.31	44±0				0.011±0.011			

Table 3: Number, percent of landing, mean size (with SE) and catch per unit effort (CPUE with SE) along with the corresponding Wilcoxon rank-sum test and signed-rank test statistics and the relative effect size (*r*) for key target and bycatch species collected using unmodified fyke-nets and those modified with a grid BRD with an 8 cm spacing. A total 23 nets of each treatment were set in Lake Opinicon, Ontario, Canada from 3 to 12 July, 2012 in water temperatures of 23 to 29℃.

Species	**Treatment**	**N**	**Percent**	**Mean Size (TL or CH)**	***W***	***p***	***r***	**CPUE (± SE)**	***V***	***p***	***r***
Bluegill	Control	11	13.92	194.91±1.44	35	0.283	0.758	0.114±0.037	48	0.505	0.139
	Grid	9	19.57	197±1.5				0.093±0.045			
Pumpkinseed	Control	43	54.43	205.17±1.97	593	0.802	0.177	0.449±0.097	156	0.1644	0.29
	Grid	27	58.7	206.17±2.38				0.272±0.068			
Largemouth bass	Control	10	12.66	274.3±20.65	12	0.75	0.218	0.101±0.032	37	0.097	0.339
	Grid	2	4.35	258±68				0.022±0.015			
Painted turtle	Control	1	1.27	79±0	_	_	_	0.012±0	_	_	_
	Grid	0	0	0				0			
Musk turtle	Control	1	1.27	48±0	_	_	_	0.008	_	_	_
	Grid	0	0	0				0			
Map turtle	Control	9	11.39	79.44±7.39	7.5	0.812	0.168	0.093±0.075	9	0.788	0.056
	Grid	2	4.35	90±1				0.02±0.014			
Snapping turtle	Control	1	1.27	149±0	_	_	_	0.01±0	_	_	_
	Grid	0	0	0				0			

Figures

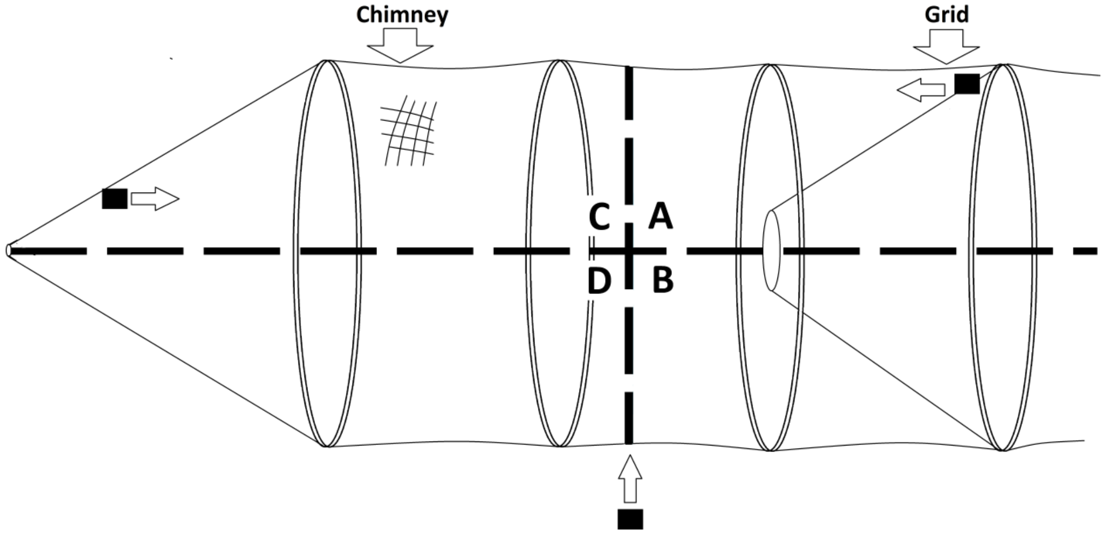

Figure 6: The cod-end of a fyke-net used for behavioral trials to determine the occupancy patterns and activity of painted, map, musk and snapping turtles collected from Lake Opinicon, Ontario, Canada. Occupancy was compared for the four sections (A,B,C and D) and behaviors were recorded using two underwater cameras (black boxes) located in the anterior and posterior of the cod-end with a third used to observe the net from profile. Arrows mark the positions of the two escape BRDs (the chimney and the grid).

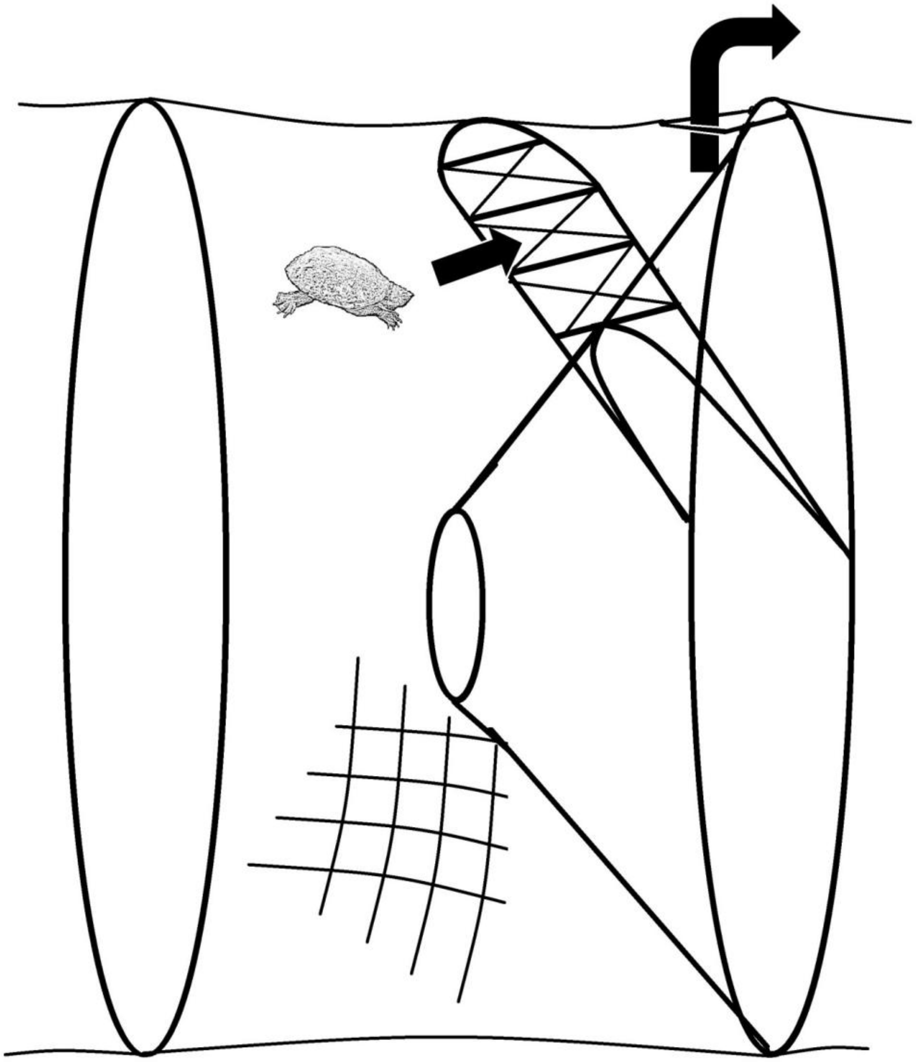

Figure 7: The “grid” escape device located in section “A” of the cod-end of a commercial fyke-net. This BRD was designed based on the turtle and fish community of Lake Opinicon, Ontario, Canada. Bars spaced 8 cm apart and diagonally stretched tarred twine serve as a selective barrier. When deployed the grid holds an 22.5 X 10 cm escape hatch. Both grid and escape hatch were woven into the mesh of the net and attach to a single structural hoop with hinges that allow the device to fully collapse during net storage.

Figure 8: An adult painted turtle passing through the selective "grid" of the prototype escape device *in situ* in Lake Opinicon, Ontario, Canada. Bars spaced 8 cm apart and diagonally stretched tarred twine serve as a selective barrier.

Figure 9: An adult painted turtle passing through the 22.5 X 10 cm escape hatch of the prototype grid escape device during controlled preliminary trials in Lake Opinicon, Ontario, Canada.

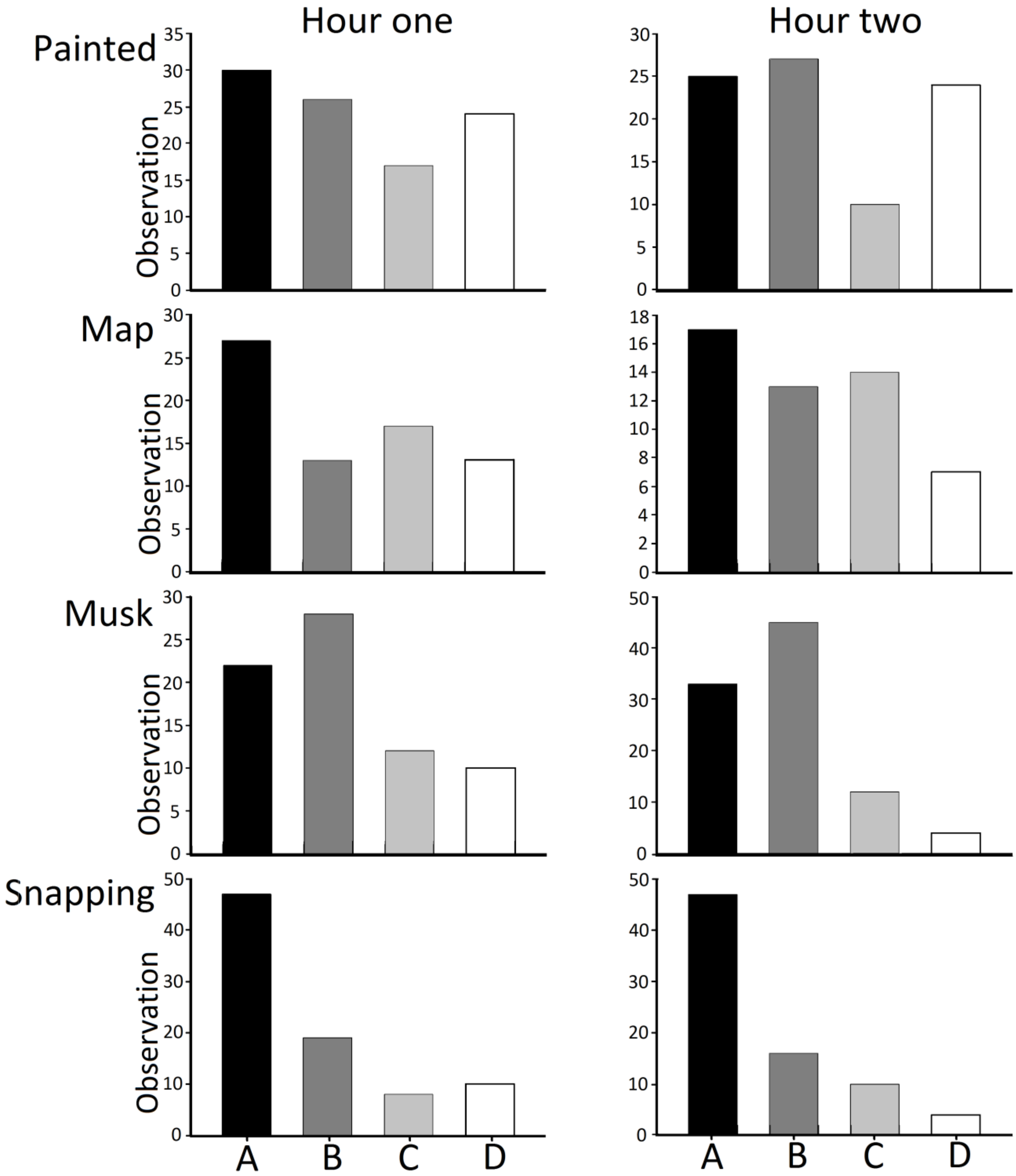

Figure 10: The observed occupancy of painted, map, musk and snapping turtles in the cod-end of a sealed fyke-net over two hour controlled trials. Ten males of each species were collected from Lake Opinicon, Ontario, Canada and tested individually observations were conducted every 5 minutes and position of the individual noted. Trials took place from 18 May to 20 June 2011 at water temperatures ranging from 16.5 to 24.5°C.

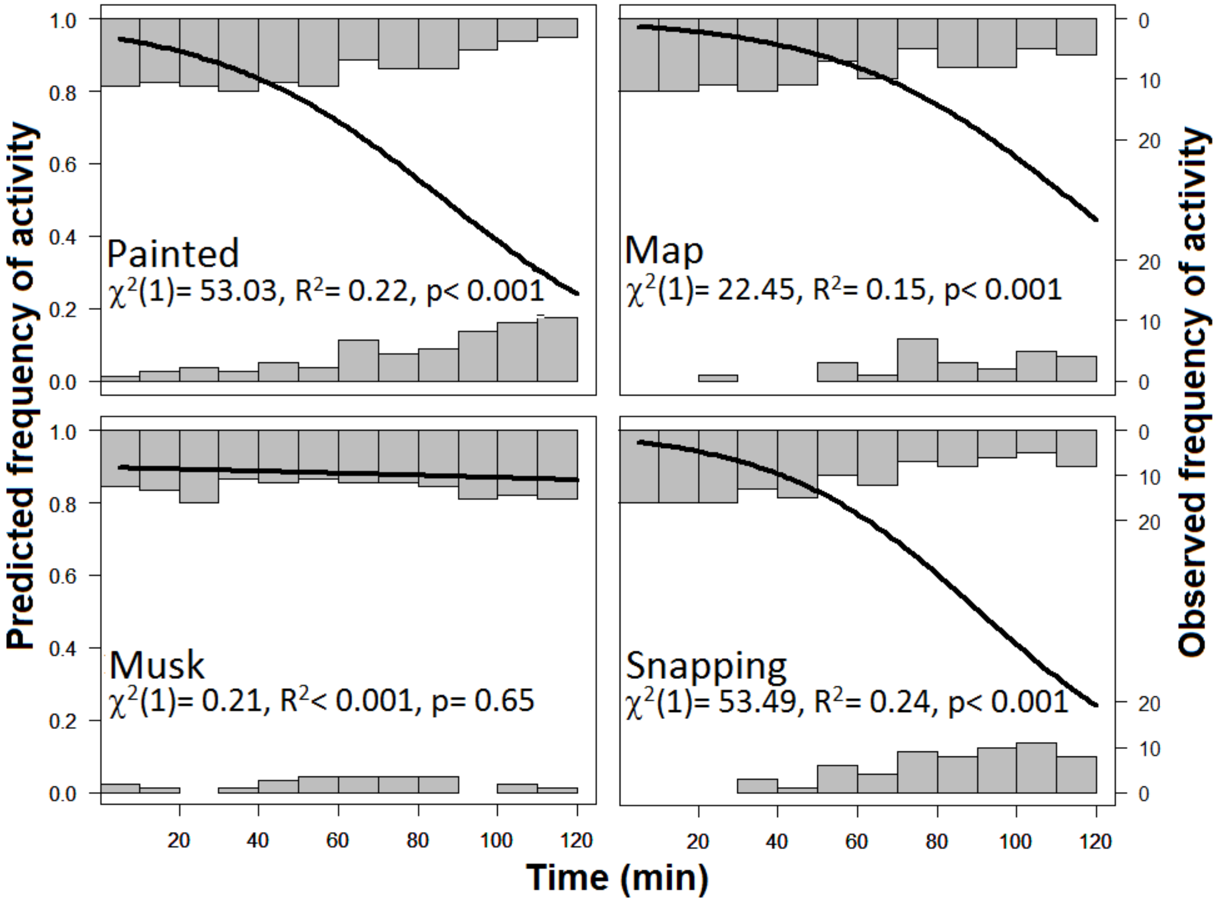

Figure 11: Binary logistic regression, Chi-square, R^2(Cox-Snell),*p*-values and histograms representing the activity of painted, map, musk and snapping turtles over a two hour submergence. Ten males of each species were collected from Lake Opinicon, Ontario, Canada and submerged individually in sealed nets and recorded for 2 hours. Trials took place from 18 May to 20 June 2011 at water temperatures ranging from 16.5 to 24.5°C. Turtles were observed every five minutes for 30 seconds and designated as active (1) or not active (0) based on if the individual was observed moving or not. The observed frequency of activity (1 or 0) is represented by a histogram and typical frequency of activity is predicted and a trend line.

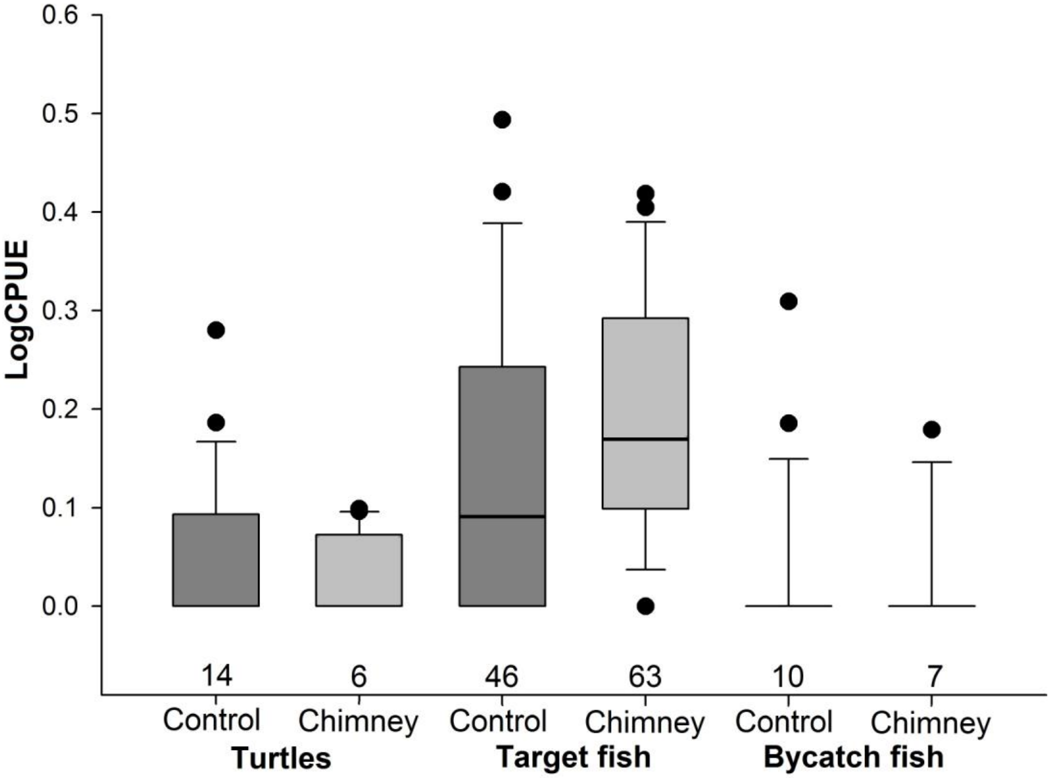

Figure 12: Logarithmically transformed differences between catch per unit effort CPUE for each turtles (3 species), target fish (5 species) and bycatch fish (2 species) collected using unmodified fyke-nets and those modified with an escape chimney BRD. A total 23 nets of each treatment were set in Lake Opinicon, Ontario, Canada from3 to 12 July, 2012 in water temperatures of 23 to 29°C. Boxes represent 25 and 75th percent of the population with whiskers the 5 and 95th percentiles. Data outside of these ranges are represented by dots. Total sample sizes are presented below each category.

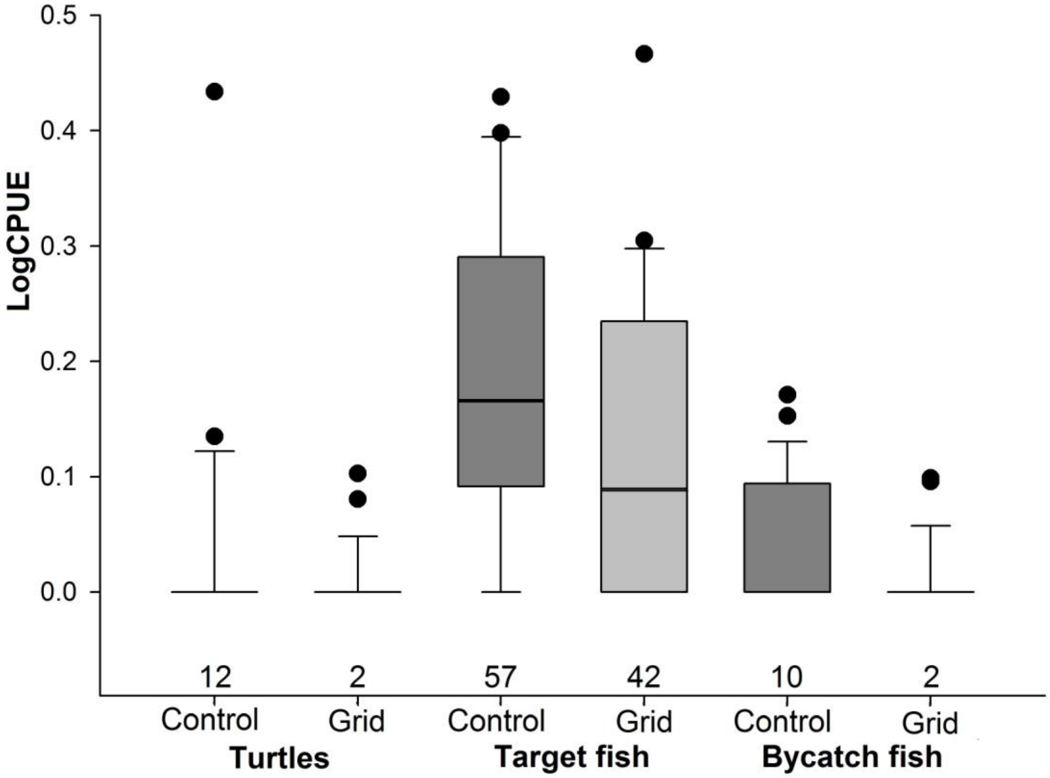

Figure 13: Logarithmically transformed differences between catch per unit effort CPUE for each turtles (4 species), target fish (5 species) and bycatch fish (1 species) collected using unmodified fyke-nets and those modified with an escape grid BRD. A total 23 nets of each treatment were set in Lake Opinicon, Ontario, Canada from3 to 12 July, 2012 in water temperatures of 23 to 29°C. Boxes represent 25 and 75th percent of the population with whiskers the 5 and 95th percentiles. Data outside of these ranges are represented by dots. Total sample sizes are presented below each category.

Chapter 4: General discussion

In this thesis, I have designed two bycatch reduction devices targeted specifically at the eastern Ontario fyke-net fishery. When used in concert, these devices can avoid almost all capture of freshwater turtles while having limited effect on target fish captures. A 5 cm constriction ring was very effective at reducing the capture of larger species of turtles; although it does reduce target fish captures it still produced high landings of target fish. The 5 cm ring does not reduce the rate of capture for smaller turtles and was ineffective at reducing musk turtle captures. The second device I developed was an escape grid with a selective spacing of 8 cm. This device facilitated the escape of smaller turtles while having minimal effect on retention of target fish. If the exclusion and escape BRDs were paired together, the combination should not change user friendliness as fyke-nets sets and retrievals with modified nets were similar to those of unmodified net. The development of these fyke-net modifications specifically for the eastern Ontario panfish fishery is important and will add to the tools available to local managers.

Along with these tools, my work also presents this fishery as a case study for the development of methods to apply to small-scale fisheries in other areas. The behavioural observations I used can be employed to modify simple exclusion and escape BRD templates in other fisheries. My research fills important holes in the methodology of designing BRDs for entrapment gear used in freshwater communities and take into account areas which are often overlooked. Most notable was the use of a complementary suite of devices and the use of quantifiable behavioural traits to overcome the challenges posed by the high target/bycatch overlap generated by highly diverse target and bycatch communities.

Findings and implications

The determination that a single exclusion or escape BRD will not be completely effective at avoiding the capture of all turtle species while maintaining all target landings was a key finding. This is likely to be a general case for BRD development in diverse communities where target and bycatch broadly overlap. The fish species targeted by this fishery are small to medium in size. If snapping turtles were the only bycatch species present, the use of an exclusion device would be all that was necessary. If musk turtles were the only bycatch species present, an escape device would be the most logical option. The turtle community in this fishery, however, is a relatively diverse turtle assemblage ranging in size from musk to snapping turtles: the latter can be as much as 300 times heavier than the former. This led to the design of the escape grid BRD, which is particularly novel in its design and its pairing with a constriction ring.

A particular emphasis was placed on behaviour in this study with observations derived from controlled and *in situ* trials. Quantified behaviour had never previously been used to design a BRD system for freshwater turtles. While conservation biology and policy typically focus on populations, but observations of the individual can provide novel perspective when designing a BRD (Sutherland, 1998; Caro, 2007). Behavioural observations can be used in conjunction with population biology to address complex conservation issues and find solutions (Caro, 1998). Behavioral observations allow researchers to observe how a device works rather than just if a device works, aiding in the differentiation between fatal design flaws and those flaws which can be solved with minor modifications (Grant *et al.*, 2004; Renchen *et al.*, 2012; Favaro *et al.*, 2012).   The ability to quickly ascertain weaknesses in a device based on preliminary results facilitates adaptive modification, allowing the most effective devices to be compared in full-scale field trials. I used this style of development for both controlled and field BRD trials to ascertain the best method of allowing a whole community of turtle species to avoid capture while retaining target fish species.

Controlled trials were integral in refining key BRD characteristics such as spacing. By observing controlled trials, I was able to determine that every species of turtle readily turned on their sides effectively reducing their minimum excludable diameter from their carapace width to their carapace height (Chap. 2). *In situ* observations also proved highly useful in informing variations in catchability between species (Chap. 2), device placement (Chap. 2 and 3), and confirming the results of controlled trials (Chap. 2 and 3).

Future research directions

Although I am confident that the devices I present here are functional and applicable to the fishery as is, further research and field testing would be beneficial for both BRDs presented, but particularly for the escape BRDs. These devices functioned well, but should be tested in the spring during the high activity periods for fish and turtles. This would allow for longer set times and higher capture rates providing a more in-depth investigation into the effects of density on fish retention. Exclusion and escape devices should also be installed on the same net to test their combined effectiveness. Fish capture and retention could likely be improved with behavioural trials conducted on target species. In particular, the use of less conductive materials for BRDs should be investigated in subsequent trials because this may increase fish captures, particularly for bullhead.

I was involved in a study on fishers' perspective that determined the interest and concerns associated with turtle BRPs and BRD implementation (Nguyen *et al.*, In Review). I tried to incorporate their concerns into my designs. I have also met with the fishers that use fyke-nets from the Ontario Commercial Fisheries' Association (OCFA) and the managers with Ontario Ministry of Natural Resources (OMNR) to show the devices I developed and discuss the benefits and potential limitations of each. Although these devices have been presented to the fishers in demonstrations on land, for these devices to gain support they should be made available to the fishers to test and review in the field. This serves two functions; it allows BRD design to be furthered by those with the greatest knowledge of the fishery while also fostering stakeholder participation in the BRP of this fishery. This along with education on the life histories of turtles will hopefully promote acceptance and understanding of the need for turtle conservation locally.

Finally, the methods used in this project should be replicated in a fishery with a different community structure, both turtle and target species, to determine broader applicability. This could represent a different area in the same fishery, or a completely different entrapment fishery. I feel the use of behavioural observations, specifically the use of underwater cameras, have been underutilized in the development of freshwater and marine BRDs.

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