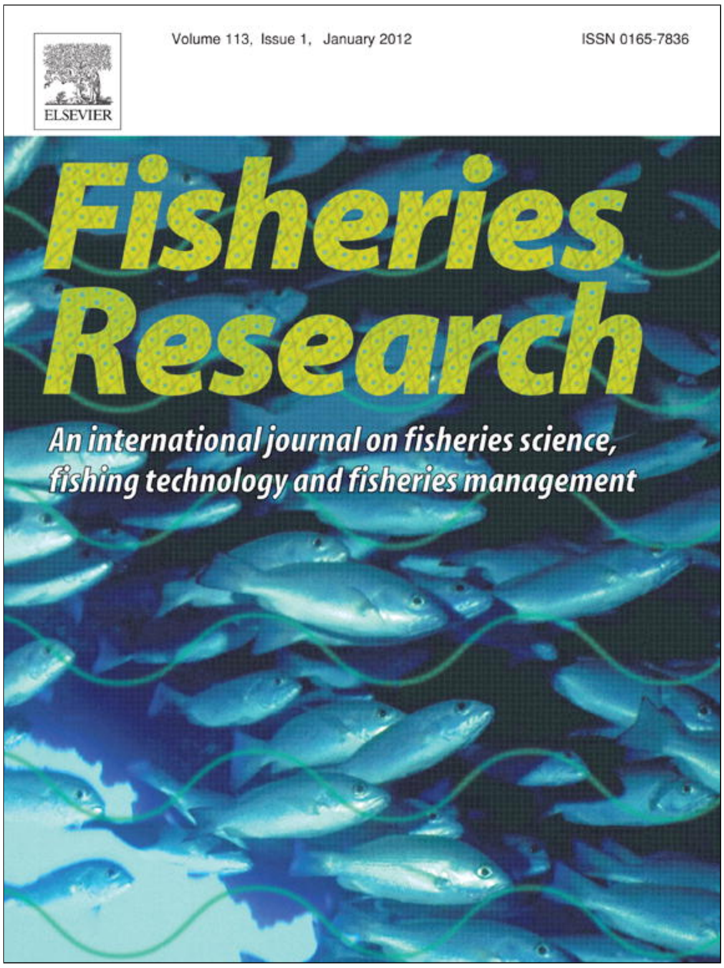
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Mitigating bycatch of freshwater turtles in passively fished fyke nets through the use of exclusion and escape modifications

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ABSTRACT

Turtles are vulnerable to population declines in response to even low levels of additional adult mortality, for instance bycatch mortality. Inland commercial fisheries that use passive gears such as fyke nets cause the drowning of some freshwater turtles. To reduce fisheries impacts on turtles, bycatch reduction devices (BRDs) successfully implemented in marine systems may be adapted to freshwater systems. We tested the efficacy of two BRDs designed to exclude turtles from fyke nets by comparing catch rates and composition to unmodified nets. We also tested the efficacy of a BRD designed to let turtles escape the net 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 did not affect fish catch rates. With the escape device, all turtles escaped (using painted turtles, *Chrysemys picta*, as an experimental model) and most (88%) fish were retained while a large hole allowed 60% and 77% of turtles and fish to escape, respectively. The escape device was the most effective for avoiding turtle bycatch mortality while retaining fish. Implementing the escape device or a combination of both exclusion and escape devices would reduce turtle bycatch mortality within fyke net fisheries. However, evaluations are needed to test the effectiveness of escape designs on additional turtle species and in different environments.

1. Introduction

Various threats are causing reptiles to decline globally, with turtles being particularly imperiled (Gibbons et al., 2002; IUCN, 2011). One such threat to turtles is their incidental capture as bycatch in commercial fisheries (Alverson et al., 1994; Hall et al., 2000; Lewison and Crowder, 2007; Lewison et al., 2004). 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; Bulté et al., 2010; Congdon et al., 1993, 1994). Thus, turtle bycatch mortality is a serious conservation issue and research on bycatch has increased dramatically over the past decade (Soykan et al., 2008). This bycatch research, however, has primarily focused 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 fyke nets, trap nets, and gill nets to capture targeted fish. For example, in a small-scale inland fishery in southeastern Ontario, fishers use fyke nets to capture sunfish (*Lepomis* spp.), bullheads (*Ameiurus* spp.), yellow perch (*Perca flavescens*), rock bass (*Ambloplites rupestris*), and black crappie (*Pomoxis nigromaculatus*; Burns, 2007). Fyke 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 fyke 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 fyke nets (and other passive nets) has been documented in fisheries globally (Barko et al., 2004; Beumer et al., 1981; Grant et al., 2004; Larocque et al., 2012; Lowry et al., 2005). Of the documented bycatch, the incidental capture of adult freshwater turtles, including species at risk (e.g., Larocque et al., 2012) is a reoccurring issue in Ontario and elsewhere. In addition, the number of adult freshwater turtles captured (e.g., 95% of turtles captured were adults in Larocque et al., 2012) indicates that bycatch is a threat to many populations (e.g., Barko et al., 2004; Michaletz and Sullivan, 2002).

With a known risk to turtle populations, efforts should be focused on ways to reduce bycatch and mortality associated with

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inland fisheries. Reductions in bycatch mortality can be achieved by making changes to fishing practices and fishing gear (Hall and Mainprize, 2005) with the most common method being gear modifications (Broadhurst, 2000; Gilman et al., 2010; Lewison et al., 2004). Gear modifications try to exploit behavioral 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). Some of these bycatch reduction devices (BRDs) designed for sea turtles have the potential to be adapted to reduce freshwater turtle bycatch in fyke 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 much smaller than between sea turtles and shrimp. However, the same size-based principle that is used to exclude sea turtles from nets has also been applied to freshwater turtles (e.g., Fratto et al., 2008; Lowry et al., 2005) and could be potentially effective with fyke nets. The second category of BRDs involves those that exploit behavioral differences between target and bycatch species to allow the latter to escape while retaining the former (Broadhurst, 2000; Crespi and Prado, 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. Escape modifications have been attempted in freshwater nets (e.g., Fratto et al., 2008; Lowry et al., 2005).

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 fyke nets. Specifically, we wished to determine the efficacy of (1) exclusion bars and (2) exclusion rings fitted at the entrance of fyke nets at rejecting turtles and allowing target fish capture by simulating commercial fyke net fishing in southeastern Ontario. 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.

2. Materials and methods

2.1. Study area

Our study was conducted during spring of 2010 and 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 warmwater lake with a mean depth of 2.8 m. Water temperatures ranged from 12.7 to 25.9 °C in spring and from 13.6 to 20.0 °C in fall.

2.2. Fyke net modifications

All fyke nets (modified and unmodified) had similar dimensions as those used in the local commercial fishery (Fig. 1a). Each fyke 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

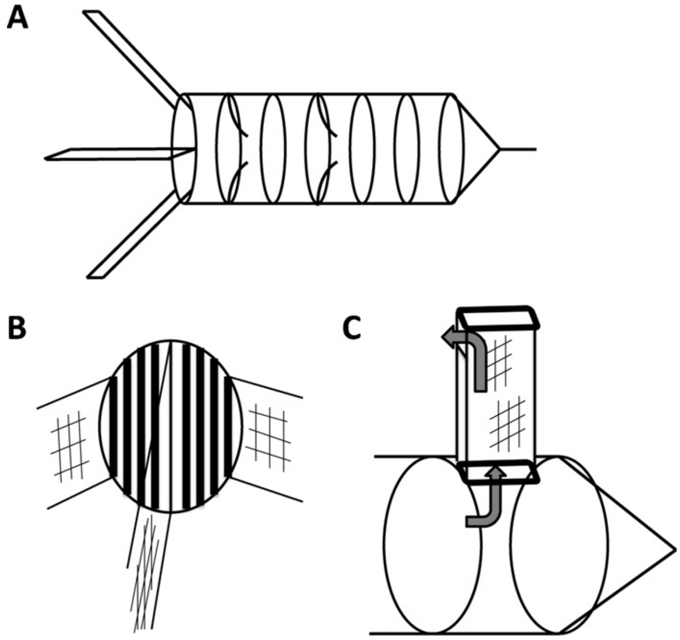

Fig. 1. Illustrations of (a) an overhead view of an unmodified fyke net with a lead and two wings attached, (b) the opening of the exclusion bar net, and (c) the cod end of a fyke net with an escape chimney attached, where arrows represent the escape route of turtles.

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.

Two fyke net modifications designed to exclude turtles were tested. Our first modification was exclusion bars that were constructed by attaching 1.27 cm diameter wooden dowels across the first hoop of the net (Fig. 1b). Eight dowels were positioned vertically across the opening of the net, all spaced 8.0 cm apart. All adult 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 that was constructed by attaching a hose clamp at the first funnel of the fyke 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 unmodified yielding funnel mesh.

Finally, an escape modification was tested by attaching a chimney-like structure to the fyke net (Fig. 1c). This escape chimney was based on Fratto et al. (2008) in which a mesh tube (1.0 cm mesh) 15 cm wide by 28 cm long by 85 cm tall was attached to the net between the sixth and seventh hoop. At the attachment site, a hole was made 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. Two steel wire rings were attached 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.

2.3. Exclusion vs. unmodified nets

Fishing practices commonly employed by commercial fishers in our study area were used. Several days were spent alongside fishers to identify how gear is deployed and the habitats targeted. We set nets in tandem by adjoining two fyke 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 h) according to water temperature to prevent turtle mortality (i.e., shorter sets with warmer water based on survival durations in 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.

2.4. Escape chimney vs. large hole

To determine the effectiveness of the escape chimney, we compared the escape capacity of turtles and fish from the chimney design to a net with a large hole (a typical damage incurred to nets during normal fishing) of similar dimensions (15 cm by 28 cm) in spring of 2010 and 2011. Both nets were set at a depth of 1.5 m and we 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 ± SE: 140.6 ± 1.7 mm; mean carapace width ± SE: 103.4 ± 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. Fish escape capacity was also tested 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 h (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: $N = 10$).

2.5. Data analyses

We compared catch rates of target fish, fish bycatch, and turtles in nets modified for the exclusion of turtles and unmodified nets. To compare net types, catch per unit effort (CPUE-catch/h) was calculated for each tandem net to standardize for variation in net set duration. For target fish catches, fish bycatch, and turtle bycatch 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.), that net was removed from the calculation. 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). The MRBP is a multivariate analysis that allows us to determine whether the capture rates of individual species differs between treatments, and the ISA indicates which species differed if an overall difference was found.

Fish were scored with either presence (e.g., abrasions, wounds) or absence of injury. The occurrence of 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 or pumpkinseed 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 efficacy of the gear modification, in terms of escape capacity, for 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. All chi square tests, Fisher's exact tests, *t*-tests, and Wilcoxon signed ranks tests were performed in SPSS 18.0.0. For all tests significance was accepted at $\alpha = 0.05$. Values are reported as mean ± SE.

3. Results

3.1. 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 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 1). Unmodified net target fish catch rates (2.86 ± 0.30 fish/h) were not significantly different from the exclusion bar net catch rates (2.89 ± 0.29 fish/h; $t_{29} = 0.498$; $P = 0.622$; $d = 0.09$; Fig. 2a). Target fish species composition also did not significantly differ between treatments ($A = 0.019$; $P = 1.00$). Fish bycatch rates in unmodified nets (0.19 ± 0.03 fish/h) were not significantly different from those of exclusion bar nets (0.21 ± 0.03 fish/h; $Z = 0.508$; $P = 0.611$; $r = 0.09$; Fig. 2b), nor did fish bycatch species composition differ significantly ($A = 0.004$; $P = 0.284$). Turtle catch rates in unmodified nets (0.10 ± 0.04 turtles/h) were significantly higher than in exclusion bar nets (0.03 ± 0.01 turtles/h; $Z = 2.107$; $P = 0.035$; $r = 0.38$; Fig. 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/h) than exclusion bar nets (0.01 ± 0.01 turtles/h; $P = 0.031$). 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; $\Phi = 0.001$). Bluegill captured in unmodified nets were significantly larger (177 ± 4 mm) than those captured in nets equipped with exclusion bars (170 ± 3 mm; $t_{28} = 4.164$; $P < 0.001$; $d = 0.77$). For pumpkinseed there was no difference in size of fish captured

Table 1
Number and composition of modified and unmodified fyke 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								
Lepomis macrochirus	1519	49.40	1629	47.94	1171	67.03	954	64.42
Lepomis gibbosus	1091	35.48	1204	35.43	385	22.04	372	25.12
Pomoxis nigromaculatus	23	0.75	33	0.97	9	0.52	11	0.74
Ambloplites rupestris	127	4.13	159	4.68	11	0.63	2	0.14
Ameiurus spp.	95	3.09	135	3.97	81	4.64	62	4.19
Perca flavescens	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								
Micropterus salmoides	135	4.39	186	5.47	58	3.32	67	4.52
Esox lucius	32	1.04	24	0.71	5	0.29	4	0.27
Micropterus dolomieu	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								
Chrysemys picta	16	0.52	10	0.29	4	0.23	4	0.27
Graptemys geographica	5	0.16	5	0.15	0	0	0	0
Sternotherus odoratus	27	0.88	7	0.21	22	1.26	5	0.34
Ondatra zibethicus	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

in unmodified (192 ± 3 mm) and exclusion bar nets (189 ± 3 mm; $Z = 0.249$; $P = 0.804$; $r = 0.05$).

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 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 1). Unmodified net target fish catch rates (2.85 ± 0.66 fish/h) were not significantly different from exclusion ring catch rates (2.59 ± 0.42 fish/h; $t_{14} = 0.072$; $P = 0.943$; $d = 0.01$; Fig. 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/h) were not significantly different from those of exclusion ring nets (0.13 ± 0.04 fish/h; $Z = 0.114$; $P = 0.910$; $r = 0.03$; Fig. 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/h) were not significantly different from those in exclusion ring nets (0.02 ± 0.01 turtles/h; $Z = 1.260$; $P = 0.208$; $r = 0.33$; Fig. 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 ($X^2{}_1 = 1.321$; $P = 0.250$; $\Phi = 0.027$). 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; $Z = 0.157$; $P = 0.875$; $r = 0.04$). The size of pumpkinseed were also similar between unmodified (180 ± 4 mm) and exclusion ring nets (176 ± 3 mm; $t_{13} = 0.782$; $P = 0.449$; $d = 0.21$).

3.2. Escape chimney vs. large hole

All ten painted turtles escaped the modified chimney net, which was significantly higher than the 60% (12/20) of turtles that escaped a net with a large hole (Fisher's exact test; $P = 0.029$, $\Phi = 0.426$). With chimney nets, the odds of a painted turtle escaping were 6.6 times higher 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; $t_{18} = 11.321$, $P < 0.001$, $r^2 = 0.88$).

4. Discussion

Both the exclusion bars and the exclusion ring net modifications reduced turtle captures, specifically eastern musk turtles, by over 50% compared to unmodified nets (Table 1), but only the catch reduction from 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 ($N = 15$), ensuing lower statistical power. 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 present in Lake Opinicon, the small eastern musk turtle was expected to be the least affected by exclusion modifications given that the musk turtle's carapace width rarely exceeds 80 mm (Ernst et al., 1994). Turtles simply encountering the exclusion barriers may explain the reduced number of catches as opposed to being physically incapable of entering nets. However, the behavior of turtles entering fyke nets has not been studied to verify what is 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 fyke 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 bars, this 4% difference is probably not biologically (or economically in the context of fishers) significant. 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. 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

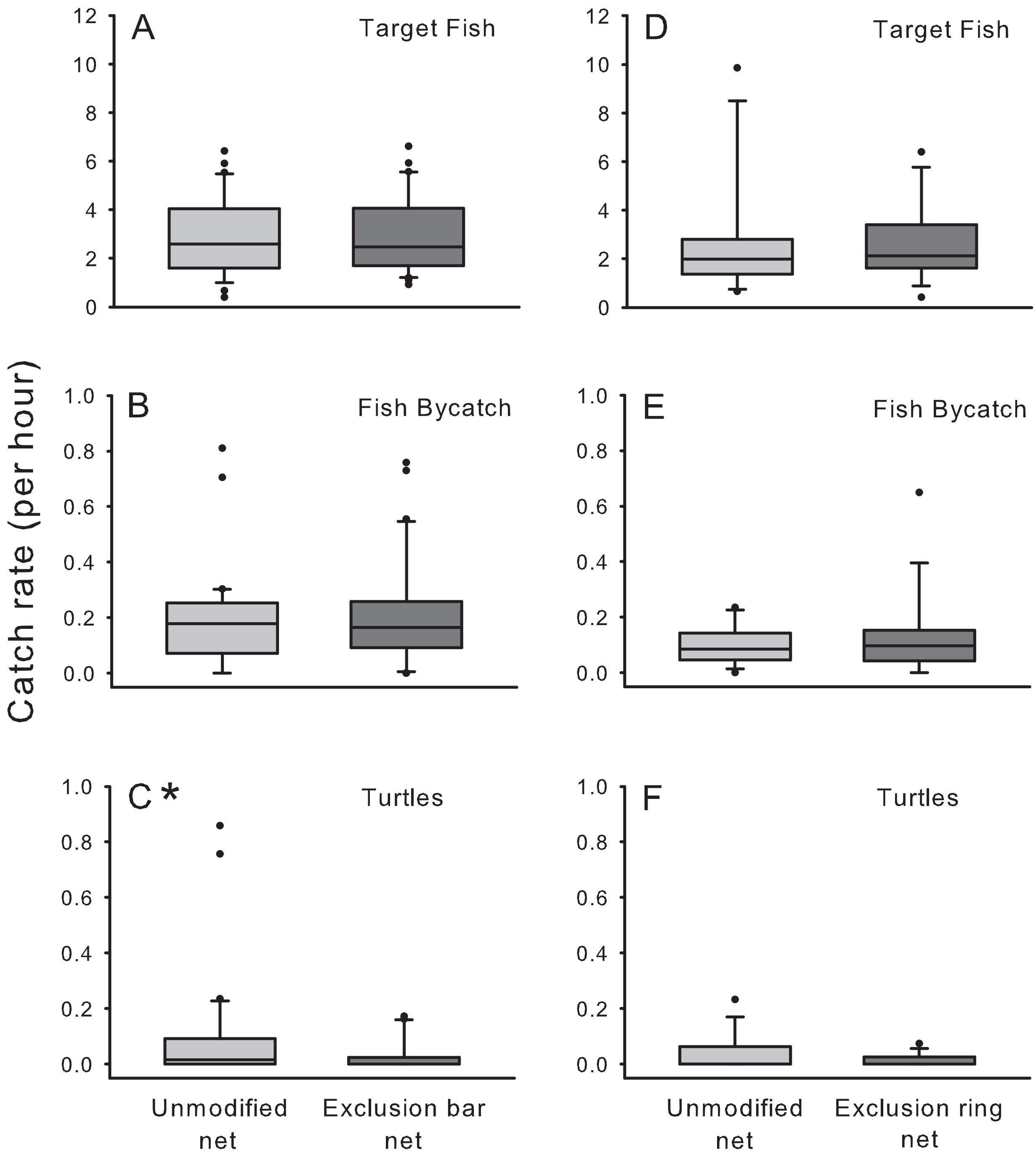

Fig. 2. Catch rates of (a) target fish and (b) fish bycatch were similar between unmodified nets and exclusion bar nets, while (c) turtles had lower capture rates in the exclusion bar net. Catch rates were similar for (d) target fish, (e) fish bycatch, and (f) turtles between unmodified nets and exclusion ring nets. Nets were set in Lake Opinicon, Ontario, and * indicates $P < 0.05$.

encounter with the barriers, it is likely that contact with the net caused most injuries to fish.

The escape chimney modification allowed more painted turtles to escape than a large hole in the net. All painted turtles escaped via the chimney, while most (88%) target fish were retained. In a field study, Fratto et al. (2008) used a similar chimney design on fyke 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 (prior to treatment), thereby negatively affecting their behavior and ability to escape the net. Acute stress from tank holdings and being handled can affect the health and behavior 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 behavior 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 fyke nets may not escape so readily. For example, Fratto et al. (2008) 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 are considered at various levels of risk in Canada (eastern musk turtle is threatened, while northern map turtles and common snapping turtles are of special concern; COSEWIC, 2011).

Environmental factors may also influence the performance of the escape chimney. Our design was tested in a lake; however, the Ontario fyke 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. (2008) 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 needed. 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 prior to implementation in the fishery.

5. Conclusion

Freshwater turtle bycatch is a conservation concern that needs to be addressed both locally and globally (Barko et al., 2004; Larocque et al., 2012; Michaletz and Sullivan, 2002). Our study focused on reducing turtle bycatch associated with a southeastern Ontario fyke net fishery, but our general findings (that simple devices can be used to reduce turtle bycatch) are applicable to most fyke 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. Using the escape chimney in combination with a device that reduces turtle entries could also be a potential avenue to eliminate turtle bycatch mortality. In addition, seasonal and temperature effects on freshwater turtle bycatch (e.g., Fratto et al., 2008; Larocque et al., 2012) 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 fyke nets.

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References

Alverson, D.L., Freeberg, M.H., Pope, J.G., Murawski, S.A., 1994. A global assessment of fisheries bycatch and discards. FAO Fish. Tech. Paper No 339, FAO, Rome.
Barko, V.A., Briggler, J.T., Osendorf, D.E., 2004. Passive fishing techniques: a cause of turtle mortality in the Mississippi River. J. Wildl. Mgmt. 68, 1145–1150.
Berry, J.F., Shine, R., 1980. Sexual size dimorphism and sexual selection in turtles (Order Testudines). Oecologia 44, 185–191.
Beumer, J.P., Burbur, M.E., Harrington, D.J., 1981. The capture of fauna other than fishes in eel and mesh nets. Aust. Wildl. Res. 8, 673–677.
Bleckmann, H., 1993. Role of the lateral line in fish behaviour. In: Pitcher, T.J. (Ed.), Behaviour of Teleost Fishes. , second ed. Chapman and Hall, London, pp. 201–246.
Broadhurst, M.K., 2000. Modifications to reduce bycatch in prawn trawls: a review and framework for development. Rev. Fish Biol. Fish. 10, 27–60.
Brooks, R.J., Brown, G.P., Glabraith, D.A., 1991. Effects of a sudden increase in natural mortality of adults on a population of the common snapping turtle (*Chelydra serpentina*). Can. J. Zool. 69, 1314–1320.
Bulté, G., Carrière, M.A., Blouin-Demers, G., 2010. Impact of recreational power boating on two populations of northern map turtles (*Graptemys geographica*). Aquat. Conserv. Mar. Freshw. Ecosyst. 20, 31–38.
Burns, C., 2007. Biological sustainability of commercial fishing in the inland waters of Kemptville District. OMNR Tech. Paper, OMNR, Kemptville.
Congdon, J.D., Dunham, A.E., Van Loben Sels, R.C., 1993. Delayed sexual maturity and demographics of blanding's turtles (Emydoidea blandingii): implications for conservation and management of long-lived organisms. Conserv. Biol. 7, 826–833.
Congdon, J.D., Dunham, A.E., Van Loben Sels, R.C., 1994. Demographics of common snapping turtle (*Chelydra serpentina*): implications for conservation and management of long-lived organisms. Am. Zool. 34, 397–408.
COSEWIC, 2011. Canadian Wildlife Species at Risk. Committee on the Status of Endangered Wildlife in Canada. http://www.cosewic.gc.ca/eng/sct0/rpt/rpt_csar_e.cfm (accessed 09.01.12.).
Crespi, V., Prado, J., 2002. Fishing Equipment: Bycatch Reduction Devices (BRD). FAO, Rome (accessed 11.10.11.) http://www.fao.org/fishery/equipment/brd/en.
Crowder, L.B., Hopkins-Murphy, S.R., Royle, J.A., 1995. Effects of turtle excluder devices (TEDs) on loggerhead sea turtle strandings with implications for conservation. Copeia 1995, 773–779.
Epperly, S.P., 2003. Fisheries-related mortality and turtle excluder devices (TEDs). In: Lutz, P.L., Musick, J.A., Wyneken, J. (Eds.), The Biology of Sea Turtles, 2. CRC Press, Boca Raton, pp. 339–353.
Ernst, C.H., Lovich, J.E., Barbour, R.W., 1994. Turtles of the United States and Canada. Smithsonian Institution Press, Washington.
Fratto, Z.W., Barko, V.A., Pitts, P.R., Sheriff, S.L., Briggler, J.T., Sullivan, K.P., McKeage, B.L., Johnson, T.R., 2008. Evaluation of turtle exclusion and escapement devices for hoop-nets. J. Wildl. Mgmt. 72, 1628–1633.
Gibbons, J.W., Scott, D.E., Ryan, T.J., Buhlmann, K.A., Tuberville, T.D., Metts, B.S., Greene, J.L., Mills, T., Leiden, Y., Poppy, S., Winne, C.T., 2002. The global decline of reptiles, déjà vu amphibians. Bioscience 50, 653–666.
Gilman, E., Zollett, E., Beverly, S., Nakano, H., Davis, K., Shiode, D., Dalzell, P., Kinan, I., 2006. Reducing sea turtle by-catch in pelagic longline fisheries. Fish Fish. 7, 2–23.
Gilman, E., Gearhart, J., Price, B., Eckert, S., Milliken, H., Wang, J., Swimmer, Y., Shiode, D., Abe, O., Peckham, S.H., Chaloupka, M., Hall, M., Mangel, J., Alfaro-Shigueto, J., Dalzell, P., Ishizaki, A., 2010. Mitigating sea turtle by-catch in coastal passive net fisheries. Fish Fish. 11, 57–88.
Grant, T.R., Lowry, M.B., Pease, B., Walford, T.R., Graham, K., 2004. Reducing the by-catch of platypuses (*Ornithorhynchus anatinus*) in commercial and recreational fishing gear in New South Wales. Proc. Linn. Soc. N.S.W 125, 259–272.
Hall, S.J., Mainprize, B.M., 2005. Managing bycatch and discards: how much progress are we making and how can we do better? Fish Fish. 6, 134–155.
Hall, M.A., Alverson, D.L., Metuzals, K.I., 2000. By-catch: problems and solutions. Mar. Pollut. Bull. 41, 204–219.
Herbert, C.V., Jackson, D.C., 1985. Temperature effects on the responses to prolonged submergence in the turtle *Chrysemys picta bellii*. I. Blood acid-base and ionic changes during and following anoxic submergence. Physiol. Zool. 58, 655–669.
Hubert, W.A., 1996. Passive capture techniques. In: Murphy, B.R., Willis, D.W. (Eds.), Fisheries Techniques. , second ed. American Fisheries Society, Bethesda, pp. 157–192.
IUCN, 2011. IUCN Red List of Threatened Species. Version 2011.1 http://www.iucnredlist.org (accessed 11.10.11.).
Kuchling, G., 1988. Population structure reproductive potential and increasing exploitation of the freshwater turtle *Erymnochelys madagascariensis*. Biol. Conserv. 43, 107–113.
Larocque, S.M., Colotelo, A.H., Cooke, S.J., Blouin-Demers, G., Haxton, T., Smokorowski, K.E., 2012. Seasonal patterns in bycatch composition and mortality associated with a freshwater hoop net fishery. Anim. Conserv. 15, 53–60.
Lewison, R.L., Crowder, L.B., 2007. Putting longline bycatch of sea turtles into perspective. Conserv. Biol. 21, 79–86.

Lewison, R.L., Crowder, L.B., Read, A.J., Freeman, S.A., 2004. Understanding impacts of fisheries bycatch on marine megafauna. Trends Ecol. Evol. 19, 598–604.
Lowry, M.B., Pease, B.C., Graham, K., Walford, T.R., 2005. Reducing the mortality of freshwater turtles in commercial fish traps. Aquat. Conserv. Mar. Freshw. Ecosyst. 15, 7–21.
McCune, B., Mefford, M.J., 2006. Multivariate Analysis of Ecological Data, version 5.20. Gleneden Beach, MjM Software Design.
Michaletz, P.H., Sullivan, K.P., 2002. Sampling channel catfish with tandem hoop nets in small impoundments. N. Am J. Fish. Mgmt. 22, 870–878.
Portz, D.E., Woodley, C.M., Cech.Jr., J.J., 2006. Stress-associated impacts of short-term holding in fishes. Rev. Fish Biol. Fish. 16, 125–170.
Raby, G.D., Colotelo, A.H., Blouin-Demers, G., Cooke, S.J., 2011. Freshwater commercial bycatch: an understated conservation problem. Bioscience 61, 271–280.
Rawson, D.S., 1952. Mean depth and the fish production in large lakes. Ecology 33, 513–521.
Soykan, C.U., Moore, J.E., Zydelis, R., Crowder, L.B., Safina, C., Lewison, R.L., 2008. Why study bycatch? An introduction to the theme section on fisheries bycatch. Endang. Species Res. 5, 91–102.