

**Occurrence and mitigation of freshwater turtle bycatch and mortality associated
with inland commercial hoop net fisheries**

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Dedication

I dedicate this piece of work to my parents for believing that I can do anything I set my mind to, no matter how strange. To my grandma, she had the sharpest memory and the kindest heart – I will never forget you. To my best of friends, Meghan, for being there for me no matter how many kilometres lie between us. Thanks to all my closest friends, present and past, for encouraging and challenging me, and putting up with my sarcasm along the way. To everyone in both the Cooke and Blouin-Demers labs that have helped make this experience worthwhile and exciting. To Steve and Gabe, for responding to emails faster than I can write them, for painting my manuscripts red, and for their tolerance for my Godzilla references and paint pictures used in presentations. Finally, I dedicate this thesis to the mysteries of nature, for always fascinating, inspiring me, and giving me the drive to protect them – of which this thesis will hopefully contribute towards.

Abstract

Freshwater turtle bycatch mortality associated with hoop nets used in commercial fisheries is a relatively unstudied conservation issue. I investigated strategies to mitigate turtle bycatch in hoop nets in eastern Ontario. I assessed the frequency of bycatch and found that numerous turtles, including at risk species, were captured. More turtles were captured in spring than in fall. I subsequently tested gear modifications to exclude turtles from entering hoop nets, allow turtles to escape, or keep turtles alive while trapped in nets. Exclusion devices reduced turtle captures with no effect on fish captures. An escape device allowed all painted turtles (*Chrysemys picta*) to escape with few fish escapes. Creating air spaces in nets reduced anoxia and thus potential drowning in turtles. All mitigation strategies reduced turtle bycatch mortality by varying degrees. This body of work increases our understanding of freshwater turtle bycatch and I provide conservation and management recommendations to mitigate such bycatch.

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Co-authorship

Chapter 2: Seasonal patterns in bycatch composition and mortality associated with a freshwater hoop net fishery. S. M. Larocque, A. H. Colotelo, S. J. Cooke, G. Blouin-Demers, T. Haxton, and K. E. Smokorowski.

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 Larocque, Colotelo, Cooke, and Blouin-Demers. Field work was conducted by Larocque and Colotelo. All writing and analysis was conducted by Larocque. All co-authors provided comments and feedback on the manuscript. This manuscript has been accepted in *Animal Conservation*.

Chapter 3: Mitigating bycatch of freshwater turtles in passively-fished hoop nets through the use of exclusion and escape modifications. S. M. Larocque, S. J. Cooke, and G. Blouin-Demers.

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Chapter 4: A breath of fresh air: avoiding anoxia and mortality of freshwater turtles in hoop nets via the use of floats. S. M. Larocque, S. J. Cooke, and G. Blouin-Demers.

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Chapter 1: General Introduction

One of the most important concerns and pressing conservation issue in fisheries today is bycatch: the incidental capture of non-targeted organisms in commercial fisheries (Alverson *et al.*, 1994; Hall and Mainprize, 2005; Harrington *et al.*, 2005; Kelleher, 2005). The rate of bycatch and associated mortality needs to be at sustainable levels, similar to targeted organisms (Hall *et al.*, 2000). For example, the unsustainable rate of capture and drowning of marine turtles in fishing gear is in part responsible for their population declines (Hall *et al.*, 2000; Lewison *et al.*, 2004; Lewison and Crowder, 2007). Among the numerous threats to turtles, bycatch and associated mortality, even at low levels, can have profound negative impacts on turtle populations and is a major conservation issue (Congdon *et al.* 1993; 1994; Hall *et al.*, 2000; Lewison *et al.*, 2004; Hall and Mainprize, 2005; Lewison and Crowder, 2007). Like marine turtles, freshwater turtles are also susceptible to capture and drowning in fishing gear, such as hoop nets (Beumer *et al.*, 1981; Barko *et al.*, 2004; Michaletz and Sullivan, 2002; Lowry *et al.*, 2005). Interestingly, however, inland commercial bycatch issues are relatively understudied in comparison to marine systems (Soykan *et al.*, 2008; Raby *et al.*, 2011). In eastern Ontario, an inland commercial fishery specializes in hoop nets and there has been anecdotal evidence of turtle bycatch mortality (Carrière, 2007). This turtle bycatch mortality is of particular concern since seven of the eight species of turtles in Ontario are considered at risk at the national level (COSEWIC, 2010). Thus, there is a risk to freshwater turtles that encounter hoop nets, both within the Ontario hoop net fishery and around the globe, which needs to be addressed.

Aside from the documentation of freshwater turtle mortality seen in hoop nets (e.g., Michaletz and Sullivan; 2002; Barko *et al.*, 2004; Carrière, 2007), few studies have tackled the conservation issue of freshwater turtle bycatch (Raby *et al.*, 2011). As such, methods to mitigate turtle bycatch mortality are novel in lentic environments. Currently, there is little understanding of the frequency with which bycatch, and potential turtle mortality, occurs over the fishing season for the eastern Ontario fishery. Investigating such patterns would discern both the extent of turtle bycatch and the potential efficacy of seasonal fishing restrictions in reducing bycatch. Other than seasonal closures, gear modifications have also been used to mitigate bycatch (Alverson *et al.*, 1994; Broadhurst, 2000; Hall and Mainprize, 2005). Bycatch reduction devices (BRDs) are designed to either prevent entry of bycatch in the nets or enable the escape of bycatch from the nets which could be effectively designed and applied to hoop nets (Broadhurst, 2000; Grant *et al.*, 2004). Alternatively, modifying nets to enable turtle bycatch to survive capture events is another mitigation method to be investigated.

Research Objectives

The overall objective of my thesis is to determine ways to mitigate freshwater turtle bycatch mortality associated with hoop nets, specifically with inland commercial fisheries in eastern Ontario, Canada. In chapter two, I investigate the occurrence and frequency of bycatch (both fish and turtles) and associated mortality occurring in the eastern Ontario fishery. This study took place during the two main fishing seasons, spring and fall, to also determine whether bycatch can be avoided with seasonal fishing. In chapters three and four, I look more specifically at modifying hoop nets to mitigate turtle bycatch. In chapter three, I investigate the use of various BRDs that I designed for hoop

nets which either aim at excluding turtles from entering hoop nets or at allowing turtles to escape, all while retaining fish catches. By experimentally testing the BRDs in controlled experiments and while emulating commercial fishing practices, I determine the effectiveness at reducing turtle bycatch. In chapter four, I explore whether turtle bycatch can survive being captured in hoop nets if an area for breathing air is created. Using a conservation physiology approach, I discern whether the hoop net modification for an air space effectively mitigated turtle mortality. Lastly, in chapter five I integrate the findings of the previous three chapters and present conservation implications, potential management recommendations, and future research directions. In the Appendix I briefly summarize a project in which I investigated whether the presence of deceased fish increases the frequency of turtle bycatch occurring in hoop nets.

Chapter 2: Seasonal patterns in bycatch composition and mortality associated with a freshwater hoop net fishery

Abstract

Although bycatch is well-known and well-studied in marine fisheries, comparatively little is known about bycatch in freshwater fisheries. Even basic information on bycatch composition and mortality in freshwater is unavailable given that few inland jurisdictions require reporting of bycatch. A small-scale inland hoop net fishery that targets pan fish (e.g., sunfish, *Lepomis* spp.) and operates primarily in the spring and fall was simulated in two lakes in southeastern Ontario to characterize both bycatch composition and mortality. We fished one lake in both spring and fall to compare catch rates, while in the other lake we set nets for two or six days during the spring to assess fish mortality associated with different net tending frequencies. In both lakes, bycatch consisted of gamefish, turtles (including several species at risk), and mammals. For fish, there was no difference in spring and fall catches. Turtles, however, were captured more often in spring. Fish mortality of both target and non-target species increased from 0.3-0.9% to 3.0-3.7% (4-10 times) when set net duration increased from 2 days to 6 days, yet surprisingly water temperature had no significant effect on mortality. Despite the provision of an air breathing space in our nets, we documented severe turtle mortality (33% in one lake) and all mammals died suggesting that provision of air spaces is not always effective. Although all bycatch mortality is a concern, turtles are prone to population declines even with low levels of non-natural mortality. As such, regulators may consider limiting commercial fishing to the fall in this region to reduce turtle

captures. Seasonal restrictions on fishing or use of frequent net tending (e.g., < 2 days) will not prevent all turtle bycatch and therefore gear modifications should be investigated to further reduce turtle captures and mortality associated with hoop nets.

Introduction

Bycatch, the incidental capture of non-targeted organisms in commercial fisheries, is a growing concern and an important conservation issue (Alverson *et al.*, 1994; Hall and Mainprize, 2005; Harrington *et al.*, 2005; Kelleher, 2005). Fisheries are now not only concerned with the sustainability of targeted organisms, but also beginning to consider whether catches of non-targeted fauna are at sustainable levels (Hall *et al.*, 2000). Reflecting this concern, the number of studies examining bycatch issues has increased exponentially in recent decades (Soykan *et al.*, 2008). These studies, however, focus primarily on marine systems, leaving freshwater bycatch issues relatively unstudied (Raby *et al.*, 2011). This is disconcerting given that biodiversity in highly diverse freshwater ecosystems is declining, with overexploitation identified as one of the leading causes (Dudgeon *et al.*, 2006). As bycatch has contributed to the degradation of marine ecosystems (Crowder and Murawski, 1998; Hall *et al.*, 2000; Lewison *et al.*, 2004), bycatch likely has had similar impacts on freshwater ecosystems. Therefore, there is a need to determine the extent and consequences of bycatch in freshwater commercial fisheries.

In freshwater commercial fisheries, hoop or fyke nets are commonly used. In southeastern Ontario, a commercial hoop net fishery operates on several lakes and large river systems. This fishery targets a variety of species such as sunfish (*Lepomis* spp.), bullheads (*Ameiurus* spp.), yellow perch (*Perca flavescens*), rock bass (*Ambloplites*

rupestris), and black crappie (*Pomoxis nigromaculatus*; Burns, 2007). Hoop nets are passive fishing gear that have limited species selectivity and are set for long durations (Hubert, 1996). Thus, hoop nets have the potential to capture non-targeted fauna that use the same habitat as targeted species, even without the use of bait. For example, turtles have been captured in this Ontario fishery, including species at risk (Carrière, 2007), and turtle captures in other hoop net fisheries have also been documented globally (Beumer *et al.*, 1981; Barko *et al.*, 2004; Lowry *et al.*, 2005). Currently, however, Ontario commercial fishers have no requirement to report bycatch, similar to most small-scale fisheries in the world. Thus, the magnitude and composition of bycatch is unknown in this Ontario hoop net fishery. Overall, we have a poor understanding of freshwater bycatch globally.

The southeastern Ontario hoop net fishery is not open year-round, and catch rates may vary by fishing season. Currently, the local regulatory body (Ontario Ministry of Natural Resources) has commercial fishing restrictions during mid-summer, and fishing during ice-over is unlikely, thereby leaving spring and fall as the prominent fishing seasons. Reproductive behaviours may change the frequency and composition of fish captures and turtle bycatch within hoop nets in spring and fall. During the breeding period, typically late spring to mid-summer, temperate warm-water fish can exhibit increased activity in courtship, territoriality, and/or parental care (Scott and Crossman, 1973; Barton, 1996). Mate searching and courtship also increase freshwater turtle activity during spring and fall mating seasons, although less so in fall (Gibbons, 1968; Ernst *et al.*, 1994). Increased movements associated with reproductive behaviours could increase the potential to encounter nets and be captured.

It is the mortality of bycatch, not just the extent of bycatch that is of primary concern for commercial fisheries management (Alverson *et al.*, 1994; Crowder and Murawski, 1998). In the southeastern Ontario hoop net fishery, there is a regulation regarding the duration of net sets: nets can be deployed for up to 7 days between lifts. Although hoop nets generally cause little to no injury to fish (Hubert, 1996), air-breathing fauna captured as bycatch are prone to mortality by drowning. Even fish may experience higher levels of mortality with longer net sets due to stress and injury associated with long-term retention (Davis, 2002). Therefore, it would aid fisheries management to know the mortality associated with leaving gear deployed for different time periods.

Our objectives were (1) to document the frequency and composition of bycatch within two shallow warm-water lakes typical of the commercial hoop net fishery in Ontario, (2) to compare bycatch between spring and fall, and (3) to determine the extent of fish mortality associated with hoop nets set for two durations. We expected that target and bycatch species would be captured more in spring due to increased activity levels. We also expected longer net sets to result in higher mortality due to additional stress and injury from net confinement.

Methods

Study Area

Our fishing occurred in two shallow warm-water lakes: Newboro Lake (44°38' N, 76°20' W), an 1846 ha lake with a mean depth of 3 m, and Lake Opinicon (44°34' N, 76°19' W), a 788 ha lake with a mean depth of 2.8 m. Both lakes are commercially fished and are ca. 100 km south of Ottawa, Ontario, Canada. Water temperatures varied within

and among sampling seasons/lakes (Newboro Lake: spring, 4.3 – 24.9 °C; Lake Opinicon: spring, 12.7 – 25.9 °C, fall, 13.6 – 20 °C).

Nets, deployment procedures, and data collection

After consultations in fall 2008, we used fishing practices employed by local commercial fishers. Newboro Lake sampling was conducted with hoop nets used by local commercial fishers, consisting of eight 0.8 m diameter wooden hoops positioned 0.5 m apart. There were three throats per net, on the first, third, and fifth hoop of the net. Each net had two wings (2.9 m long and 0.8 m high) and a lead (11 m long and 0.8 m high) attached to the front hoop. We sampled Lake Opinicon using similar nets that contained seven 0.9 m diameter steel hoops positioned 0.5 m apart. There were two throats per net, located at the second and fourth hoops. Each net had two wings (4.5 m long and 0.9 m high) and a lead (10.7 m long and 0.9 m high) attached to the front hoop. All nets, wings, and leads were constructed with 5.08 cm stretch nylon mesh. To emulate the commercial fishery, all nets were set in tandem by adjoining two hoop nets by their leads with the net openings facing each other and extending the wings to a forty-five degree angle from the entrance of the net (Figure 2-1).

Newboro Lake fishing occurred in spring of 2009, while Lake Opinicon fishing was during spring and fall of 2010. In spring, fishing began after “ice-off” (early April) and continued until the end of the legal fishing season (June 20). In fall, fishing began just after the beginning of the legal fishing season (i.e., first Monday of September) and ended on October 2. In both lakes, we set nets in vegetated shallows (1-1.75 m depth), and recorded water temperature when setting and lifting. In the commercial fishery, hoop nets are completely submerged. In Newboro Lake, however, we placed plastic jugs in the

end of each net to create airspaces for air-breathing fauna. In Lake Opinicon we fished using nets with and without airspaces, and net set durations varied (8-48 hours) according to water temperature to prevent mortality of turtles, specifically species at risk. Set durations decreased with warmer water and were based on reduced anoxia tolerance and survival durations found by Herbert and Jackson (1985). To determine the extent of fish mortality in hoop nets of different set durations, we set nets in Newboro Lake for either two or six days. For both durations, nets were set for two days allowing animals to enter, and either lifted (two-day set) or were closed off by tying a wing in front of the net entrance to prohibit the entrance of any other organisms and left for four more days (six-day set). All non-fish bycatch were removed from the nets prior to closing the net off for the six-day set. This allowed for a comparison of fish caught and retained in the nets for 0-2 days and 4-6 days. In all cases, after the set period we lifted the tandem net and all organisms were identified to species and tallied. Any mortality was recorded.

Data Analysis

As fishing occurred in Newboro Lake and Lake Opinicon during different years and with different nets we only documented catches in these lakes. However we compared seasonal differences (spring and fall) for Lake Opinicon. Due to the low frequency of captures ($N = 6$), mammals were excluded from non-fish bycatch analyses, leaving only turtles. To compare spring and fall catches in Lake Opinicon, we calculated catch per unit effort (CPUE – catch/hr) to standardize for set duration, under the assumption that CPUE would be similar in relation to set durations with net sets <48 hours as found by Breen and Ruetz (2006). We calculated CPUE for each tandem net by taking the total catch from both nets and dividing by the summed net set duration. Nets

were removed from the calculation if one of the nets in a tandem did not fish properly (e.g., holes in the net). We calculated CPUE for target fish, fish bycatch, turtle catches, and each species.

We compared spring and fall catch rates for target fish, fish bycatch, and turtle catches. We log transformed target fish CPUE to meet the assumptions of normality and homogeneity of variance and used an independent t-test. Both fish bycatch CPUE and turtle CPUE were non-normal and therefore a Wilcoxon rank-sum test was used. These tests were performed in SPSS 18.0.0 (IBM Inc.; www.spss.com).

We compared species composition of target fish, fish bycatch, and turtles between spring and fall fishing in Lake Opinicon using species CPUE values in a multi-response permutated procedure (MRPP) and indicator species analysis (ISA; PC-ORD 5.20: McCune and Mefford, 2006). ISA is a post-hoc test for MRPP, and was used when species composition differed significantly. Thus, using MRPP and ISA, we could determine whether the capture rates of individual species differed in spring and fall. For fish bycatch and turtles, we only included trials (net sets) that contained fish bycatch or turtles, respectively, to look at compositional differences that were unaffected by seasonal presence/absence differences of the respective groups (fish bycatch: spring N = 37; fall N = 39; turtles: spring N = 36; fall N = 20). For target fish we used all samples (N = 45 per season).

To control for variations in total catch, proportion mortality for target fish and fish bycatch for two- or six-day net sets in Newboro Lake were calculated, averaging each net in the tandem. If one of the nets in a tandem did not fish properly (i.e., holes, net collapsed), it was removed from the calculations. Proportion mortality for both target fish

and fish bycatch violated the assumptions of normality and homogeneity of variance. Thus, to deal with these violations and control for changes in water temperature, we performed a non-parametric Rank Transformed Analysis of Covariance (RT ANCOVA; Conover and Iman, 1982) in SPSS 18.0.0. For all statistical tests, significance was accepted at $\alpha = 0.05$. All means are reported $\pm 1SE$.

Results

Catch quantity and composition

In Newboro Lake we set 56 tandem nets (29 two-day sets with 2463 total fishing hours; 27 six-day sets with 2024 total fishing hours) and captured 7702 fish of ten species (Table 2-1). In Lake Opinicon we set 45 tandem nets per season (with 1780 and 1626 total fishing hours in spring and fall, respectively) and captured 5452 fish of eight species in spring, and 4242 fish of seven species in fall (Table 2-1). Bluegill (*Lepomis macrochirus*) and pumpkinseed (*Lepomis gibbosus*) were caught the most (>65% of entire catch, a primary target of the fishers), and largemouth bass (*Micropterus salmoides*) and northern pike (*Esox lucius*) were the most common bycatch fish (>97%; Table 2-1). Fish made up 94.7% of all bycatch in Newboro Lake, while in Lake Opinicon fish composed 70.4% and 79.3% of bycatch in spring and fall, respectively. In Newboro Lake, we captured 58 non-fish organisms as bycatch (2 mammal species; 3 turtle species) of which most (93.1%) were turtles (Table 2-1). Similarly, in Lake Opinicon we captured 118 non-fish organisms as bycatch (1 mammal species; 4 turtle species) consisting of 98.3% turtles in spring and 100% of the 66 non-fish bycatch were turtles in fall (3 species; Table 2-1). All captured turtles were adults, except for three female eastern musk turtles (*Sternotherus odoratus*), and four female and two male northern map turtles

(*Graptemys geographica*) that were at or just under size of maturity, according to secondary sexual characteristics and the reported plastron length at maturity in Ernst *et al.* (1994). Painted turtles (*Chrysemys picta*) and snapping turtles (*Chelydra serpentina*) composed 98.0% of Newboro Lake turtle catches, while in Lake Opinicon we mostly caught painted turtles and eastern musk turtles (>85%) in both spring and fall (Table 2-1). Of the air-breathing organisms captured, all six mammals died, and 33% of 54 turtles captured in Newboro Lake perished also. No turtle mortalities occurred in Lake Opinicon.

Spring/fall comparison

Total spring and fall captures for target fish were similar (Table 2-1). Mean target fish capture rates in spring (3.29 ± 0.33 fish/hour) were not significantly different from mean capture rates in fall (2.61 ± 0.27 fish/hour; $t_{88} = 1.612$; $P = 0.111$; Figure 2-2). Target fish composition varied between spring and fall ($A = 0.023$; $P = 0.003$): we captured more pumpkinseed and rock bass in spring (Table 2-2).

Total fish bycatch captures were similar in spring and fall (Table 2-1). Mean fish bycatch rates were also similar between spring (0.19 ± 0.03 fish/hour) and fall (0.12 ± 0.02 fish/hour; $W_s = 1831.00$; $Z = 1.750$; $P = 0.080$; Figure 2-2). Fish bycatch composition differed significantly between spring and fall ($A = 0.049$; $P < 0.001$): northern pike and smallmouth bass (*Micropterus dolomieu*) were captured more in spring (Table 2-2).

Total turtle captures in spring were nearly double the captures in fall (Table 2-1). Mean turtle catch rates in spring (0.12 ± 0.03 turtles/hour) were significantly higher than mean turtle catch rates in fall (0.04 ± 0.01 ; $W_s = 1657.50$; $Z = 3.236$; $P = 0.001$; Figure 2-

2). Turtle species composition also differed between seasons ($A = 0.026$; $P = 0.016$): northern map turtles were more frequently captured in spring (Table 2-2).

Net set duration mortality

Bluegill, pumpkinseed, and northern pike represented most of the mortalities for both two-day and six-day nets (Table 2-3). The proportion of target fish dead in nets after two days (0.003 ± 0.002) was significantly less than after six days (0.030 ± 0.017 ; $F_{1,52} = 6.327$; $P = 0.015$; Figure 2-3a). Temperature had no effect on the proportion of dead target fish ($F_{1,52} = 0.362$; $P = 0.550$; Figure 2-3a). The proportion of bycatch fish dead in two-day net sets (0.009 ± 0.006) was significantly less than in six-day net sets (0.037 ± 0.015 ; $F_{1,52} = 4.994$; $P = 0.030$) and temperature had no effect on the proportion of dead bycatch fish ($F_{1,52} = 0.022$; $P = 0.882$; Figure 2-3b).

Discussion

Overall, catches mostly consisted of target fish (>85%), but there was still considerable bycatch. Bycatch consisted of fish (i.e., gamefish), turtles, and mammals. Fish were the most frequently captured bycatch, yet turtle catches were relatively high in both lakes. The majority of the turtles captured were adults, which is typical of hoop nets (Ream and Ream, 1966). According to COSEWIC (Committee on the Status of Endangered Wildlife in Canada; 2010), eastern musk turtles are threatened while northern map turtles and snapping turtles are listed as special concern. Therefore, 48.2%, 58.6%, and 66.6% of individual turtles captured in Newboro Lake, Lake Opinicon in spring, and Lake Opinicon in fall, respectively, are considered at risk – a disconcerting result along with the sheer numbers captured.

We provided breathing spaces in most of our nets to prevent mortality of turtles and mammals; however, nets fished in Newboro Lake still caused mortality. The airspaces provided may have been too small for air-breathing organisms to use as the shorter net set durations in Lake Opinicon did not result in turtle mortality. Bury (2011) reported that nets with airspaces yielded little turtle mortality, but based on our findings there may need to be a minimum size of air space for them to be effective. Thus, ensuring that nets adequately breach the surface could reduce the mortality we observed.

There were no differences in fish catch rates (both target and fish bycatch) in spring and fall although the species composition varied. Our findings were consistent with a review by Pope and Willis (1996) that found that fish catch rates generally peak in spring and fall in temperate regions. Similar catch rates for spring and fall may be a consequence of heightened fish activity in both the spring as waters warm and in the fall as fish move to overwintering areas (Pope and Willis, 1996). As for catch composition, northern pike, pumpkinseed, rock bass, and smallmouth bass were more prominent in spring than in fall. Keast (1968) found that both pumpkinseed and rock bass abstain from eating during cooler temperatures. Northern pike activity is also lowest in the fall (Cook and Bergerson, 1988). It is possible that these species reduced foraging activities and mobility as temperature dropped in fall, thus contributing to the lower catch rates as these fishes prepared for winter.

Turtles were captured more in spring than in fall. Based on land movement studies, it is assumed that turtles are most mobile in water during spring due to reproductive behaviours (Gibbons *et al.*, 1990), increasing net encounter rates and therefore catch rates. Gibbons (1968) found painted turtle captures declined in the fall,

when compared to similar temperatures in spring, and attributed higher spring catches to reproductive behaviours. However, Gibbons (1968) had similar numbers captured during spring and summer, suggesting that reproductive behaviour may not be the sole reason for higher activity in spring. In fall, temperate freshwater turtles in large water bodies retreat to the bottom to over-winter (Gibbons *et al.*, 1990). Obbard and Brooks (1981) found snapping turtles are mostly inactive and buried in mud by mid-September, even though water temperatures were relatively high. Similarly, northern map turtles start aggregating at hibernacula in August and September (Flaherty, 1982; Pluto and Bellis, 1988). Unless nets were set at hibernacula, northern map turtles may not be encountered in the fall, coinciding with our findings. Thus, the fall reduction in catches may be from turtles preparing for hibernation and therefore encountering nets less frequently, particularly if they have already moved to their overwintering sites.

Fish mortality was higher with longer net set durations, suggesting that stress and related injuries in fish elevate over time to a lethal level, a finding consistent with marine bycatch research (Davis, 2002). Although the proportion of mortality for gamefish and target fish was low (<0.04), the stress involved with capture and retention could have long-term effects on fitness related to immune function or energy allocation, or induce delayed mortality after release (Portz *et al.*, 2006). Mortality levels may also be higher in commercial fisheries with longer net sets as the six-day treatment was only fished for two days. The increased fish densities from longer sets could increase stress levels and thereby mortality (Portz *et al.*, 2006). Northern pike were more prone to mortality than other species by having the highest percent mortality that was attributed to more than a single mortality event. Northern pike's susceptibility to mortality could be partially

attributed to their small head girth allowing them to get tangled and gilled (Hamley, 1975). Mortality in hoop nets can also arise from stress and injury associated with abrasion, confinement, starvation, interaction with other individuals, including other taxa, as well as environmental parameters such as variability in dissolved oxygen (DO; Portz *et al.*, 2006). We observed mortalities that were attributable to both being gilled (fish were found gilled) and other causes (fish were dead in the net).

Interestingly, there was no water temperature effect on mortality. In recreational fisheries, water temperature is one of the primary factors influencing the outcome of a catch-and-release fishing event, with stress and mortality levels generally positively correlated with water temperature (Cooke and Suski, 2005). Water temperature is also linked to DO levels: DO typically decreases as temperature increases. However, the constant mixing in the lake from wind/wave action may have kept DO levels high throughout the study and not affect mortality. Temperature was not associated with mortality within hoop nets in this study, although the low levels of mortality may have made this effect difficult to detect.

Management implications

Bycatch of gamefish and turtles should be of concern to regulatory agencies. Immediate or delayed mortality of non-target fish is not accounted for in current management regimes where bycatch is not reported and fishers' quotas are based on mass of target species harvested. Given that northern pike and largemouth bass represent important gamefish species, it is necessary to quantify bycatch mortality to ensure that fishery management activities consider both commercial and recreational fishing mortality (Coggins *et al.*, 2007). Also of importance is the capture of adult turtles. Turtles

are slow maturing, long-lived organisms and even slight additional adult mortality makes them vulnerable to population declines (Brooks *et al.*, 1991; Congdon *et al.*, 1993; 1994). Commercial nets are set completely submerged to minimize attention, vandalism, and theft, and because some commercial fishers believe that submerged nets increase catch rates of target fish. Therefore, adult turtle mortality is highly likely to occur in the fishery. A caveat to consider is that the extent of turtle (and mammal) mortality would depend on fishing effort, the duration of the net sets, and the extent to which turtles (and mammals) can access air and not become exhausted or lethally injured. The negative impact of hoop nets on turtle populations has been suggested for other fisheries (Michaletz and Sullivan, 2002; Barko *et al.*, 2004). Thus, there is a risk of capturing, killing, and causing local population declines of freshwater turtles with hoop nets.

One way to mitigate turtle bycatch mortality can be with temporal restrictions, such as having seasonal closures (Lewison *et al.*, 2003; 2004). For example, emphasizing fishing in fall does not appear to affect fish catches, yet reduces turtle captures. Another temporal restriction to reduce bycatch could be altering net set durations. Painted turtles can remain submerged for approximately three days at 15 °C, but this duration exponentially decreases as temperatures increase (Herbert and Jackson, 1985), and other freshwater turtles are less capable to withstand similar submergences (Ultsch, 1985). Reduced net sets would improve bycatch survival, but it is impractical to check nets frequently (every 24 hours or less) to release captured turtles and mammal mortality would still occur. A combination of emphasized fishing in the fall with shorter net sets at warmer temperatures is likely to be the best in reducing turtle bycatch using temporal restrictions.

The use of hoop nets extends beyond this specific Ontario commercial fishery. The death of adult turtles can quickly cause population declines and therefore there is a need to determine and implement ways to reduce freshwater turtle bycatch mortality beyond temporal restrictions. Such methods can include modifications to fishing gear (Lewison *et al.*, 2004). Previous studies on hoop net modifications in other systems and fisheries (e.g., Lowry *et al.*, 2005; Fratto *et al.*, 2008a, 2008b) could give insight for candidate modifications in our study system. In conclusion, we have documented bycatch in hoop net fisheries and associated conservation issues with freshwater turtles. Efforts should now focus on reducing turtle mortality associated with hoop nets, whether in fisheries or for research, to aid turtle populations.

Tables

Table 2-1. Number and composition of hoop net catches from two lakes in southeastern Ontario, Canada. There were 56 net sets in Newboro Lake and 45 net sets per season in Lake Opinicon.

Target fish species	Newboro		Opinicon - Spring		Opinicon - Fall	
	Number caught	Overall percentage	Number caught	Overall percentage	Number caught	Overall percentage
Bluegill	3546	45.70%	3108	53.13%	2915	64.45%
Pumpkinseed	1737	22.38%	1889	32.29%	1054	23.30%
Bullhead spp.	1182	15.23%	189	3.23%	211	4.67%
Black crappie	100	1.29%	75	1.28%	29	0.64%
Rock bass	51	0.66%	189	3.23%	27	0.60%
Yellow perch	39	0.50%	2	0.03%	6	0.13%
White sucker	7	0.09%	0	0%	0	0%
Redhorse spp.	2	0.03%	0	0%	0	0%
Common carp	1	0.01%	0	0%	0	0%
Total	6665	85.89%	5452	93.20%	4242	93.79%
Fish bycatch species						
Largemouth bass	835	10.76%	230	3.93%	198	4.38%
Northern pike	202	2.60%	42	0.72%	17	0.38%
Smallmouth bass	0	0%	8	0.14%	0	0%
Total	1037	13.36%	280	4.79%	215	4.75%

Non-fish species

Painted turtle	28	0.36%	48	0.82%	22	0.49%
Snapping turtle	25	0.32%	3	0.05%	1	0.02%
Northern map turtle	1	0.01%	13	0.22%	0	0%
Eastern musk turtle	0	0%	52	0.89%	43	0.95%
Beaver	3	0.04%	0	0%	0	0%
Muskrat	1	0.01%	2	0.03%	0	0%
Total	58	0.75%	118	2.02%	66	1.46%
Grand total	7760	100%	5850	100%	4523	100%

Table 2-2. Indicator species analysis results comparing spring and fall catch rates (per hour) of freshwater fish (target and bycatch) and turtles in Lake Opinicon, Ontario, Canada. Group indicates the season in which the species had the highest indicator value, while indicator values represent the percent of a perfect indication for a given season. * indicates catch rates of species that differed significantly between spring and fall (P<0.05).

Groups compared	Species	Group	Indicator value	P
Target fish	Bluegill	Fall	50.2	0.9726
	Pumpkinseed	Spring	65.9	0.0002*
	Black crappie	Spring	27.2	0.3813
	Rock bass	Spring	39.2	0.0244*
	Yellow perch	Fall	9.5	0.1892
	Bullhead spp.	Fall	44.9	0.0748
Fish bycatch	Largemouth bass	Spring	56.8	0.1696
	Northern pike	Spring	44.6	0.0070*
	Smallmouth bass	Spring	13.5	0.0224*
Turtles	Painted	Spring	41.2	0.2607
	Northern map	Spring	27.8	0.0210*
	Snapping	Spring	4.2	0.7698
	Eastern musk	Spring	38.3	0.7786

Table 2-3. Sum and overall percentage of fish deaths relative to total catch that occurred in two- and six-day hoop net sets from Newboro Lake, Ontario, Canada.

Species	Two-day net set		Six-day net set	
	Deaths	Percent mortality	Deaths	Percent mortality
Bluegill	6	0.28%	39	2.71%
Northern pike	3	2.68%	14	15.56%
Pumpkinseed	2	0.19%	19	2.74%
Bullhead spp.	1	0.14%	1	0.20%
White sucker	1	20.00%	1	50.00%
Rock bass	1	3.45%	1	4.55%
Yellow perch	0	0%	3	11.11%
Largemouth bass	0	0%	2	0.57%
Black crappie	0	0%	0	0%
Redhorse spp.	0	0%		
Common carp			0	0%
Total	14	0.31%	80	2.54%

Figures

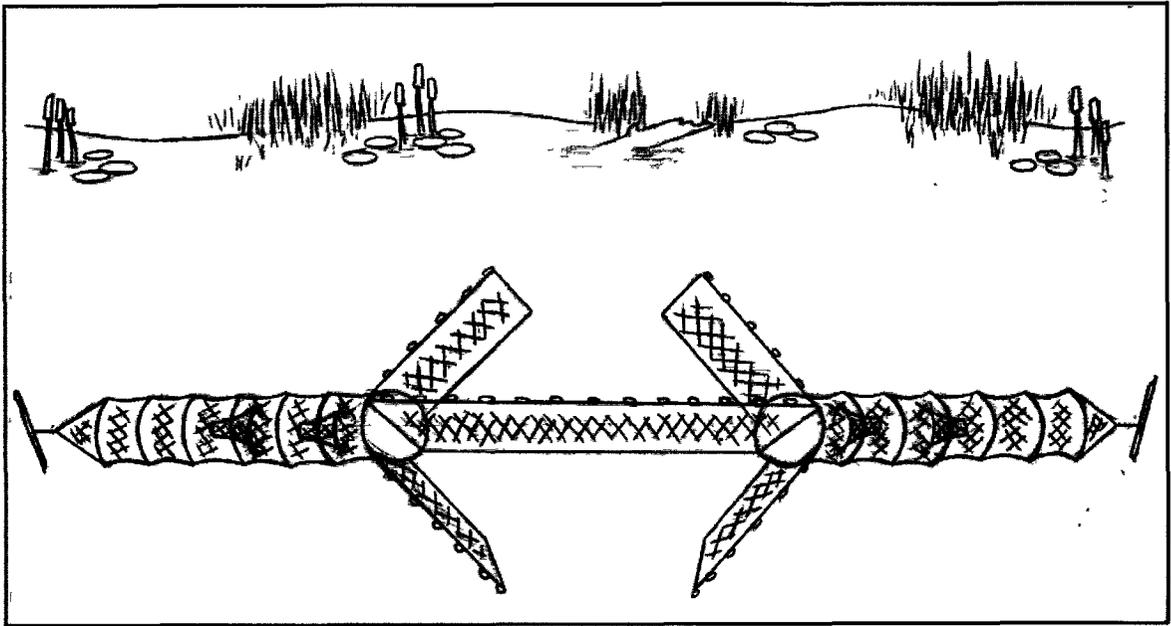


Figure 2-1. Illustration of a bird's eye view of tandem commercial hoop nets connected by a lead with two wings attached per net, set parallel to shore.

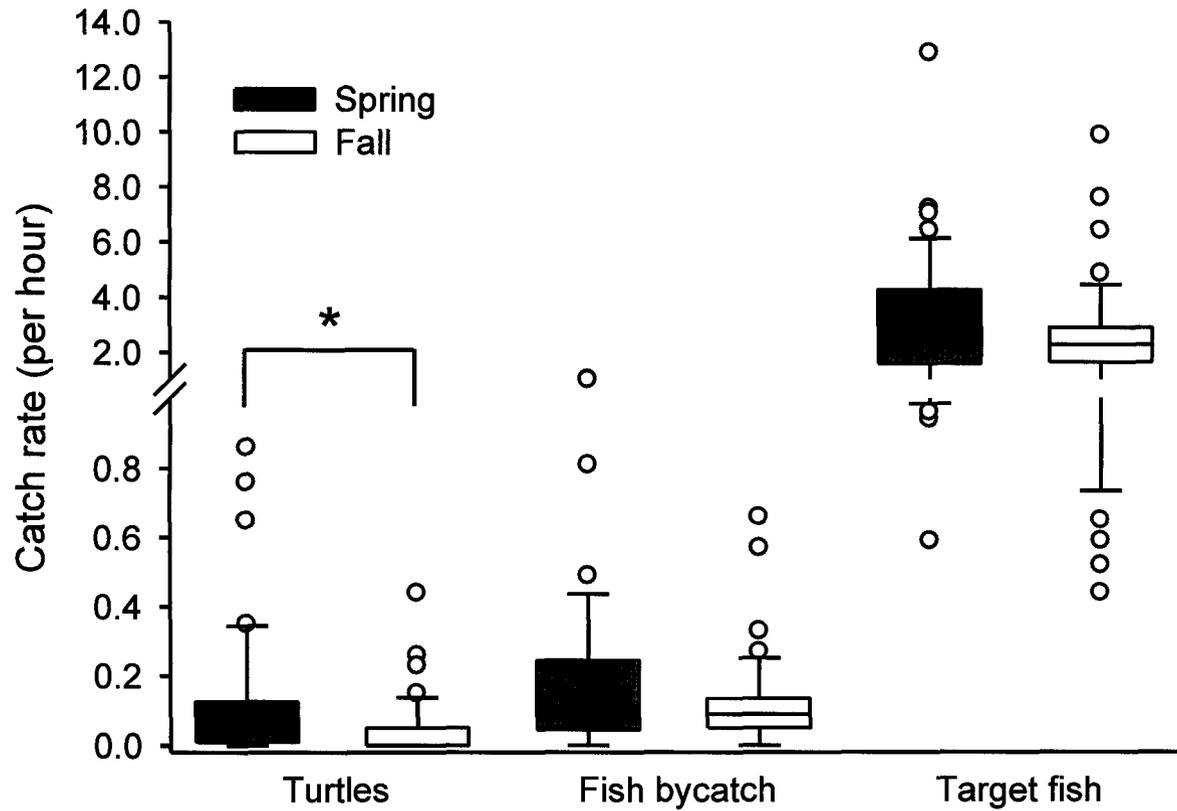


Figure 2-2. Turtles were captured more often in spring than in fall in hoop nets set in Lake Opinicon, Ontario, Canada, but catches of both fish bycatch and target fish did not vary seasonally.

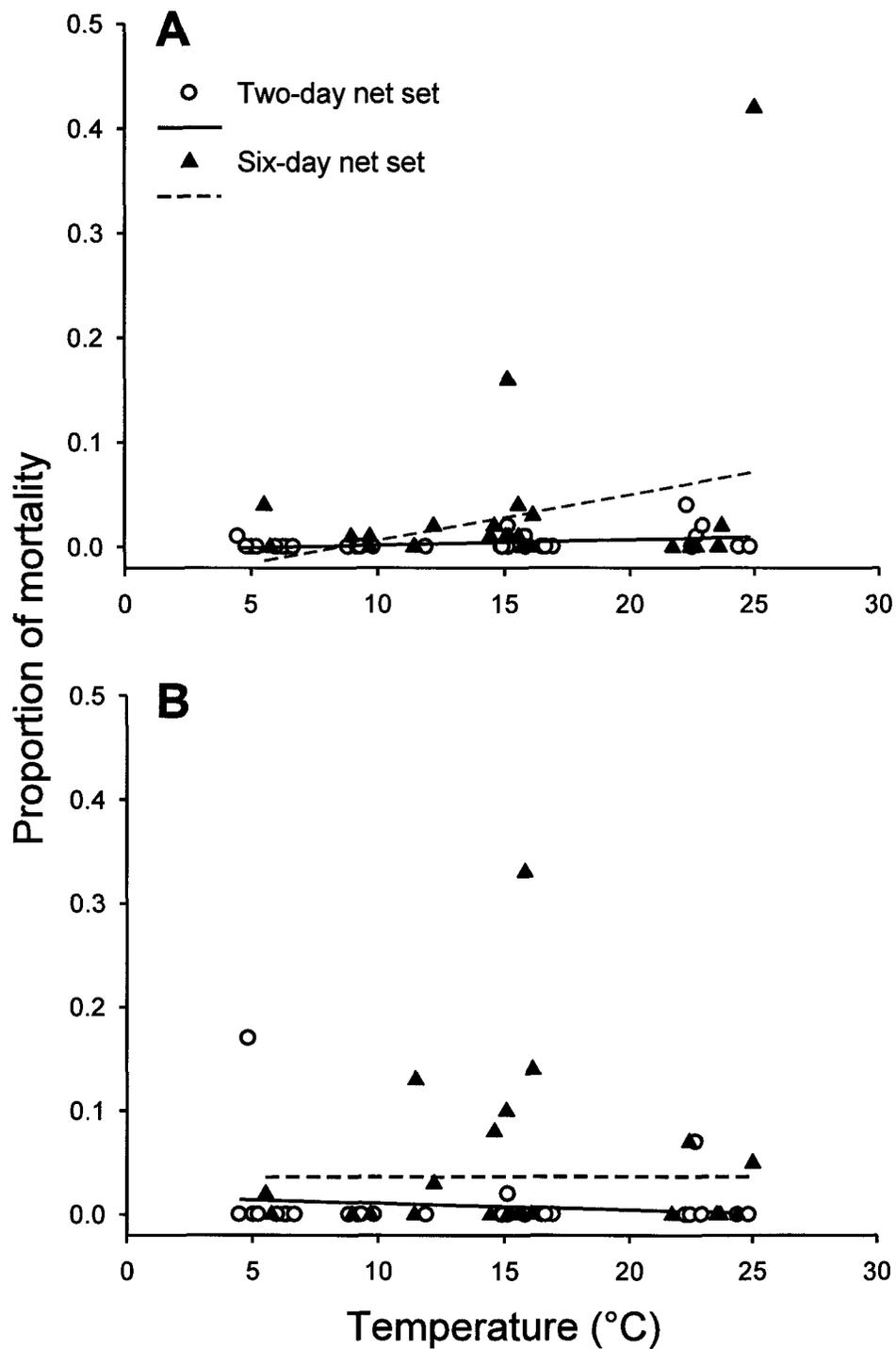


Figure 2-3. Proportion mortality of (A) target fish and (B) fish bycatch were both lower in two-day net sets than in six-day net sets in Newboro Lake, Ontario, Canada, yet mortality was unaffected by water temperature.

Chapter 3: Mitigating bycatch of freshwater turtles in passively-fished hoop nets through the use of exclusion and escape modifications

Abstract

Turtles are vulnerable to population declines ensuing from low levels of adult mortality, including bycatch mortality. Inland commercial fisheries, specifically those operating with passive gears such as hoop nets, have been documented to cause the drowning of freshwater turtles. As such, freshwater turtle bycatch is a major conservation issue. To reduce fisheries impacts on turtles, bycatch reduction devices (BRDs) have been successfully implemented in marine systems and BRDs may be adapted to freshwater systems. We tested the efficacy of two BRDs designed to exclude turtles from hoop nets by comparing catch rates and composition to unmodified nets. We also tested the efficacy of a BRD designed to let turtles escape through a chimney-like structure by comparing turtle and fish escape capacities to a large hole in the net. The exclusion device with bars across the net opening significantly reduced turtle catch rates, and both exclusion devices (i.e., the aforementioned bars and a constriction ring) did not affect fish catch rates. With the escape chimney, all turtles escaped and most (88%) fish were retained while a large hole allowed 60% and 77% of turtles and fish to escape, respectively. The escape chimney was the most effective for avoiding turtle bycatch mortality while retaining fish. Evaluations are needed to test the effectiveness of escape chimneys on additional turtle species and in different environments. Most of our BRDs effectively reduced freshwater turtle mortality putting us closer to the ultimate goal of completely eliminating the risk of turtle bycatch mortality in passive fishing gears.

Introduction

Various threats are causing reptiles to decline globally, with turtles being particularly imperilled (Gibbons *et al.*, 2002; IUCN, 2010). One such threat to turtles is their incidental capture as bycatch in commercial fisheries (Alverson *et al.*, 1994; Hall *et al.*, 2000; Lewison *et al.*, 2004; Lewison and Crowder, 2007). Turtles are long-lived organisms with naturally high juvenile mortality and low adult mortality, and are therefore prone to population declines in response to even low levels of additional adult mortality (Brooks *et al.*, 1991; Congdon *et al.*, 1993; 1994; Bulté *et al.*, 2010). Thus, turtle bycatch mortality is a serious conservation issue and research on bycatch has increased dramatically over the past decade (Soyken *et al.*, 2008). This bycatch research, however, has primarily focussed on marine systems while freshwater bycatch remains relatively unstudied (Raby *et al.*, 2011). As such, the bycatch of freshwater turtles in inland commercial fisheries is largely unknown; yet, like sea turtles, freshwater turtles are also vulnerable to bycatch.

In inland commercial fisheries, fishers commonly use passive gears such as hoop nets, trap nets, and gill nets to capture targeted fish. In a small-scale inland fishery in southeastern Ontario, fishers use hoop nets to capture sunfish (*Lepomis* spp.), bullheads (*Ameiurus* spp.), yellow perch (*Perca flavescens*), rock bass (*Ambloplites rupestris*), and black crappie (*Pomoxis nigromaculatus*; Burns, 2007). Hoop nets are passively fished, catching any mobile species that inhabits the same area and is large enough not to pass through the mesh (Hubert, 1996). Thus, non-targeted fauna can be captured in hoop nets. Unfortunately, the occurrence and extent of bycatch is not well known because fishers in most small-scale inland commercial fisheries worldwide are not required to report

bycatch. However, bycatch within hoop nets (and other passive nets) has been documented in fisheries globally (Beumer *et al.*, 1981; Barko *et al.*, 2004; Grant *et al.*, 2004; Lowry *et al.*, 2005; Carrière, 2007; Larocque *et al.*, in press). Of the documented bycatch, the incidental capture of adult freshwater turtles, including species at risk (e.g., Carrière, 2007; Larocque *et al.*, in press) is a recurring issue in Ontario and elsewhere. In addition, the number of adult freshwater turtles captured indicates that bycatch is a threat to many populations (e.g., Michaletz and Sullivan, 2002; Barko *et al.*, 2004).

With a known risk to turtle populations, efforts should be focused on ways to reduce bycatch and mortality associated with inland fisheries. Reductions in bycatch mortality can be achieved by voluntary or regulated changes to fishing practices and fishing gear (Hall and Mainprize, 2005) with the most common method being gear modifications (Broadhurst, 2000; Lewison *et al.*, 2004; Gilman *et al.*, 2010). Gear modifications try to exploit behavioural and physical differences between target and bycatch species to reduce the capture of the latter (Broadhurst, 2000; Lowry *et al.*, 2005). Such gear modifications have been made that reduce sea turtle bycatch for trawls, long-lines, gill nets, and pound nets (Epperly, 2003; Gilman *et al.*, 2006; 2010). Thus, some of these bycatch reduction devices (BRDs) designed for sea turtles have the potential to be adapted to reduce freshwater turtle bycatch in hoop nets.

Two categories of BRDs are often employed. The first category involves BRDs that take advantage of physical differences between the target and bycatch species to exclude the latter and retain the former (Broadhurst, 2000; Crespi and Prado, 2002; Lowry *et al.*, 2005). The classic example is the use of turtle excluder devices in trawl nets, in which large sea turtles are effectively excluded from the cod-end of the net by

bars while shrimp pass through the bars and are captured (Crowder *et al.*, 1995; Epperly, 2003). In freshwater, the size difference between target (e.g., fish) and bycatch (e.g., turtles) species is a lot smaller than between sea turtles and shrimp. However, the same size-based principle that is used to exclude sea turtles from nets has been entertained for freshwater turtles (e.g., Lowry *et al.*, 2005; Fratto *et al.*, 2008a) and could be potentially effective with hoop nets. The second category of BRDs involves those that exploit behavioural differences between target and bycatch species to allow the latter to escape while retaining the former (Broadhurst, 2000; FAO, 2002; Lowry *et al.*, 2005). Most escape modifications employed with marine trawl nets enable fish to swim out of an escape exit, leaving shrimp immobilized in the cod-end (Broadhurst, 2000). Taking a similar approach for freshwater turtle bycatch, BRDs could provide an escape exit for turtles by exploiting how turtles surface for air whereas fish do not exhibit the same behavioural surfacing response. Escape modifications have been attempted in freshwater nets (e.g., Lowry *et al.*, 2005; Fratto *et al.*, 2008a) and could potentially be used in the southeastern Ontario hoop net fishery.

In this study, our objectives were to determine whether exclusion and escape net modifications, designed using concepts from marine BRDs for sea turtles, effectively reduce freshwater turtle bycatch in hoop nets. Specifically, we wished to determine the efficacy of (1) exclusion bars and (2) exclusion rings fitted at the entrance of hoop nets at rejecting turtles and allowing target fish capture by simulating commercial hoop net fishing. We also wanted to determine the efficacy of (3) an escape chimney at enabling escape of turtles while retaining fish by experimentally introducing painted turtles (*Chrysemys picta*) and fish in nets to quantify their escape rate.

Methods

Study area

We conducted our study during spring of 2010/2011 (late April – mid June) and fall of 2010 (early September – mid October) in Lake Opinicon (44° 34' N, 76° 19' W) approximately 100 km south of Ottawa, Ontario, Canada. Lake Opinicon is a 788 ha shallow warm-water lake with a mean depth of 2.8 m. Water temperatures ranged from 12.7 – 25.9°C in spring and from 13.6 – 20.0°C in fall.

Hoop net modifications

All hoop nets (modified and unmodified) had similar dimensions as those used in the commercial fishery (Figure 3-1a). Each hoop net contained seven 0.9 m diameter steel hoops positioned 0.5 m apart. There were two throats per net, located at the second and fourth hoops. Each net had two wings and a lead attached to the front hoop which measured 4.6 m long by 0.9 m high, and 10.7 m long by 0.9 m high, respectively. All the nets, wings, and leads were constructed from 5.08 cm stretch nylon mesh.

We tested two hoop net modifications designed to exclude turtles. Our first modification had “exclusion bars” which involved attaching 1.27 cm diameter wooden dowels across the first hoop of the net (Figure 3-1b). We positioned eight dowels vertically across the opening of the net all spaced 8.0 cm apart. All adult aquatic turtles encountered in Lake Opinicon except eastern musk turtles (*Sternotherus odoratus*), (i.e., painted turtles, northern map turtles, *Graptemys geographica*, and snapping turtles, *Chelydra serpentina*), have a carapace width larger than 8.0 cm and should be prevented from entering the net (if swimming upright) with this device.

Our second exclusion modification was an “exclusion ring” which involved attaching a hose clamp at the first funnel of the hoop net. The hose clamp was shaped to be a rectangle (18 cm high by 7.5 cm wide), and attached such as to create a small narrow vertical slot. This rigid narrow slot was shaped to restrict turtles from entering the first funnel of the net, contrary to the standard yielding funnel mesh.

We also tested an escape modification by attaching a chimney-like structure to the hoop net (Figure 3-1c). This escape chimney was based on Fratto *et al.* (2008a): we attached a mesh tube (1.0 cm mesh) 15 cm wide by 28 cm long by 85 cm tall to the net between the sixth and seventh hoop. At the attachment site, we made a hole in the net in which we attached a 19 mm diameter PVC pipe ring, with inner ring dimensions of 15 cm by 28 cm, to keep the entrance to the chimney open. We attached two steel wire rings to the mesh tube to keep the chimney from collapsing. The top of the chimney also contained a 32 mm diameter PVC pipe ring, with inner ring dimensions of 15 cm by 28 cm that kept the chimney afloat and oriented towards the surface. At the top of the chimney, a 5.0 cm high by 15 cm long hole was made on one side of the mesh tube to allow turtles to swim out of the net.

Exclusion vs. unmodified nets

We used fishing practices commonly employed by commercial fishers in our study area. We spent time shadowing fishers to identify how gear is deployed and the habitats targeted. We set nets in tandem by adjoining two hoop nets (of the same treatment type) by their leads with the net openings facing each other and extending the wings at a 45° angle from the entrance of the net. In spring 2010, the “exclusion bars” and unmodified nets were set simultaneously at 30 sites chosen at random within the

areas normally fished by commercial fishers in Lake Opinicon. In fall 2010, the “exclusion ring” and unmodified nets were set simultaneously at 15 sites. All nets were set completely submerged at depths of 1-2 m in vegetated shallows parallel to the shoreline. Nets were set within 15 m of each other to reduce habitat variation. Net set duration varied (8-48 hours) according to water temperature to prevent turtle mortality (i.e., shorter sets with warmer water from reduced anoxia tolerance and survival durations based on Herbert and Jackson (1985)). When we lifted nets, all vertebrates were identified to species and counted. The first 20 fish per species in a net were assessed for the presence or absence of injury (e.g., scale loss, abrasions, fin fray) to determine whether the exclusion modifications injured fish. The first 20 bluegill (*Lepomis macrochirus*) and pumpkinseed (*Lepomis gibbosus*) per net were measured for total length to determine whether the modifications limited the entry of larger fish.

Escape chimney vs. large hole

To determine the effectiveness of the escape chimney, we compared the escape capacity of the chimney design to a net with a large hole of similar dimensions (15 cm by 28 cm) in spring of 2010 and 2011. We set both nets at a depth of 1.5 m and closed off the net opening. Temperature variation was minimal (19 - 24°C) for the duration of the experiment. To test turtle escape capacity, we put male painted turtles (mean carapace length \pm SE: 140.6 \pm 1.7 mm; mean carapace width \pm SE: 103.4 \pm 1.0 mm) into the cod-end of a net for four hours (chimney trials: N = 10; large hole trials: N = 20). A preliminary study on painted turtles indicated that swimming activity in submerged nets was greatly reduced after four hours and escape would thus be unlikely after this period. Whether the turtle escaped was recorded. We also tested fish escape capacity for each net

treatment. One hundred *Lepomis* spp. (*Lepomis macrochirus* and *Lepomis gibbosus*) greater than 130 mm in total length (to ensure fish could not escape through the mesh) were experimentally introduced into the cod-end of each net for 24 hours (i.e., a time frame that is more representative of commercial fishing). The number of fish that escaped was counted at the end of each trial (chimney trials: N = 10; large hole trials: N = 10).

Data analyses

We compared catch rates of target fish, fish bycatch, and turtles in nets modified for the exclusion of turtles and unmodified nets. For comparing net types, we calculated catch per unit effort (CPUE – catch/hr) for each tandem net to standardize for variation in net set duration. We calculated CPUE by taking the total catch from both nets in the tandem and dividing by the summed duration that each net was set for. If one of the nets in the tandem did not fish properly (e.g., we found holes in the net, a dowel broke, etc.), we removed that net from the calculation. We calculated the CPUE for target fish catches, fish bycatch, and turtle bycatch. Catch rates from each exclusion modification (“exclusion bars” and “exclusion ring”) were compared to their respective unmodified nets using paired t-tests. Target fish catch rates were log transformed to meet the assumption of normality and homogeneity of variance. Both fish and turtle bycatch rates were non-normal even after transformation and we used Wilcoxon signed ranks tests to compare net types. We also compared target fish, fish bycatch, and turtle catch compositions between the exclusion and unmodified nets, using individual species CPUE that corresponded to each respective comparison, in a blocked multi-response permutated procedure (MRBP; this controlled for site variation) and indicator species analysis (ISA; post-hoc test for MRBP) using PC-ORD 5.20 (McCune and Mefford, 2006). Fish were

scored with either presence (e.g., abrasions, wounds) or absence of injury. Injury was compared between exclusion modifications and unmodified nets with a chi squared test. We determined the mean total length of bluegill and pumpkinseed per net set and compared exclusion modifications and unmodified nets. Trials in which one of the treatments contained no bluegill were excluded. We used paired t-tests for bluegill lengths with the “exclusion bars” (N = 29) and pumpkinseed lengths with the “exclusion ring” (N = 14). Due to non-normality of the data, we used Wilcoxon signed ranks tests for pumpkinseed lengths for the “exclusion bars” (N = 30) and bluegill lengths for the “exclusion ring” (N = 15).

We compared the escape capacity of turtles with the escape chimney to a large hole using a Fisher’s exact test. For fish, we used the proportion of escaped fish in an independent samples t-test which met the assumptions of normality and homogeneity of variance. All chi square tests, Fisher’s exact tests, t-tests, and Wilcoxon signed ranks tests were performed in SPSS 18.0.0 (IBM Inc.; www.spss.com). For all tests significance was accepted at $\alpha = 0.05$ and values are reported as mean \pm SE.

Results

Exclusion vs. unmodified nets

In 30 unmodified tandem nets set during spring 2010 we captured 2855 target fish of 5 species, 170 fish bycatch of 3 species, and 50 other vertebrates (1 mammal species, 3 turtle species; Table 3-1). In 30 “exclusion bar” tandem net sets, we captured 3163 target fish of 6 species, 212 fish bycatch of 3 species, and 23 other vertebrates (1 mammal species; 3 turtle species; Table 3-1). Unmodified net target fish catch rates (2.86 ± 0.30 fish/hour) were not significantly different from the “exclusion bar” net catch rates ($2.89 \pm$

0.29 fish/hour; $t_{29} = 0.498$, $P = 0.622$; Figure 3-2a). Target fish species composition also did not significantly differ between treatments ($A = -0.019$; $P = 1.000$). Fish bycatch rates in unmodified nets (0.19 ± 0.03 fish/hour) were not significantly different from those of “exclusion bar” nets (0.21 ± 0.03 fish/hour; $Z = 0.508$, $P = 0.611$; Figure 3-2b), nor did fish bycatch species composition significantly differ ($A = 0.004$; $P = 0.284$). Turtle catch rates in unmodified nets (0.10 ± 0.04 turtles/hour) were significantly higher than in “exclusion bar” nets (0.03 ± 0.01 turtles/hour; $Z = 2.107$, $P = 0.035$; Figure 3-2c). Turtle species composition within unmodified and “exclusion bar” nets were significantly different ($A = 0.031$; $P = 0.011$), specifically eastern musk turtles were captured more frequently in unmodified nets (0.06 ± 0.02 turtles/hour) than “exclusion bar” nets (0.01 ± 0.01 turtles/hour; $P = 0.031$). There was no association between presence of fish injury and net type as fish in both modified and unmodified nets had a 7.8% chance of injury ($X^2_1 = 0.006$; $P = 0.941$). Bluegill captured in unmodified nets were significantly larger (177 ± 4 mm) than those captured in nets equipped with “exclusion bars” (170 ± 3 mm; $t_{28} = 4.164$; $P < 0.001$). Conversely, for pumpkinseed there was no difference in size of fish captured in unmodified (192 ± 3 mm) and “exclusion bar” nets (189 ± 3 mm; $Z = 0.249$; $P = 0.804$).

In 15 unmodified tandem nets set during the fall we captured 1658 target fish of 6 species, 63 fish bycatch of 2 species, and 26 turtles representing 2 species (Table 3-1). In 15 “exclusion ring” tandem net sets, we captured 1401 target fish of 5 species, 71 fish bycatch of 2 species, and 9 turtles representing 2 species (Table 3-1). Unmodified net target fish catch rates (2.85 ± 0.66 fish/hour) were not significantly different from “exclusion ring” catch rates (2.59 ± 0.42 fish/hour; $t_{14} = 0.072$, $P = 0.943$; Figure 3-2d).

The species composition of target fish was similar between unmodified nets and the “exclusion ring” ($A = -0.018$; $P = 0.610$). Fish bycatch rates in unmodified nets (0.10 ± 0.02 fish/hour) were not significantly different from those of “exclusion ring” nets (0.13 ± 0.04 fish/hour; $Z = 0.114$, $P = 0.910$; Figure 3-2e), nor did fish bycatch species composition differ between treatments ($A = -0.027$; $P = 0.892$). Turtle catch rates in unmodified nets (0.04 ± 0.02 turtles/hour) were not significantly different from those in “exclusion ring” nets (0.02 ± 0.01 turtles/hour; $Z = 1.260$, $P = 0.208$; Figure 3-2f). Turtle species composition within unmodified and “exclusion ring” nets were not significantly different ($A = 0.053$; $P = 0.069$). There was no association between treatments and whether fish were injured with a 1.5% chance of injury in unmodified nets and a 0.9% chance of injury in “exclusion ring” nets ($X^2_1 = 1.321$; $P = 0.250$). The size of captured bluegill did not differ significantly between unmodified nets (166 ± 3 mm) and nets equipped with the “exclusion ring” (167 ± 2 mm; $Z = 0.157$; $P = 0.875$). The size of pumpkinseed were also similar between unmodified (180 ± 4 mm) and “exclusion ring” nets (176 ± 3 mm; $t_{13} = 0.782$; $P = 0.449$).

Escape chimney vs. large hole

All ten painted turtles escaped the modified chimney net, which was significantly greater than the 60% (12/20) of turtles that escaped a net with a large hole (Fisher’s exact test; $P = 0.029$). With chimney nets, the odds of a painted turtle escaping were 6.6 times greater than in a net with a simple hole. The proportion of fish that escaped in the chimney net (0.13 ± 0.03) was significantly less than in the net with a large hole (0.77 ± 0.05 ; $t_{18} = 11.321$, $P < 0.001$).

Discussion

Both the “exclusion bars” and the “exclusion ring” net modifications reduced turtle captures by over 50% compared to unmodified nets (Table 3-1), but only the “exclusion bars” was statistically significant. The non-significant reduction of turtle catches from the “exclusion ring” modification may be from the smaller sample size (N = 15), resulting in lower statistical power, as well as sampling in the fall. Turtles are captured less frequently in fall compared to spring (Gibbons, 1968; Larocque *et al.*, in press), which could have made turtle capture rate differences with the “exclusion ring” modification more difficult to detect. The composition of turtle species differed with the “exclusion bars”, in which eastern musk turtles were less frequently encountered than in unmodified nets. Of the turtles encountered, the small eastern musk turtle was expected to not be affected by exclusion modifications given the musk turtle’s carapace width hardly exceeds 80 mm (Ernst, 1994; S. M. Larocque, unpublished data). Simply having turtles encounter the exclusion barriers and be startled may explain the reduced number of catches as opposed to being physically incapable of entering nets. However, the behaviour of turtles entering hoop nets has not been studied to verify what was keeping turtles out of the nets.

For both exclusion modifications, fish captures (target and bycatch) were similar to those in unmodified nets. Fish species compositions (both target and bycatch) were also similar between modified and unmodified hoop nets, indicating that small and large fish species were equally likely to be captured. Although the mean total length of bluegill captured was significantly smaller with the “exclusion bar” net, this was not considered biologically (or economically in the context of fishers) significant with only a body

length reduction of 4%. Thus, the barriers of the exclusion modifications (i.e., both the exclusion bars and rings) were spaced enough to allow fish species of all sizes to enter the net, yet they reduced turtle entries. Furthermore, fish injuries were similar among treatments. Unlike turtles, the lateral line of fish helps them avoid obstacles (Bleckmann, 1993) and avoid injuries potentially associated with the barriers of the exclusion nets. Given the brief encounter with the barriers, it is likely that contact with the net caused most injuries to fish.

The escape chimney modification was more effective than a large hole in the net. All painted turtles escaped via the chimney, while most (88%) target fish were retained. Fratto *et al.* (2008a) used a similar chimney design on hoop nets in a river system which reduced turtle captures by 84% compared to their control; however, fish captures were also reduced by 60%. Fish in our study may have been stressed from initial capture and transport, thereby negatively affecting their behaviour and ability to escape the net. Acute stress from tank holdings and being handled can affect the health and behaviour of fish (Portz *et al.*, 2006). It is possible that the escape chimney would allow more fish to escape than what we documented if fish entered the net on their own. Also, the combination of turtles, target fish, and fish bycatch in the net concurrently may affect escape rates in real-life situations. Multiple species, potential predators (e.g., largemouth bass, *Micropterus salmoides*), and high densities in the net could influence fish behaviour and escape capabilities (Portz *et al.*, 2006).

Different species of turtles may differ in their abilities to escape through the chimney design. We used painted turtles to test the efficacy of the escape chimney and found that all turtles succeeded, yet other species of turtles captured in hoop nets may not

escape so readily. For example, Fratto *et al.* (2008a) noticed that smaller turtles were able to escape the net while larger turtles remained captured. It is essential to ensure these large aquatic turtles are able to escape and avoid mortality, as larger turtles are often females and have higher reproductive potential (Berry and Shine, 1980; Kuchling, 1988). Also, turtle species with different lifestyles may not be as likely to escape as painted turtles. For instance, eastern musk turtles and snapping turtles are bottom-crawlers as opposed to the actively swimming painted turtles (Ernst *et al.*, 1994). Bottom-crawlers may not be able to escape as readily through the escape chimney. Determining whether all turtle species captured can escape in the chimney design is important prior to implementation, especially given that the other species in our system (eastern musk turtle, northern map turtle, and common snapping turtle) are considered at various levels of risk in Canada (COSEWIC, 2010).

Environmental factors may also influence the performance of the escape chimney. Our design was tested in a lake; however, the Ontario hoop net fishery extends to rivers as well. Fast flowing waters could reduce the stability of the chimney design and prevent turtles from escaping. Water depth is another variable that may affect the performance of escape chimneys. Our nets were set at a constant depth and escape rates of both turtles and fish may differ with different depths. Fratto *et al.* (2008a) found that increased depth reduced turtle captures (for escape chimney nets and controls), but increased depth could also reduce fish captures (Rawson, 1952). The escape chimney is a promising avenue for reducing freshwater turtle bycatch. Additional evaluations of the escape chimney are however recommended. Evaluating the efficacy of the escape

chimney on multiple turtle species of various sizes and lifestyles, as well as in different environmental conditions and systems, is especially warranted.

Having BRDs that reduce turtle captures (e.g., our “exclusion bar” net) is a good start towards mitigating the threat posed by commercial fisheries to freshwater turtles, yet completely eliminating the risk of turtle bycatch mortality is preferable. The escape chimney, potentially used in conjunction with a device that reduces turtle entries, appears to be a potential avenue to eliminate turtle bycatch mortality. Another method to avoid turtle mortality is to create air spaces within the nets (Grant *et al.*, 2004). Currently, commercial fishers set nets completely submerged to minimize attention, vandalism, theft, and potential predation by birds, thereby creating a major mortality risk to air-breathing organisms like turtles. Using flotation devices in hoop nets could prevent turtle mortalities. Bury (2011) indicated only few turtle mortalities occurred when using air spaces in hoop nets; however, Larocque *et al.* (in press) documented considerable mortalities even in the presence of floats. Thus, more thorough testing of the effectiveness of air spaces in hoop nets to reduce turtle mortality is needed. Ultimately, implementing modifications that completely eliminate the risk of turtle bycatch mortality should be the goal for fisheries management.

Conclusions

Freshwater turtle bycatch is a conservation concern that needs to be addressed both locally and globally (Michaletz and Sullivan, 2002; Barko *et al.*, 2004; Larocque *et al.*, in press). Our study focused on reducing turtle bycatch associated with a southeastern Ontario hoop net fishery, though our findings can be generalized to most hoop net uses (e.g., biological sampling/research; commercial fishing) that have associated freshwater

turtle bycatch. The “exclusion bars” and escape chimney modifications were deemed effective and could be implemented for bycatch mitigation, although we also recommend further refinement of such devices. In addition, seasonal and temperature effects on freshwater turtle bycatch (e.g., Fratto *et al.*, 2008a; Larocque *et al.*, in press) should be considered in conjunction with the use of bycatch reduction devices to minimize the impacts of commercial fishing on freshwater turtle populations. Most of the BRDs used in this study were effective at reducing turtle bycatch and, as such, are a step towards the near complete elimination of freshwater turtle bycatch mortality in hoop nets.

Tables

Table 3-1. Number and composition of modified and unmodified hoop net catches from Lake Opinicon, Ontario, Canada. There were 30 net sets per net type in spring, and 15 net sets per net type in fall.

	Spring				Fall			
	Unmodified net		"Exclusion bar" net		Unmodified net		"Exclusion ring" net	
	Number captured	Total Percentage	Number captured	Total Percentage	Number captured	Total Percentage	Number captured	Total Percentage
Target species								
<i>Lepomis macrochirus</i>	1519	49.40%	1629	47.94%	1171	67.03%	954	64.42%
<i>Lepomis gibbosus</i>	1091	35.48%	1204	35.43%	385	22.04%	372	25.12%
<i>Pomoxis nigromaculatus</i>	23	0.75%	33	0.97%	9	0.52%	11	0.74%
<i>Ambloplites rupestris</i>	127	4.13%	159	4.68%	11	0.63%	2	0.14%
<i>Ameiurus</i> spp.	95	3.09%	135	3.97%	81	4.64%	62	4.19%
<i>Perca flavescens</i>	0	0%	3	0.09%	1	0.06%	0	0%
Total	2855	92.85%	3163	93.08%	1658	94.91%	1401	94.60%
Fish bycatch species								
<i>Micropterus salmoides</i>	135	4.39%	186	5.47%	58	3.32%	67	4.52%
<i>Esox lucius</i>	32	1.04%	24	0.71%	5	0.29%	4	0.27%
<i>Micropterus dolomieu</i>	3	0.10%	2	0.06%	0	0%	0	0%
Total	170	5.53%	212	6.24%	63	3.61%	71	4.79%
Non-fish species								
<i>Chrysemys picta</i>	16	0.52%	10	0.29%	4	0.23%	4	0.27%
<i>Graptemys geographica</i>	5	0.16%	5	0.15%	0	0%	0	0%
<i>Sternotherus odoratus</i>	27	0.88%	7	0.21%	22	1.26%	5	0.34%

<i>Ondatra zibethicus</i>	2	0.07%	1	0.03%	0	0%	0	0%
Total	50	1.63%	23	0.68%	26	1.49%	9	0.61%
Grand total	3075	100%	3398	100%	1747	100%	1481	100%

Figures

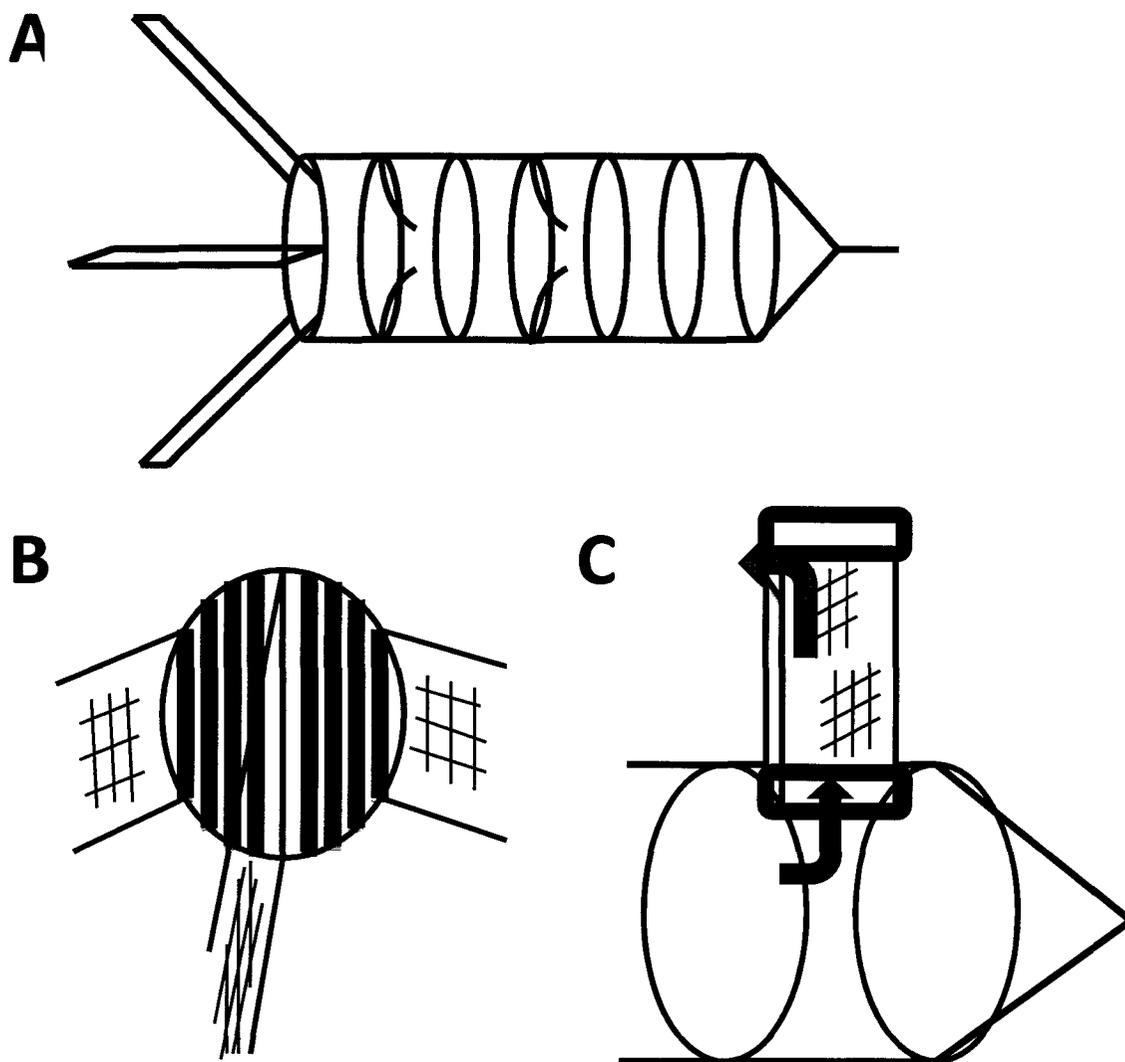


Figure 3-1. Illustrations of (A) an overhead view of an unmodified hoop net with a lead and two wings attached, (B) the opening of the “exclusion bar” net, and (C) the cod end of a hoop net with an escape chimney attached, where arrows represent the escape route of turtles.

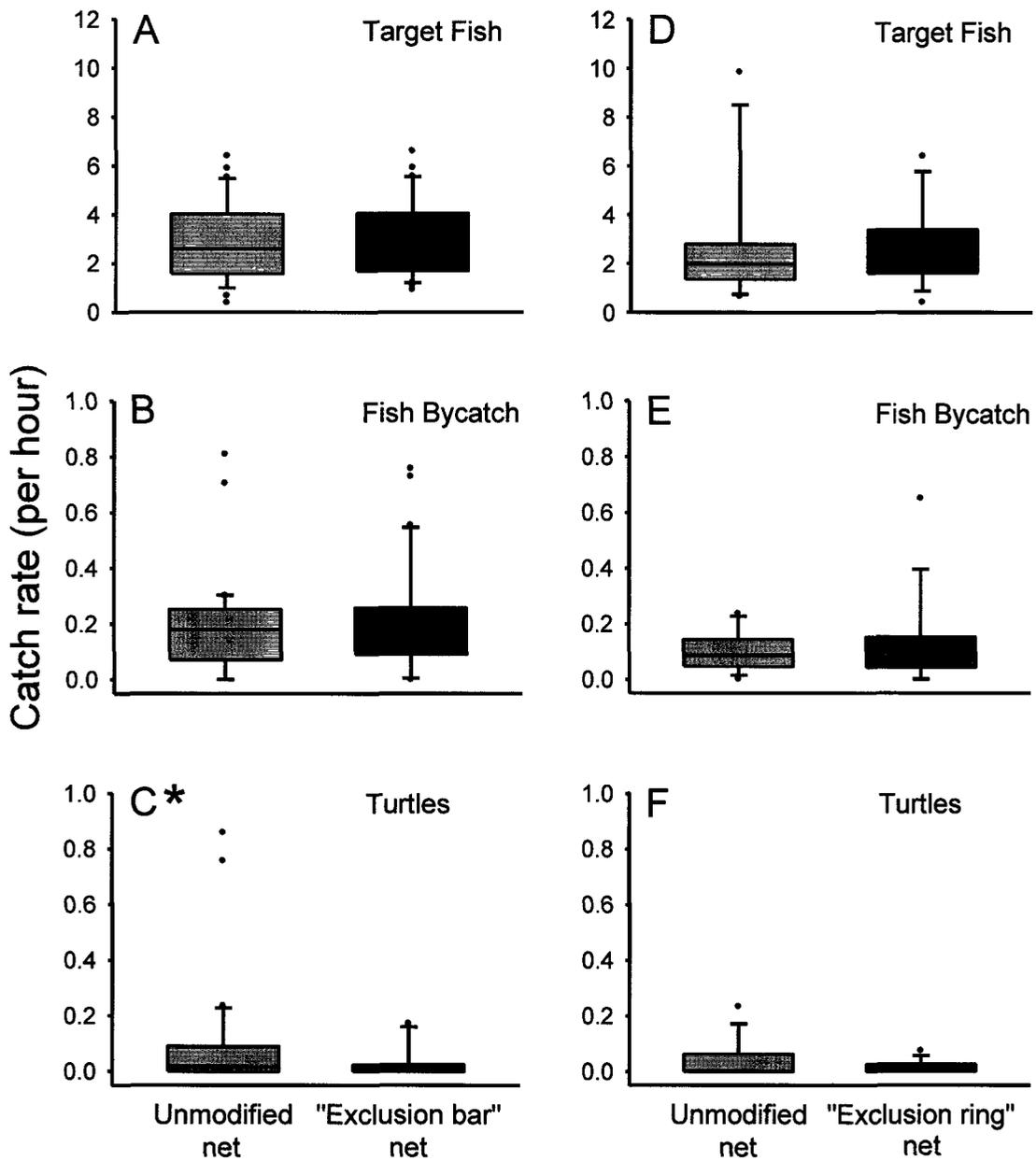


Figure 3-2. Catch rates of (A) target fish and (B) fish bycatch were similar between unmodified nets and “exclusion bar” nets, while (C) turtles had lower capture rates in the “exclusion bar” net. Catch rates were similar for (D) target fish, (E) fish bycatch, and (F) turtles between unmodified nets and “exclusion ring” nets. Nets were set in Lake Opinicon, Ontario, and * indicates $P < 0.05$.

Chapter 4: A breath of fresh air: avoiding anoxia and mortality of freshwater turtles in hoop nets via the use of floats

Abstract

Freshwater turtles are susceptible to drowning in commercial fishing nets and this is a major conservation concern. Methods to mitigate turtle bycatch mortality typically involve reducing the capture of bycatch via gear modifications. Another method to reduce mortality is to keep bycatch alive following capture. Using physiological measures of anoxia, we determined whether providing air spaces using floats within hoop nets could prevent turtles from drowning. In a controlled setting, we compared blood lactate and pH of painted turtles (*Chrysemys picta*) experimentally introduced into submerged nets, nets with floats, and nets that breached the surface. While emulating commercial fishing practices, where turtles and fish voluntarily entered nets, we compared catch rates and compositions, as well as blood lactate in turtles captured in submerged nets with and without floats. Painted turtles in submerged nets exhibited elevated blood lactate and pronounced acidosis compared with turtles from nets with floats and surfaced nets. Catch rates and compositions from emulated fishing were statistically similar in nets with and without floats. However, total fish captured in the study was roughly 1/3 less in nets with floats. We observed the same pattern of physiological disturbance with turtles captured in submerged nets with and without floats as in the controlled experiment. Overall, blood physiology indicated that anoxia occurred in turtles in submerged nets while nets with floats reduced physiological disturbance. However, variation in blood lactate levels when fishing hoop nets with floats suggests

that turtles were experiencing slight anoxia and so the size of air spaces may be important in allowing access to air. Creating air spaces in hoop nets using floats is a simple and cost effective method to avoid the drowning of turtles.

Introduction

Bycatch, the inadvertent capture of non-targeted fauna, is a growing conservation concern in commercial fisheries (Alverson *et al.*, 1994; Hall *et al.*, 2000; Lewison *et al.*, 2004; Lewison and Crowder, 2007). This concern is particularly acute when long-lived organisms with late maturation and naturally low recruitment, such as turtles, are incidentally captured as adults in a fishery and mortality ensues (Whitehead *et al.*, 1997; Lewison *et al.*, 2004). Slight additional adult mortality is often sufficient to put turtle populations in jeopardy (Brooks *et al.*, 1991; Congdon *et al.*, 1993; 1994). Aside from sea turtle bycatch (e.g., Alverson *et al.*, 1994; Lewison *et al.*, 2004; Lewison and Crowder, 2007), freshwater turtles are also prone to accidental capture and mortality within fisheries around the world (Beumer *et al.*, 1981; Barko *et al.*, 2004; Lowry *et al.*, 2005; Larocque *et al.*, in press). The prevalence of freshwater bycatch is less publicised than marine bycatch, yet freshwater bycatch is still an important threat for turtles (Raby *et al.*, 2011).

Efforts to mitigate bycatch and associated mortality typically involve modifications to the fishing gear and/or methods (Broadhurst, 2000; Lewison *et al.*, 2004; Gilman *et al.*, 2010). In freshwater commercial fisheries, passive nets like hoop nets, fyke nets, and trap nets are commonly used and, as such, there have been attempts to modify hoop nets to reduce turtle bycatch (Lowry *et al.*, 2005; Fratto *et al.*, 2008a; 2008b; Larocque *et al.*, in review). Exploiting physical and behavioural differences between the

target species (in our case fish) and bycatch species (in our case turtles), modifications can involve permanent alterations to the net that can prevent turtles from entering nets or that allow turtles to escape the net after entry (Broadhurst, 2000). Although some of these net alterations appear to be effective (e.g., Lowry *et al.*, 2005; Fratto *et al.*, 2008a, Larocque *et al.*, in review), net alterations also tend to be extensive, potentially expensive for commercial fishers to implement, and may not eliminate the problem of bycatch mortality completely.

Another potential avenue to mitigate freshwater turtle bycatch mortality is to keep turtles alive in nets instead of focusing on avoiding bycatch in the nets. The drowning of turtles in submerged nets is the primary concern. As turtles require air to breathe, the creation of air spaces within hoop nets could prevent anoxia (the lack of oxygen) and ensuing mortality (Grant *et al.*, 2004). Bury (2011) documented that the use of air spaces in hoop nets largely prevent turtle mortality, yet Larocque *et al.* (in press) found that the use of floats in nets (to keep the nets partially at the surface) was not always effective and substantial turtle mortality occurred. Thus, there is a need to verify whether air spaces created with floats in hoop nets prevent freshwater turtle bycatch mortality while still maintaining fish catch rates.

Instead of using death as an end-point to determine the effectiveness of air spaces in hoop nets at negating turtle mortality, we adopted a conservation physiology approach (Wikelski and Cooke, 2006) and used physiological variables to quantify anoxia. During anoxia, blood lactate accumulates as anaerobic metabolism occurs, and the increase in lactic acid results in a decrease in blood pH. The ability of freshwater turtles to deal with anoxia decreases with increasing temperature (Herbert and Jackson, 1985). Therefore,

blood lactate and pH levels should be good, quick responding indicators of anoxia in turtles during warmer water temperatures. Our objective here was to determine, both in a controlled setting (when turtles were experimentally introduced into nets void of fish) and while emulating commercial fishing practices (when turtles and fish entered nets on their own), whether providing air spaces in hoop nets reduces signs of anoxia in freshwater turtles that are captured in these nets. We also wished to determine whether the provision of air spaces reduces fish captures.

Methods

Study site

We conducted our study on Lake Opinicon (44° 34' N, 76° 19' W) approximately 100 km south of Ottawa, Ontario, Canada. Lake Opinicon is a 788 ha shallow warm-water lake with a mean depth of 2.8 m. We conducted our controlled experiments in August 2009 during which time lake temperatures ranged from 18 - 21°C. We emulated commercial fishing practices in spring (late April – mid June) 2010 during which time lake temperatures ranged from 12.7 – 25.9°C.

Hoop nets

We used hoop nets that had similar dimensions as those used in the commercial fishery. Each hoop net contained seven 0.9 m diameter steel hoops positioned 0.5 m apart. There were two throats per net, located at the second and fourth hoops. Each net had two wings and a lead attached to the front hoop that measured 4.6 m long by 0.9 m high, and 10.7 m long by 0.9 m high, respectively. All the nets, wings, and leads were constructed with 5.08 cm stretch nylon mesh.

Controlled experiment

Under controlled conditions, we wanted to determine whether turtles use air spaces provided in nets. Using hoop nets, we captured 30 painted turtles (*Chrysemys picta*: mean carapace length \pm SE: 140.67 ± 2.23 mm; mean weight \pm SE: 353.53 ± 17.39 g). We had three net treatments and we assigned painted turtles randomly to each. The submerged treatment was a hoop net set completely underwater at a depth of 1.5 m. The float treatment was a hoop net set with an air space created by putting at least two floats (e.g., water jugs; Styrofoam) in the cod-end of the net (ensuring that the floats and nets breached the surface). The surfaced treatment was a hoop net set at a depth of 0.5 m in which about half of the net was submerged to be a control for net effects on turtles. For all treatments, the opening of the net was closed after the insertion of a turtle. Trials involved putting an individual painted turtle into the net for four hours. Preliminary trials indicated that after four hours at $\sim 20^{\circ}\text{C}$, painted turtles reduced activity and showed signs of anoxia. After four hours, we retrieved turtles and, within 2-5 min, we drew a blood sample to measure blood lactate and blood pH. Ten trials were completed for the submerged treatment, while 9 trials were completed for the surfaced and float treatments as one turtle escaped in each.

Emulating commercial fishing

We compared nets with and without air spaces provided using floats. We set nets according to fishing practices commonly employed by commercial fishers in the area. We set nets in pairs by joining two hoop nets (of the same treatment type) by their leads with the net openings facing each other and extending the wings 45° from the entrance of the net. Submerged nets (without floats) and nets with floats were simultaneously set in 30 locations within Lake Opinicon that were shallow (1-2 m) and vegetated. Submerged and

float net pairs were set within 15 m of each other to reduce habitat variation. Net set durations varied (8-48 hours) to minimize mortality of turtles: we decreased net set duration as water temperatures increased based on reduced anoxia tolerance and survival durations found by Herbert and Jackson (1985). When lifting the nets, we took blood from all turtles (all species) within 5 min to measure blood lactate. Blood pH was not measured due to difficulty of onsite calibration and accurate measures. We identified to species and tallied all organisms encountered. Any mortality was documented.

Blood sampling and analysis

We sampled turtle blood from the caudal vein on the dorsal part of the tail using a 1 ml luer-lock sodium-heparinized (10,000 USP units/ml, Sandoz, QC, Canada) syringe with a 25 gauge 38 mm needle (BD, Franklin Lakes, NJ). When we measured both blood lactate and pH (i.e., controlled experiment), we took a minimum of 0.2 ml of blood. If we measured blood lactate only (i.e., emulation of commercial fishing), we took 0.05 ml of blood. All lactate and pH measurements were done onsite. We measured whole blood lactate using a Lactate Pro meter (Arkray Inc., Japan). Lactate Pro only reads between 0.8 and 23.3 mmol/l, therefore when readings indicated “low” we assumed lactate levels to be 0.7 mmol/l. The use of Lactate Pro to measure lactate has been validated with teleost fish (Brown *et al.*, 2008), and we assumed it to be accurate for turtles. We measured blood pH with a 3-point calibrated minilab IQ128 Elite pH meter (IQ Scientific Instruments Inc., USA).

Data analysis

For the controlled experiment, we compared blood lactate and pH for painted turtles among the three treatments. Blood lactate levels were not normally distributed for

all treatments, so we used a non-parametric Kruskal-Wallis test. To determine which treatments differed, we used post-hoc non-parametric Mann-Whitney U tests with a Bonferroni correction. Blood pH, however, did not violate the assumptions of normality and homogeneity of variance and we used an ANOVA to compare the three treatments. We used post-hoc Tukey's tests to determine which treatments differed in blood pH.

For the emulation of commercial fishing experiment, we compared fish and turtle catch rates, catch composition, and blood lactate of turtles between nets with and without floats. To compare catch rates for the two net types, we calculated catch per unit effort (CPUE – catch/hr) for each net pair to standardize for differences in net set duration. We calculated CPUE by taking the total catch from both nets in the pair and dividing it by the summed duration that each net was set. If one of the nets in a pair did not fish properly (e.g., we found holes in the net; wings twisted), we removed that net from the calculation. We calculated the CPUE for fish and turtle catches. We log transformed fish catch rates to meet the assumptions of normality and homogeneity of variance to then compare nets with and without floats using a paired samples t-test. Turtle catch rates were non-normal and we used non-parametric Wilcoxon signed ranked tests to compare net types. We determined whether nets with and without floats were catching the same composition of species by comparing species catch rates from each net type (N = 30 per net type) using a multi-response blocked procedure (MRBP; blocking controlled for site variation) in PC-ORD 5.20 (McCune and Mefford, 2006).

Blood lactate in turtles was compared in submerged nets and nets with floats. Both painted turtles and eastern musk turtles (*Sternotherus odoratus*) had sample sizes larger than six for each treatment and were thus used to compare net types using an

ANOVA and a Tukey's post-hoc comparison. We performed all statistical tests, unless otherwise stated, with SPSS 18.0.0 (IBM Inc.; www.spss.com). Significance was accepted at $\alpha = 0.05$, except when a Bonferroni correction was indicated. Values are reported as mean \pm SE.

Results

In the controlled experiment, painted turtle blood lactate levels were significantly different among treatments ($H_2 = 22.123$, $P < 0.001$). All treatments were significantly different from each other ($P < 0.005$; Figure 4-1A). Turtles from the surfaced net had the lowest lactate levels (1.0 ± 0.1 mmol/l), turtles from the float net had slightly higher lactate levels (2.2 ± 0.3 mmol/l), and turtles from the submerged net had the highest lactate levels (16.8 ± 0.6 mmol/l; Figure 4-1A). Blood pH levels in painted turtles also differed significantly among treatments ($F_{2,25} = 577.157$, $P < 0.001$). Turtles in both the surfaced and float nets had similar blood pH with 8.11 ± 0.02 and 8.05 ± 0.015 pH, respectively, while turtles in submerged nets had significantly lower pH (7.38 ± 0.02 pH; $P < 0.05$; Figure 4-1B).

When emulating the commercial fishery using submerged hoop nets, we captured 3025 fish of eight species, and 50 non-fish fauna (3 turtle species and 1 mammal species) for a total of 3075 organisms captured during our study (Table 4-1). We captured fewer animals with hoop nets with floats: 2040 fish of nine species, and 35 turtles of four species, for a total catch of 2075 (Table 4-1). We experienced mortality during our study. In submerged nets and float nets, 12.5% (4/32) and 23.5% (4/17) of northern pike (*Esox lucius*) died, respectively. Minimal mortality (<0.005%) of bluegill (*Lepomis macrochirus*) and pumpkinseed (*Lepomis gibbosus*) occurred for each net type. Turtle

mortality (N = 3) only occurred in submerged nets, in which 12.5% (2/16) of painted turtles and 20% (1/5) of northern map turtles captured died. Mammals, specifically muskrat (*Ondatra zibethicus*), were only captured in submerged nets and all died.

Catch rates were similar for fish ($T_{29} = 1.862$, $P = 0.073$) although mean catch rates were slightly higher in submerged nets (3.05 ± 0.31 fish/hour) than nets with floats (2.54 ± 0.34 fish/hour). Finally, turtle catch rates were also similar between submerged nets (0.10 ± 0.04 turtles/hour) and nets with floats (0.06 ± 0.02 turtles/hour; $Z = -0.224$, $P = 0.823$). Species composition also did not vary between net types ($A = 0.012$, $P = 0.172$).

Blood lactate levels in turtles differed significantly between individuals captured in nets with floats and those without as well as between species ($F_{3,47} = 112.843$, $P < 0.001$, $R^2 = 0.870$). Painted turtles in submerged nets (N = 16) had significantly higher lactate levels than any other group (16.1 ± 0.6 mmol/l; Figure 4-2). Eastern musk turtles in submerged nets (N = 19) had significantly lower lactate levels (13.8 ± 0.5 mmol/l) than submerged painted turtles (Figure 4-2). Both painted turtles (N = 8) and eastern musk turtles (N = 8) in nets with floats had similar lactate levels (4.2 ± 0.9 and 1.9 ± 0.5 mmol/l, respectively) which were significantly lower than lactate levels in both turtle species from submerged nets (Figure 4-2).

Discussion

In the controlled experiment, painted turtles in submerged nets had significantly higher blood lactate levels and significantly lower blood pH than both surfaced nets and nets with floats, thus indicating that turtles in submerged nets were experiencing anoxia. Previous studies of anoxic painted turtles at 20-22 °C (i.e., Keiver et al 1992a; Warren and Jackson, 2004) yielded lactate and blood pH values that were consistent with the

values we observed when we sampled turtles from submerged nets without air spaces, thus confirming that turtles in our submerged nets did indeed experience anoxia. Given that baseline lactate and pH levels for painted turtles are typically ~1.5 mmol/l and ~7.8 pH, respectively (Keiver et al, 1992a; 1992b; Warren and Jackson, 2004), our results indicate that turtles were using the air space in both the surfaced net and the net with floats to breathe, and were not experiencing anoxia. Turtles in nets with floats had slightly (yet significantly) higher lactate levels and lower blood pH than turtles in surfaced nets, so it appears that turtles in nets with floats had more difficulty obtaining air. Lactate and blood pH levels from turtles in nets with floats still fell within the baseline measures from previous studies. Therefore, in comparison to submerged nets, nets with floats significantly reduced the risk of anoxia and ensuing drowning in painted turtles.

When using commercial fishing practices, there was no statistically significant difference in catch rates or catch composition between submerged nets and nets with floats. Both submerged and float nets experienced similar levels of fish mortality; minimal mortality of *Lepomis* spp. and substantial mortality (>12%) of pike. Even though the two net types fished similarly with no statistically significant difference, mean catch rates for fish and turtles was lower in nets with floats. This lower catch rate in nets with floats translated into a reduction of 1000 organisms (or 32.5%) in the total catches compared to control nets (Table 4-1). As commercial fishers typically have much greater fishing effort, using floats in nets could result in a reduction in their overall catches and, thus, resistance to the adoption of this gear modification (Broadhurst, 2000). A possible explanation for this slightly lower catch rate is that floats in the cod-end of nets cause the

nets to be set diagonally instead of horizontally. As set depth increases, the severity of the diagonal net set increases and this may make it less likely for organisms to swim through the funnels of the hoop net to be captured.

Both painted turtles and eastern musk turtles had significantly lower blood lactate levels in nets with floats compared to submerged nets when using commercial fishing practices. Turtle mortality experienced in submerged nets indicated that turtles were in nets long enough to experience anoxia, and variation in lactate levels was likely due to the unknown duration that turtles spent in the submerged net prior to lifting (Figure 4-2). On the other hand, the absence of mortality and low blood lactate levels of turtles in nets with floats indicate that floats prevented anoxia in turtles. Mean lactate levels of painted turtles in nets with floats, however, were two-fold higher than when tested in our controlled conditions. Variation in blood lactate levels (0.7 - 8.3 mmol/l) of turtles in nets with floats suggest that these turtles may still experience anoxia and/or some level of physical exhaustion while attempting to escape, albeit much less severe than in nets without floats. The size of the air space created by floats may play a role in effectively mitigating anoxia in turtles, as Larocque *et al.* (in press) documented substantial (33%) turtle mortality in a lake even with the use of floats in hoop nets.

Painted turtles experienced higher lactate levels than musk turtles in both submerged nets and nets with floats. The difference in lactate levels is likely due to morphological and physiological differences between the two species. Most aquatic turtles are bimodal breathers (exchanging O₂ and CO₂ in both air and water; Gage and Gage, 1886; Ernst *et al.*, 1994). Eastern musk turtles, however, excel at obtaining oxygen in water through various morphological adaptations while painted turtles are poor at

doing so (Ultsch and Wasser, 1990; Ernst *et al.* 1994). Thus, musk turtles can obtain more oxygen underwater and lactate levels would therefore be less likely to increase as much as in painted turtles (Ultsch and Wasser, 1990; Prassack *et al.*, 2001).

Physiologically, painted turtles are anoxia tolerant and are capable of sustaining high lactate levels, whereas musk turtles are relatively anoxia intolerant (Jackson *et al.*, 2007). If trapped in nets in normoxic water, however, musk turtles may be able to withstand longer submergence as they are better able to extract oxygen from the water than painted turtles.

The use of floats could be a potential solution to mitigating the mortality of freshwater turtles and other air breathing organisms captured in hoop nets. Blood lactate levels, an indicator of anaerobic metabolism (including exercise) and anoxia, were reduced when using floats in hoop nets instead of submerged nets. Although we did not detect a statistical difference in catch rates, the overall total catch was roughly 1/3rd less when floats were used while emulating commercial fisheries, so there may be some challenges with acceptance of float use by fishers. Using floats will also make the nets more visible than if they were totally submerged, although less so than if using surfaced nets in shallower waters, which are less likely to be fished. Net visibility is of concern to commercial hoop net fishers as there is the potential for an increased risk of vandalism and theft as well as a perceived (but not studied) risk of avian predation on fish when nets are visible. Aside from commercial fisheries, other organisations (e.g., academic and government research) use hoop nets for research and monitoring, and should use floats in nets to mitigate turtle mortality. Although the use of floats to create air spaces of

sufficient size will not reduce bycatch in hoop nets, it is a simple, immediate, and cost effective method to avoid the drowning of turtles that are encountered.

Tables

Table 4-1. Number and composition of organisms captured in hoop nets that were submerged or had floats (N = 30 paired net sets per net type) in Lake Opinicon, Canada.

Group	Species	Submerged		Floats	
		Number caught	%	Number caught	%
Fish	Bluegill	1519	49.40%	1044	50.31%
	Pumpkinseed	1091	35.48%	750	36.14%
	Largemouth bass	135	4.39%	95	4.58%
	Rock bass	127	4.13%	59	2.84%
	Bullhead spp.	95	3.09%	43	2.07%
	Northern pike	32	1.04%	17	0.82%
	Black crappie	23	0.75%	29	1.40%
	Smallmouth bass	3	0.10%	2	0.10%
	Yellow perch	0	0.00%	1	0.05%
	Non-fish bycatch	Eastern musk turtle	27	0.88%	18
Painted turtle		16	0.52%	9	0.43%
Northern map turtle		5	0.16%	7	0.34%
Muskrat		2	0.07%	0	0.00%
Common snapping turtle		0	0.00%	1	0.05%
Grand total		3075	100%	2075	100%

Figures

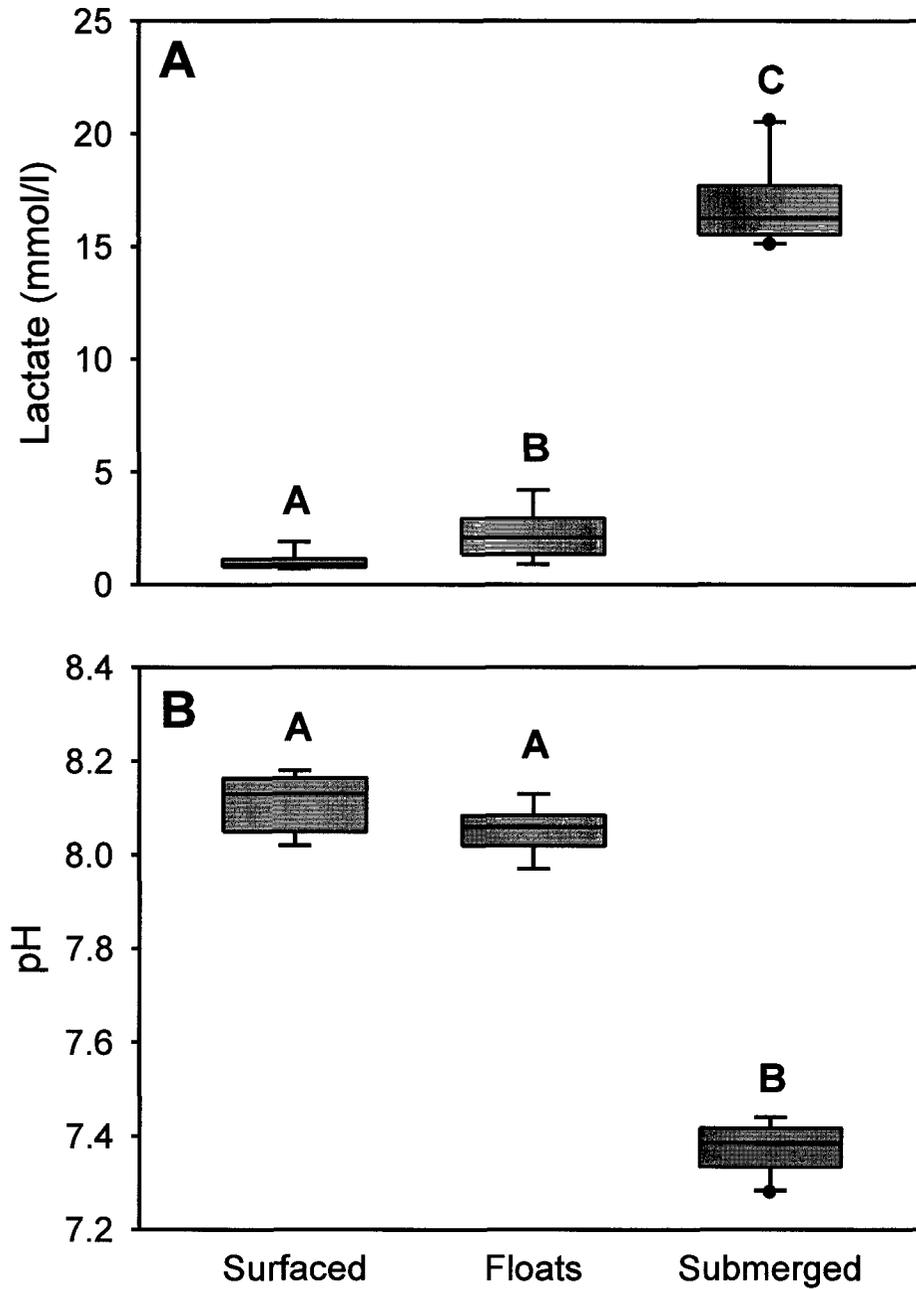


Figure 4-1. A) Blood lactate (mmol/l) from painted turtles (*Chrysemys picta*) after being subjected to four hours in one of three net types was lowest in surfaced hoop nets, slightly higher in hoop nets with floats, and highest in submerged hoop nets while B) blood pH was highest in surfaced nets and nets with floats and lowest in submerged nets.

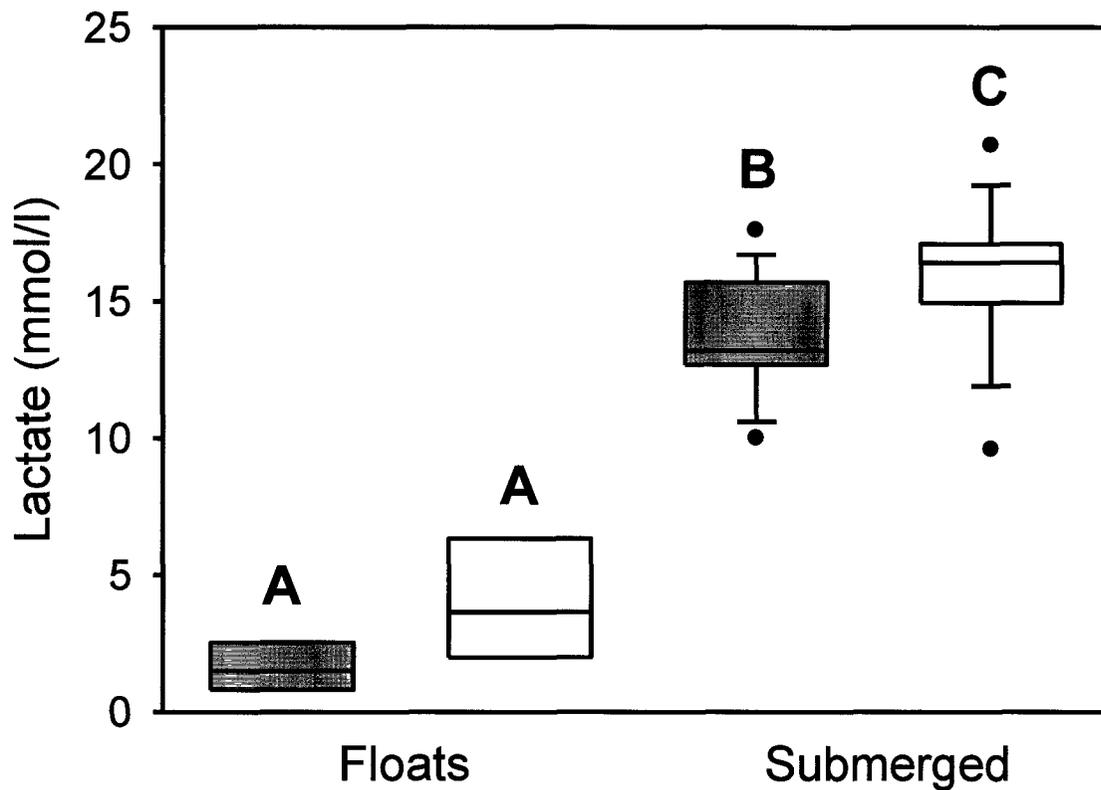


Figure 4-2. Blood lactate (mmol/l) was lowest in both painted turtles (*Chrysemys picta*; white boxes) and eastern musk turtles (*Sternotherus odoratus*; grey boxes) captured in hoop nets with floats, second highest in eastern musk turtles captured in submerged hoop nets, and highest in painted turtles captured in submerged hoop nets that were set in Lake Opinicon, Canada.

Chapter 5: General discussion

Through three complementary studies, this thesis forms a cohesive account of different approaches to mitigate freshwater turtle bycatch in hoop nets. Although my fishing designs were emulated for the eastern Ontario inland commercial fisheries, the results should be applicable to similar fisheries worldwide. The approaches to mitigate bycatch and associated mortality that I investigated were temporal variations in bycatch reduction via seasonal restrictions (Chapter 2), the use of bycatch reduction devices (Chapter 3), and preventing mortality of bycatch with gear modifications (Chapter 4). Importantly, this thesis contains the first study to document both the species composition of bycatch encountered and the rate at which bycatch species are captured within hoop nets in temperate warm-water lakes in eastern Ontario (Chapter 2). I also provide a synopsis of the effects of dead fish, a potential food source and attractant, on the capture rate of turtles into hoop nets (Appendix I). The overall objective of this thesis was to highlight the importance of the turtle bycatch issue and to explore freshwater turtle bycatch mitigation techniques. Many of these bycatch mitigation methods have been applied to marine systems; I have shown here the effectiveness of these mitigation methods in freshwater. More specifically, I have expanded our knowledge of freshwater turtle bycatch and discovered effective bycatch mitigation methods for the eastern Ontario inland commercial hoop net fishery.

Findings and implications

Few studies have addressed freshwater bycatch, let alone freshwater turtle bycatch (Raby *et al.*, 2011). Only a handful of studies have documented the occurrence of turtle bycatch in inland commercial fisheries (e.g., Michaletz and Sullivan, 2002; Barko

et al., 2004; Carrière, 2007). Thus, by determining the species composition of bycatch, as well as their potential catch rates and mortality rates in chapter two, I have broadened our knowledge considerably. Given that most small-scale commercial fisheries worldwide are not required to document bycatch, the bycatch composition and rate information presented here is particularly valuable. The occurrence of turtle catches, including at risk species, was more frequent than anticipated and motivated mitigation measures explored in the subsequent studies (Figure 5-1).

In chapter two, I found that turtles were captured more frequently in the spring than in the fall, while there was no seasonal pattern for fish. This has direct implications for the eastern Ontario commercial hoop net fishery. One method of bycatch mitigation involves temporal closures of a fishery (Broadhurst, 2000). Given the difference in turtle captures between the two most common fishing seasons, I recommend to encourage fishing primarily in the fall to reduce turtle captures. Aside from reduced turtle catches in autumn, water temperatures were cooler in fall and turtles would thus be more tolerant of anoxia (Herbert and Jackson, 1985). Also, cooler temperatures would enhance fish flesh quality. However, fishing only in fall would not eliminate turtle bycatch mortality completely and gear modifications are still warranted.

Gear modifications to mitigate turtle bycatch mortality were the focus of chapters three and four. All methods, whether to exclude turtles, allow their escape, or keep them alive, were effective. Gear modifications that are easy to use, low cost, and with no negative effects on target catch rates are more likely to be accepted by commercial fishers (Broadhurst, 2000). I kept these factors in mind while designing the gear modifications that I evaluated. Nets with air spaces were the easiest and cheapest of the methods to

implement (Figure 5-2). There was no effect of the exclusion devices on target fish (Figure 5-3A; 5-3B). The escape chimney, however, allowed 12% of target fish to escape (Figure 5-4) and nets with air spaces had an overall total catch that was 33% lower than unmodified nets. Thus, commercial fishers would be most likely to accept the exclusion devices. In terms of avoiding turtle mortality, both the escape chimney and nets with air spaces were considered effective. Nets with air spaces can still lead to turtle drowning as turtles can get captured in parts of the net without an air space (S. M. Larocque, unpublished data). Taking all these factors into consideration, I recommend using hoop nets with either an air space or an escape chimney to prevent most turtle mortality. The use of the escape chimney in tandem with an exclusion device would also be a good solution as the exclusion device should exclude large turtles, while the small turtles should escape through the chimney. I found evidence, however, that small eastern musk turtles were excluded, but not larger species. In any case, exclusion devices alone do not prevent all turtle captures/mortality.

In conclusion, I have a few recommendations for management and hoop net fishers to mitigate turtle bycatch mortality. I advise to concentrate fishing efforts in the fall, use nets with air pockets, or use the escape chimney with exclusion bars/ring. Bycatch mitigation can involve an integration of various bycatch reduction methods, and so the most effective turtle mortality mitigation option would be to advocate fall fishing, while using an escape chimney/exclusion device combination. Some of my recommendations would prevent turtle mortality and maintain target fish catches more than others. Providing the evidence to commercial fishers and obtaining their feedback and involvement is an important step towards the acceptance of changes in fishing

practices or gears (Kennelly, 1999; Hall and Mainprize, 2005). With managers and commercial fishers working together, the information I presented here will provide the impetus for a move towards the reduction of freshwater turtle bycatch to sustainable levels.

Future research directions

Although in this thesis I have contributed many potential tactics to reduce freshwater turtle bycatch effectively, it is only the first step towards implementing solutions within the fishery and further research is required. For instance, although I documented the rate at which turtle bycatch occurs in temperate warm-water lakes, we do not know what proportion of the total turtle population bycatch represents. Comparing population sizes to turtle bycatch from commercial fishing would give a more accurate idea of the potential impact of hoop nets on turtle populations.

Future research on mitigation methodologies would complement the findings I presented here. As the eastern Ontario commercial fishery operates on both inland lakes and large river systems, it would be appropriate to determine if the seasonality of turtle catches are the same and if the gear modifications are equally effective in the river systems. Water flow, water temperature, and habitat differ between lakes and rivers and my results may not thus apply to lotic systems.

Additional research can help optimize the gear modifications. For example, determining the behaviour of turtles when entering and within the nets could inform the design of even more effective gear modifications. Expanding this research to species other than painted turtles (e.g., testing the efficacy of the escape chimney) is necessary.

The common painted turtle was a good model species, but determining whether modifications prevent mortality of the at risk species should be a priority.

Finally, if turtles were to survive a capture event within a hoop net, the question remains whether turtles are negatively affected after their release. Both short and long-term consequences of a capture event are unknown. Potentially, turtles are subject to post-capture mortality, as can happen with fish (Davis, 2002). Determining methods to minimize deleterious effects and accelerate recovery of captured turtles could mitigate potential post-capture mortality. All of these future research directions would solidify freshwater turtle bycatch mitigation techniques as well as provide a deeper understanding of freshwater turtle bycatch in hoop nets.

Figures

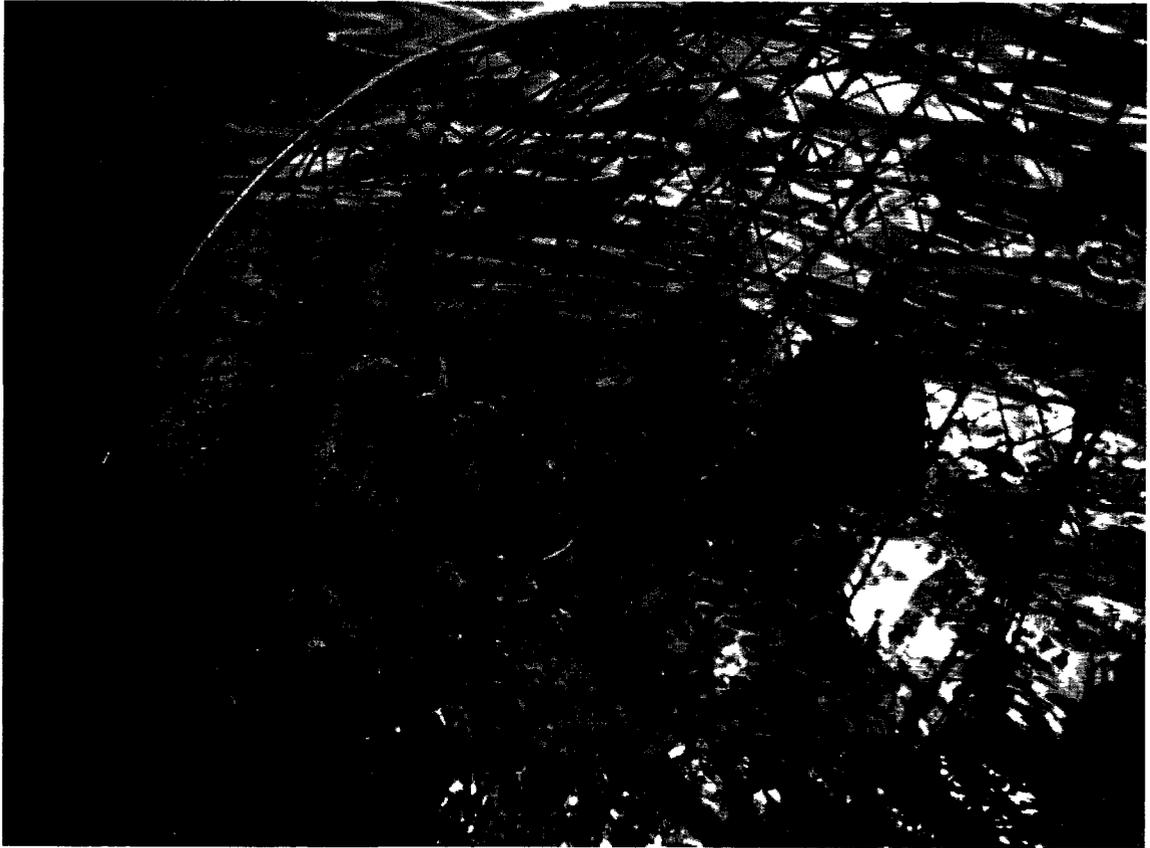


Figure 5-1. A hoop net being pulled out of the water containing both eastern musk turtle (*Sternotherus odoratus* – turtle on the left) and painted turtles (*Chrysemys picta* – three turtles to the right).



Figure 5-2. A hoop net breaches the surface through the use of floats (i.e., water jugs and Styrofoam in a black garbage bag).



Figure 5-3. A hoop net with an exclusion device attached that either has A) vertically placed exclusion bars (i.e., wooden dowels) fitted over the net opening or B) a rectangular-shaped rigid exclusion ring (i.e., hose clamp) placed at the first funnel of the net – shown by the circle.

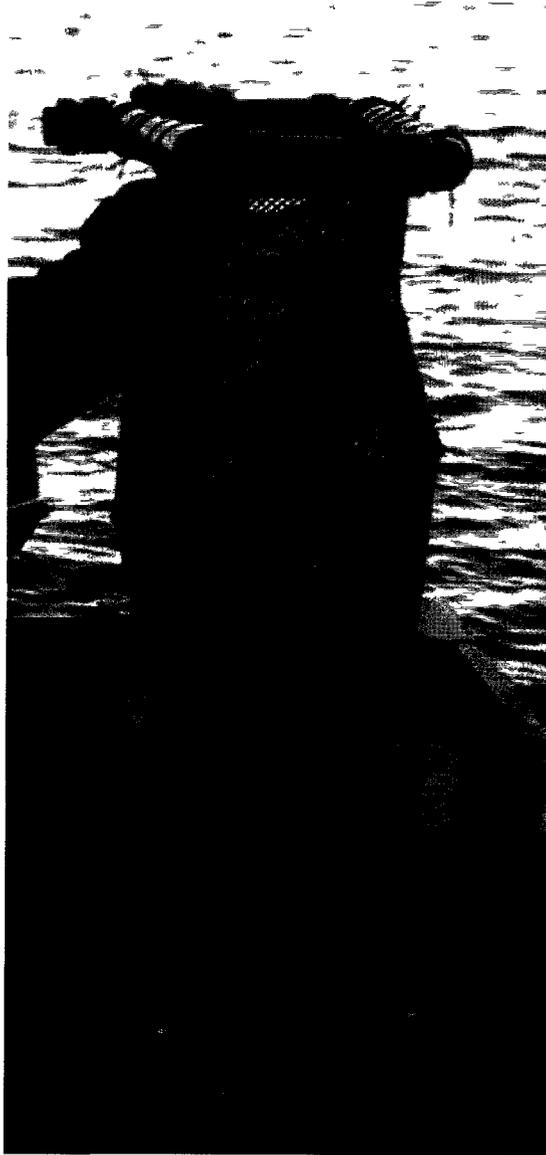


Figure 5-4. Escape chimney attached to the cod-end of a hoop net. A small hole exists in the mesh at the top of the chimney to allow turtles to swim out.

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Appendix I: Accidental lure: are deceased fish increasing freshwater turtle bycatch in commercial hoop nets?

Abstract

Bycatch of turtles in passive inland hoop net fisheries has been poorly studied, yet is an important conservation issue given the decline in many freshwater turtles.

Prolonged submergence in nets can lead to stress and the eventual drowning of turtles.

Fish that die within passive fishing nets that are infrequently checked are a potential food source for many freshwater turtles and could thus act as attractants and increase turtle captures. We investigated the attraction of turtles to decomposing fish within hoop nets in eastern Ontario. We emulated commercial fisheries in the region and set hoop nets with either 1 kg of one-day or five-day decomposed fish, or no decomposed fish in the cod end of the net. Decomposing fish did not significantly alter the capture rate of turtles and fish nor the species composition. Thus, increasing the frequency of net tending is unlikely to alter turtle bycatch rates by reducing attraction. Interestingly, increased water temperatures significantly increased turtle bycatch rates. Water temperature also influences turtle mortality depending on the duration a net is fished, thus establishing a maximum water temperature that nets can be set was a suggested regulation change. Greater effort needs to be devoted to mitigate turtle bycatch mortality to reduce the impact of passive hoop net fisheries on turtle populations.