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

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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 south-eastern 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 2 or 6 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 to 6 days. 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 & Mainprize, 2005; Harrington, Myers & Rosenberg, 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, Alverson & Metuzals, 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 & 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 south-eastern 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, Burbur & Harrington, 1981; Barko, Briggler & Osendorf, 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 south-eastern 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 & 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, Lovich & Barbour, 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 & Murawski, 1998). In the south-eastern 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 as a result of 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 to: (1) document the frequency and composition of bycatch within two shallow warm-water lakes typical of the commercial hoop net fishery in Ontario; (2) compare bycatch between spring and fall; (3) 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 because of increased activity levels. We also expected longer net sets to result in higher mortality because of additional stress and injury from net confinement.

Materials and 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 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 45° angle from the entrance of the net (Fig. 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

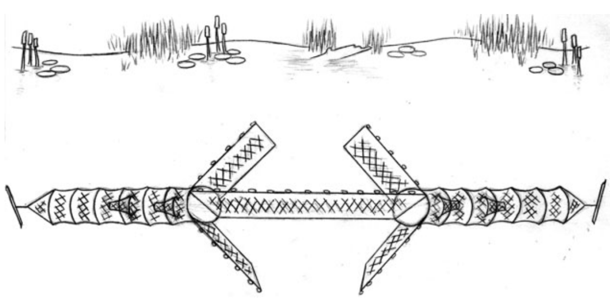

Figure 1 Illustration of a bird’s eye view of tandem commercial hoop nets connected by a lead with two wings attached per net, set parallel to shore.

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 h) 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 & Jackson (1985). To determine the extent of fish mortality in hoop nets of different set durations, we set nets in Newboro Lake for either 2 or 6 days. For both durations, nets were set for 2 days allowing animals to enter, and either lifted (2-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 4 more days (6-day set). All non-fish bycatch were removed from the nets prior to closing the net off for the 6-day set. This allowed for a comparison of fish caught and retained in the nets for 0–2 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. Because of 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/hour) to standardize for set duration, under the assumption that CPUE would be similar in relation to set durations with net sets < 48 h as found by Breen & 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 CPUEs and turtle CPUEs were non-normal and therefore a Wilcoxon rank-sum test was used. These tests were performed in SPSS 18.0.0.

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 multiresponse permutated procedure (MRPP) and indicator species analysis (ISA; PC-ORD 5.20: McCune & 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 2- or 6-day net sets in Newboro Lake was 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 & Iman, 1982) in SPSS 18.0.0. For all statistical tests, significance was accepted at $a = 0.05$. All means are reported ± 1SE.

Results

Catch quantity and composition

In Newboro Lake we set 56 tandem nets (29 2-day sets with 2463 total fishing hours; 27 6-day sets with 2024 total fishing hours) and captured 7702 fish of 10 species (Table 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 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 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 (two mammal species; three turtle species), of which most (93.1%) were turtles (Table 1). Similarly, in Lake Opinicon, we captured 118 non-fish organisms as bycatch (one mammal species; four turtle species), consisting of 98.3% turtles in spring and 100% of the 66 non-fish bycatch were turtles in fall (three species; Table 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 1). Of the air-breathing organisms captured, all six mammals died, and 33% of the 54 turtles captured in Newboro Lake perished also. No turtle mortalities occurred in Lake Opinicon.

Table 1 Number and composition of hoop net catches from two lakes in south-eastern Ontario, Canada

	Newboro		Opinicon – Spring		Opinicon – Fall	
	Number caught	Overall percentage	Number caught	Overall percentage	Number caught	Overall percentage
Target fish species						
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

There were 56 net sets in Newboro Lake and 45 net sets per season in Lake Opinicon.

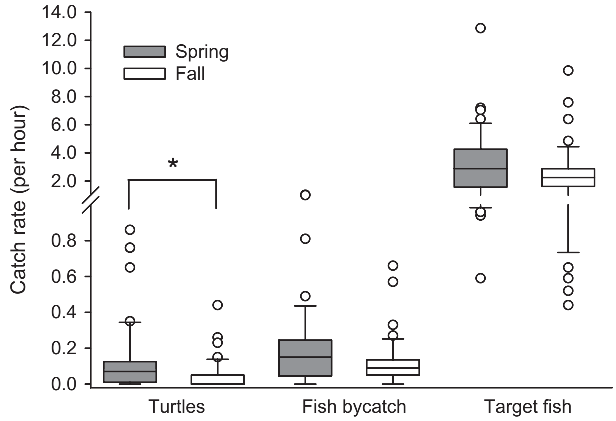

Figure 2 Turtles were captured more often in spring than in fall in hoop nets set in Lake Opinicon, Ontario, Canada, but catches of both fish bycatch and target fish did not vary seasonally.

Spring/fall comparison

Total spring and fall captures for target fish were similar (Table 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; $t_{88} = 1.612$; $P = 0.111$; Fig. 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).

Total fish bycatch captures were similar in spring and fall (Table 1). Mean fish bycatch rates were also similar between spring (0.19 ± 0.03 fish/hour) and fall (0.12 ± 0.02 fish/hour; $W_s = 1831.00$; $Z = 1.750$; $P = 0.080$; Fig. 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).

Total turtle captures in spring were nearly double the captures in fall (Table 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; $W_s = 1657.50$; $Z = 3.236$; $P = 0.001$; Fig. 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).

Net set duration mortality

Bluegill, pumpkinseed and northern pike represented most of the mortalities for both 2- and 6-day nets (Table 3). The proportion of target fish dead in nets after 2 days (0.003 ± 0.002) was significantly less than after 6 days (0.030 ± 0.017; $F_{1,52} = 6.327$; $P = 0.015$; Fig. 3a). Tempera-

Table 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

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

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 ($P < 0.05$).

Table 3 Sum and overall percentage of fish deaths relative to total catch that occurred in 2- and 6-day hoop net sets from Newboro Lake, Ontario, Canada

	Two-day net set		Six-day net set	
Species	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

ture had no effect on the proportion of dead target fish ($F_{1,52} = 0.362$; $P = 0.550$; Fig. 3a). The proportion of bycatch fish dead in 2-day net sets (0.009 ± 0.006) was significantly less than in 6-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 ($F_{1,52} = 0.022$; $P = 0.882$; Fig. 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 & Ream, 1966). According to the Committee on the Status of

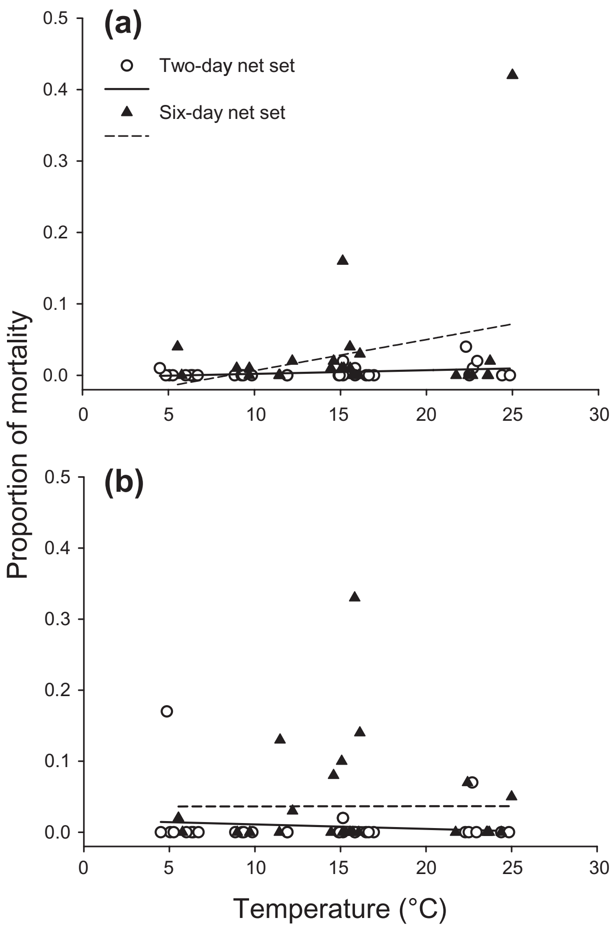

Figure 3 Proportion mortality of (a) target fish and (b) fish bycatch were both lower in 2-day net sets than in 6 day net sets in Newboro Lake, Ontario, Canada, yet mortality was unaffected by water temperature.

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 & 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 & 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 & Bergersen, 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 because of reproductive behaviours (Gibbons, Greene & Congdon, 1990), increasing net encounter rates and therefore catch rates. Gibbons (1968) found painted turtle captures declined in the fall, when compared with 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 overwinter (Gibbons *et al.*, 1990). Obbard & Brooks (1981) found that 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 & 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, Woodley & Cech Jr, 2006). Mortality levels may also be higher in commercial fisheries with longer net sets as the 6-day treatment was only fished for 2 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 & 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 Jr *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, Brown & Glabraith, 1991; Congdon, Dunham & Van Loben Sels, 1993; Congdon, Dunham & Van Loben Sels, 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 & 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, Crowder & Shaver, 2003; Lewison *et al*., 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 3 days at 15°C, but this duration exponentially decreases as temperatures increase (Herbert & 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; Fratto, Barko & Scheibe, 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.

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