Using Behavioral Observations to Develop Escape Devices for Freshwater Turtles Entrapped in Fishing Nets

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Abstract

The drowning of freshwater turtles following incidental capture in fishing gear has the potential to cause population declines. Fyke nets can be equipped with bycatch reduction devices that enable the escape of turtles before they drown. We employed quantitative and qualitative behavioral observations (with action cameras deployed underwater) to develop a new, collapsible, escape bycatch-reduction device that mounts internally in the terminal end of a fyke net. We also used behavioral observations to identify areas of the net most used by turtles, thus revealing the most logical placement for an escape bycatch-reduction device. When turtles were introduced into modified nets, escape was rapid (mean of 12.4 min), with 100% escape for map *Graptemys geographica* and musk turtles *Sternotherus odoratus* and 94% escape for painted turtles *Chrysemys picta*. Our preliminary field trials indicated that modified fyke nets decreased the capture rate of turtles relative to unmodified nets. Escape devices can be used as a key component of a bycatch reduction program and be particularly effective when paired with exclusion bycatch-reduction devices. The escape device developed in this study can potentially be used in the local fishery or modified for other fisheries. The use of behavioral observation to guide the development of bycatch reduction devices may provide an extra tool for managers to increase selectivity and maintain sustainable harvests of target fish.

Keywords: entrapment gear; camera; small-scale fisheries; bycatch; *Chrysemys picta; Graptemys geographica; Sternotherus odoratus*

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Introduction

Modification of fishing equipment with bycatch reduction devices (BRDs) can improve gear selectivity by excluding nontarget species or enabling bycatch to escape (Broadhurst 2000). The avoidance of bycatch through BRDs often focuses on devices that prevent the capture of an individual, referred to as exclusion BRDs. Exclusion BRDs typically comprise rigid grids, bars, or rings to limit the size or shape of organisms that can enter the net (Bury 2011). Exclusion BRDs are particularly effective when bycatch animals are larger than the target animals (Broadhurst 2000; Hall et al. 2000). In fisheries where target and bycatch species overlap in size, exclusion of bycatch can be incomplete (Fratto et al. 2008b). If this is the case, smaller individuals and smaller species can still be collected, which can result in demographic, population, and community shifts (Roosenburg et al. 1997; Hall et al. 2000; Dorcas et al. 2007; Wolak et al. 2010). In the case of entrapment gear, however, escape BRDs can be used in addition to, or instead of, exclusion BRDs.

Fyke nets and other entrapment-style fishing gear intercept mobile aquatic animals and retain them until they are collected by fishers (Hubert 1996). Animals captured by entrapment typically remain mobile and unharmed (Hubert 1996), at least for a period shortly after capture (Larocque et al. 2012b). Entrapment gear is passive, so any escape device must allow bycatch species to escape under their own volition and power. In the case of species that require atmospheric oxygen (e.g., turtles, mammals, birds), escape must occur before the effects of forced submergence lead to behavioral or physiological impairments or death (Stoot et al. 2013). Thus, an effective escape BRD is a simple device positioned to promote the rapid escape of bycatch species without significantly reducing the catch of targeted species.

Escape BRDs are most effective when there are morphological differences, particularly differences in size, between target and bycatch species. However, in fisheries where morphology alone does not fully discriminate between target and bycatch, the inclusion of behavioral differences may help distinguish between the two (Broadhurst 2000; Cairns et al. 2013). Quantification of animal behavior and the application of behavioral principles is an underutilized tool in conservation biology (Caro 1998; Sutherland 1998; Broadhurst 2000). Differences in behavior can be co-opted as selective criteria to be used independently or in concert with morphological differences to reduce bycatch. For example, air-breathing species, such as freshwater turtles, typically occupy higher positions in entrapment gear as a result of their surface-seeking behavior than do targeted fish species (Lowry et al. 2005). Escape BRDs can be placed to take advantage of this spatial segregation between bycatch species and target species.

In some freshwater fisheries with entrapment gear, turtles are regularly collected as bycatch (Bishop 1983; Lowry et al. 2005; Bury 2011; Raby et al. 2011; Larocque et al. 2012a). Although this gear type does not tend to injure turtles, forced submergence can lead to physiological disturbances, behavioral impairments (Stoot et al. 2013), and drowning (Bishop 1983; Roosenburg et al. 1997; Barko et al. 2004). Turtles rely on low adult mortality, negligible senescence, and numerous reproductive events per individual to maintain populations (Brooks et al. 1991; Congdon et al.1993, 1994; Miller 2001; Midwood et al. 2015). The sensitivity of most turtle populations to the loss of even a limited number of adult females have rendered many turtle species and populations at risk (Turtle Taxonomy Working Group 2012). By drowning adult turtles, some entrapment fisheries threaten the persistence of local populations (Barko et al. 2004; Midwood et al. 2015).

Because of the threat that fisheries pose to freshwater turtles, a number of escape BRDs have been developed to improve gear selectivity and to reduce incidental capture (Wood 1997; Bury 2011; Larocque et al. 2012b, 2012c). Net modifications designed for bycatch escape are often external, chimney-style devices, where a tube of mesh joins the terminal compartment of the net to the surface of the water, allowing the amphibious turtles to escape while aquatic fish are retained (Roosenburg et al. 1997; Fratto et al. 2008a; Bury 2011; Larocque et al. 2012b). These devices are effective for some species, but their efficacy at freeing multiple species of turtles has rarely been documented (Larocque et al. 2012b). Also, reliance on the water surface as the escape route limits the depth for net setting, which can be a concern for fishers (Nguyen et al. 2013). Ease of setting modified nets and the ability to set in variable conditions (water depth, wind, current) are often cited as useful qualities by fishers (Nguyen et al. 2013). Thus, BRDs contained entirely within the net should be generally desirable (Lowry et al. 2005; Fratto et al. 2008a). Although previous studies included video observations of turtles to determine whether they interacted with internal BRDs as expected (Lowry et al. 2005), there are very few published studies where observed behavior was used to inform the design of escape BRDs.

Although turtles generally can survive prolonged submergence, some turtles can become behaviorally or physiologically impaired within hours of being submerged depending on conditions (Stoot et al. 2013). Time to impairment is not only species-specific (Ultsch et al. 1984; Stoot et al. 2013), but is also dependent upon water temperature (Ultsch 1985) and size of the individual (Ultsch et al. 1984). A physiological disturbance, such as exhaustion, often manifests itself behaviorally and may be used to inform BRD development. For example, tolerance of forced submergence varies between species (Ultsch et al. 1984; Stoot et al. 2013), so the behavior of the least tolerant species may require particular attention during BRD design to maximize overall efficiency. Behavioral observations (e.g., underwater video or time-lapse imagery) of entrapped turtles can potentially be used to improve the effectiveness of BRDs because the mechanisms and time line of escape can be observed and quantified (Renchen et al. 2012; Favaro et al. 2013). Such observations are easier to make since the advent of relatively inexpensive waterproof action cameras (Struthers et al. 2015).

Our goal was to design an escape BRD for commercial fyke nets that would be easy to use and effective for a community of freshwater turtles: painted turtle *Chrysemys picta,* northern map turtle *Graptemys geographica,* eastern musk turtle *Sternotherus odoratus,* and snapping turtle *Chelydra serpentina*. To accomplish this goal, we observed the behavior of turtles while trapped and submerged using high-resolution underwater video and time-lapse cameras. We used these observations to determine 1) whether there was a region in the net turtles occupy more than others and whether occupancy patterns change as submergence progresses, and 2) how long turtles were active enough to free themselves using a passive BRD. We then used this information to design a novel escape BRD that is internal and collapsible. Without additional efforts, the modified net can be set at the same depth and in the same water conditions as an unmodified fyke net.

Study Area

We conducted this study on Lake Opinicon at the Queen's University Biological Station (QUBS; 44°34′N, 76°19′W) ~100 km southwest of Ottawa, Ontario, Canada. Lake Opinicon is a shallow (mean depth of 2.8 m), mesotrophic lake with a surface area of ~780 ha (Agbeti et al. 1997). This lake is within the jurisdiction of a small-scale commercial fishery operating on freshwater lakes and large rivers in eastern Ontario (Burns 2007; Larocque et al. 2012a). This fishery provides an ideal case study for freshwater turtle bycatch in entrapment nets. Fishers use fyke nets to collect a variety of panfish (*Lepomis* spp., *Pomoxis nigromaculatus, Perca flavescens*) along with larger species such as bullhead *Ameiurus* spp., suckers *Catostomus* spp., and carp *Cyprinus carpio*. Sympatric turtles are regularly collected as bycatch (Larocque et al. 2012a); based on 590 unmodified net sets, the most commonly collected species are the painted turtle (43%), the eastern musk turtle (41%), the northern map turtle (9%), and the snapping turtle (7%). Until 2013, reporting of turtle bycatch was not mandatory in this fishery so little is known about actual capture rates and associated mortality. Ontario Ministry of Natural Resources audits in 2013 and 2014 of a nearby fishery indicated that 12% of nets contained turtles (16 of 129 nets). Although 26 turtles were observed, the proportion of turtles relative to fish captures was not assessed at the time of the audit (Ontario Ministry of Natural Resources 2014). In another study on the eastern Ontario fishery, Larocque et al. (2012a) found that turtles could represent 2% of all individual animals captured and found rates of drowning in turtles as high as 33%, sufficient to have major population effects (Brooks et al. 1991; Midwood et al. 2015).

Methods

Nets

The fyke nets were constructed of seven 0.91-m structural hoops made from 0.64-cm steel rods and attached together with #15 knotted nylon, 2.54-cm square mesh (5.08-cm stretch; Christiansen's Nets Company, Duluth, MN). Throats or funnels on the second and fourth hoops directed organisms into the terminal end of the net and minimized escape. We set nets in pairs, connected mouth to mouth by a lead net 10.7 m long and 0.91 m tall. Each net had 4.6-m-long wings made of the same material set at ~45° angle from the lead. We set nets in shallow water (1–2.5 m). For collecting turtles and fish, we typically set nets for 24 h (see Larocque et al. 2012a for details), whereas we set the nets for 4 h for field trials of BRDs.

Documenting in-net behavior and activity

To quantify behavior, we conducted observations using a completely submerged net and underwater video recording. We observed and compared in-net position and activity for the four species of turtles. We conducted trials from 18 May to 20 June 2011 in a shallow (maximum depth 2 m) bay of Lake Opinicon. Water temperatures during the trials ranged from 16.5 to 24.5°C. We used male turtles to avoid potentially harming reproductive females (Brooks et al. 1991; Midwood et al. 2015). We collected males using unmodified fyke nets fished for 24 h. Following capture, we held turtles outside in 700-L fiberglass flow-through tanks with access to basking platforms for a minimum of 24 h before trials. We used 39 turtles of four species (10 painted, 10 map, 10 musk, and 9 snapping turtles) in these trials. We placed each turtle in the mouth of a sealed net and observed its behavior in real time and recorded it for 3 h using three underwater cameras (Figure 1).

If we did not observe a turtle moving for 15 min, or if it appeared to be in acute distress, we ended the trial and removed the turtle from the net immediately. The terminal end of the net was divided into quadrants (along the x/y axis as viewed from the side; Figure 1). To account for the unidirectional movements within hoop nets and the reduction in activity of most species beyond 2 h, we limited in-net behavioral analysis to the terminal end of the net between 5 and 120 min. We also compared the first and second hours to determine whether occupancy for each species varied between these two periods. We compared the occupancy of the four terminal-end quadrants by species using a chi-

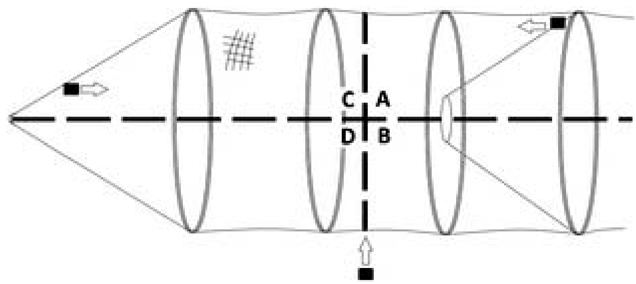

Figure 1. Diagram of the terminal end of a fyke net used for behavioral trials to determine the occupancy and activity patterns of male painted turtle *Chrysemys picta,* northern map turtle *Graptemys geographica,* eastern musk turtle *Sternotherus odoratus,* and snapping turtle *Chelydra serpentina*. Trials were conducted from 18 May to 20 June 2011 in a shallow bay of Lake Opinicon, Ontario, Canada, in water temperatures ranging from 16.5 to 24.5°C. A total of 39 turtles (10 of each species with the exception of 9 snapping turtles) were used for observation. Each turtle was placed individually in the mouth of a sealed net and occupancy was compared for the four quadrants (A, B, C, and D). Behaviors were observed in real time and recorded using three underwater cameras (black boxes with arrows indicating direction), two located in the opposite ends of the trap with a third external one used to observe the net in profile. From these recordings, observations of turtle activity and position were made every 5 min for 2 h noting the quadrant occupied and activity of the turtle at the beginning of the observation period.

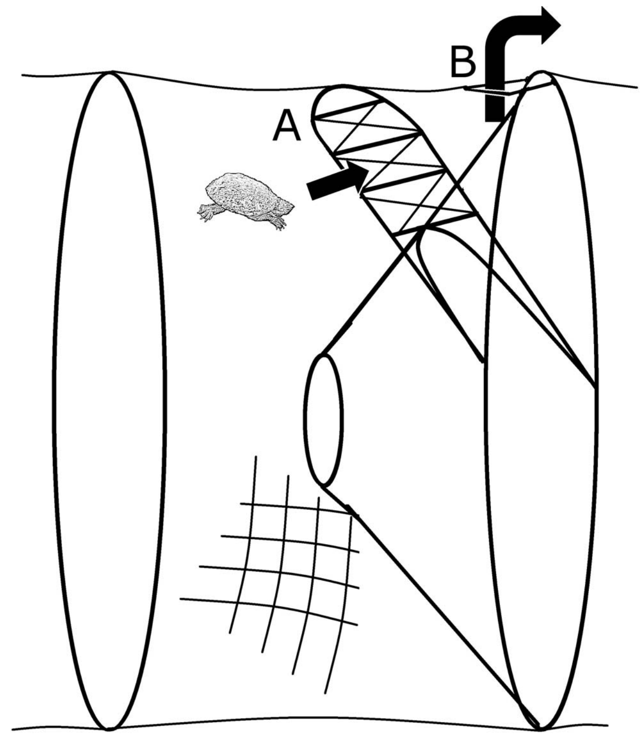

Figure 2. Diagram of the passive in-net turtle escape device (PIN-TED) bycatch reduction device (BRD) located above the funnel in the anterior portion of the terminal end of a commercial fyke net, used for behavioral trials conducted from 18 May to 20 June 2011 in a shallow bay of Lake Opinicon, Ontario, Canada. The horizontal bars of the selective grid (A) are spaced 8 cm apart; two lengths of tarred twine are stretched diagonally across the gap between bars. When deployed, the grid serves as a selective barrier to access a 22.5 $\times$ 10-cm escape opening (B). Both the grid and opening were woven into the mesh of the net and attached to a single structural hoop with hinges that allow the device to fully collapse during net storage. Arrows indicate the path a turtle would follow to escape using the PIN-TED BRD.

squared goodness-of-fit test and repeated G-tests of goodness-of-fit for comparisons between hours. To determine whether turtles changed their activity patterns over time, we completed 30 s of observation every 5 min from the video generated. We assigned a 1 if the subject was active (crawling, swimming, or pulling on the netting) and a 0 if inactive (sitting on the bottom or clinging to the netting without pulling). We used binary logistic regression to determine the relationship between activity and time for each species. We conducted all analyses using R statistical software (R Development Core Team 2012) and set alpha to 0.05.

Passive in-net turtle escape device

Based on the observed behavior of turtles in unmodified nets, we designed a BRD that would maximize the likelihood of turtle escape while retaining target fish species. The passive in-net turtle escape device (PIN-TED) is composed of two parts: the selective grid and the escape opening, both positioned in the terminal compartment (Figure 1) of the fyke net over the funnel (Figure 2). We constructed the grid of 0.64-cm steel rods welded into the shape of a crescent with the points attached to the structural hoops of the net with a hinge that allowed the device to collapse along with the rest of the net for storage. We attached this crescent to the mesh on the inside of the net above the funnel as well as to the mesh of the funnel itself. When deployed, the grid was roughly 45° to the orientation of the hoops. We constructed the escape opening of a 0.64-cm steel rod bent into a rectangle 22.5 $\times$ 10 cm and affixed with a hinge to the structural hoop (Figure 2). We wove both grid and escape opening into the mesh of the net, which allowed the tension of the net during normal setting to deploy the BRD. The grid provided the morphologically selective component of the BRD; it was a set of horizontal 0.64-cm steel bars within the crescent-shaped frame that operated as a horizontally oriented exclusion device to take advantage of the dorsoventrally flattened shape of most turtles. We spaced the bars 8 cm to limit the size of the organism that could pass through the grid. We stretched tarred twine diagonally across each gap to provide a barrier for fish smaller than 8 cm in height (Figure 2). We based the use of an 8-cm spacing on the size of exclusion BRDs effective at reducing turtle captures in this community (Larocque et al. 2012b).

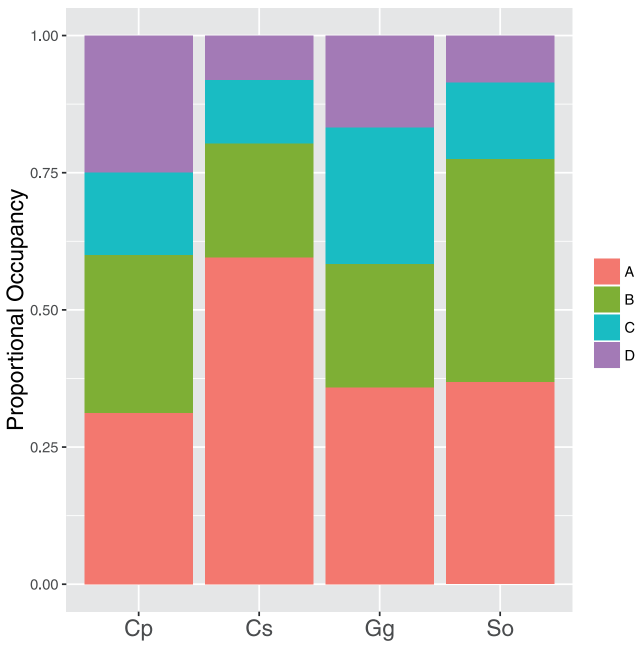

Figure 3. The observed proportional occupancy of male turtles in the terminal section of a sealed fyke net over 2-h trials. Ten painted turtles *Chrysemys picta* (Cp), 10 northern map turtles *Graptemys geographica* (Gg), 10 eastern musk turtles *Sternotherus odoratus* (So), and 9 snapping turtles *Chelydra serpentina* (Cs) collected from Lake Opinicon, Ontario, Canada, using unmodified fyke nets were used in the trials. Trials took place from 18 May to 20 June 2011 in water temperatures ranging from 16.5 to 24.5°C. A single turtle was introduced to a sealed fyke net submerged in a shallow bay and recorded to gauge occupancy within the terminal section of a fyke net. This section was divided into four quadrants the top-anterior (A), the bottom-anterior (B), the top-posterior (C), and the bottom posterior (D). Observations were made from recordings every 5 min and position of the individual noted. Musk and snapping turtles preferred the anterior quadrants of the net while painted and map turtles occupied no area more than would be expected at random. This suggests that bycatch reduction device placement in the anterior portion of the net would likely increase encounter rates for musk and snapping turtles while not affecting those of painted and map turtles.

Preliminary trials with the PIN-TED

We conducted preliminary trials to determine the effectiveness the PIN-TED before it was tested under realistic fishing conditions. We used similar methods as the in-net behavioral observation with the notable difference that turtles could escape from the net using the PIN-TED. A total of 14 painted, 11 map, and 7 musk turtles which had not been used in previous trials were used to observe the effectiveness of the PIN-TED. We conducted trials from 25 May to 24 June 2012 in water temperatures ranging from 18 to 23°C. We recorded turtle interactions with the BRD until we noted escape and time to escape.

Field trials with the PIN-TED

To test the effectiveness of the PIN-TED for turtle escape and target fish retention, we installed BRDs in standard fyke nets and fished mimicking the commercial fishery. We set nets in 2012 from 3 to 12 July in water temperatures of 23 to 29°C. Nets modified with an escape PIN-TED were each connected by a lead net to paired unmodified nets and fished together for ~4 h. The restricted fishing time is not typical of the commercial fishery, but we chose it to prevent drowning turtles (Barko et al. 2004). GoPro (Woodman Labs, San Mateo, CA) waterproof action cameras mounted inside the nets (Figure 1) to monitor escape and turtle interactions with the PIN-TED took photos every 5 s for ~3.5 h. Upon net retrieval, we identified target and bycatch individuals to species and measured them. We compared total catch and composition of all target and bycatch species between treatment and control nets. To account for the small sample sizes resulting from the early termination of this portion of the study owing to the unusually warm water temperatures, we used Fisher's exact tests. We used counts of each species and category (target fish, bycatch fish, turtle) to test for differences in overall catch rates. Then, using the proportional composition of the control nets as expected values, we compared overall composition of the catch. For post hoc procedures, we withheld categories from analysis one at a time and reran the tests using the pairwise.table command in the R package "RVAideMemoire" (Hervé 2016). Although total length of target fish met the assumptions of a parametric test, carapace height (CH) of bycatch turtles was not normal. As such, we used a Wilcoxon rank sum test with a continuity correction to test for overall differences in total length as well as CH between treatments. We excluded from comparisons fish with a total length <190 mm because this size class is not targeted and can account for only 10% of a fisher's landings (Ontario Ministry of Natural Resources 2013). We returned all organisms to the site of capture immediately.

Results

Documenting in-net behavior and activity

There was a difference between the number of observations per quadrant and the expected even distribution of net occupancy for both musk turtles ($\chi^2 = 17.71$, $df = 3$, $P < 0.001$) and snapping turtles ($\chi^2 = 27.65$, $df = 3$, $P < 0.001$; Figure 3). In general, turtles were observed more often in quadrant A than in quadrant B; musk turtles most favored quadrant B followed by quadrant A; and snapping turtles favored quadrant A. No significant difference in the occupancy of each quadrant was found for painted turtles ($\chi^2 = 3.73$, $df = 3$, $P = 0.29$) or for map turtles ($\chi^2 = 4.29$, $df = 3$, $P = 0.23$; Figure 3). In general, turtles spent more time in the areas of the net with acute angles, such as the seam between the throat and the structural hoop of the net, as well as the terminal portion of the net where the mesh is pulled into a tight cone. There was no difference for any species in net occupancy patterns between the first and the second

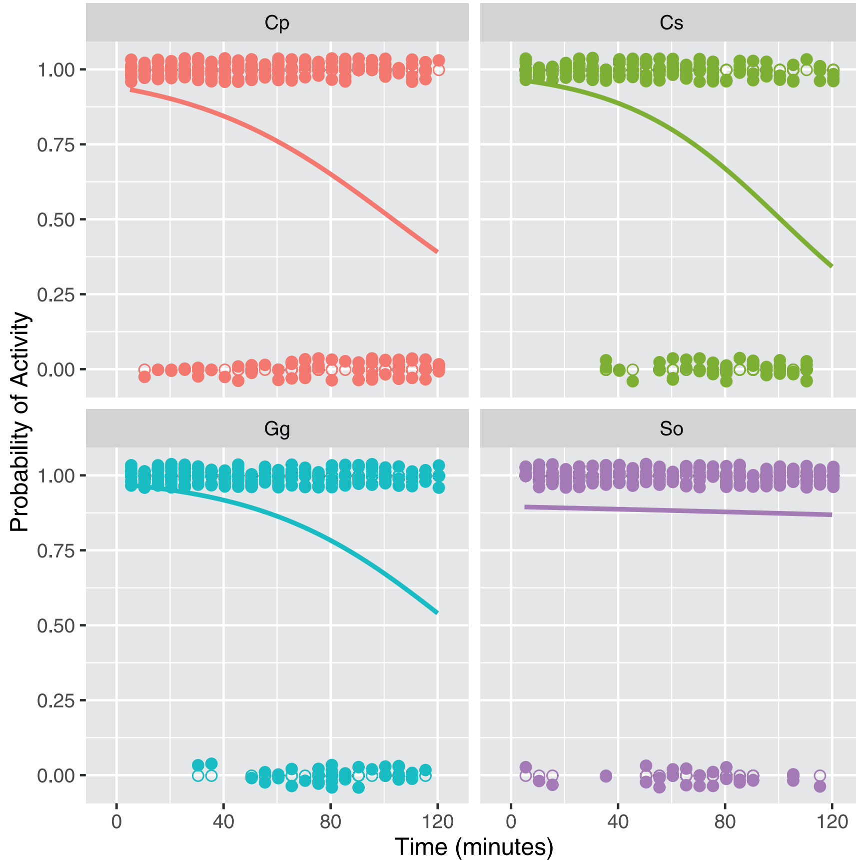

Figure 4. Binary logistic regressions representing the activity of turtles over a 2-h submergence in a sealed fyke net. Ten painted turtles *Chrysemys picta* (Cp), 10 northern map turtles *Graptemys geographica* (Gg), 10 eastern musk turtles *Sternotherus odoratus* (So), and 9 snapping turtles *Chelydra serpentina* (Cs) collected from Lake Opinicon, Ontario, Canada, using unmodified fyke nets were used in the trials. A single turtle was introduced to a sealed fyke net submerged in a shallow bay and recorded. Turtles were observed every 5 min for 30 s and designated as active (1) or inactive (0) based on whether the individual was moving or not. Trials took place from 18 May to 20 June 2011 in water temperatures ranging from 16.5 to 24.5°C. Observed scores were jittered along the y-axis to improve clarity. All species but the musk turtle showed a decrease in activity over 2 h of forced submergence, suggesting that the probability of an interaction with a bycatch reduction device decreases with time.

hour of submergence (painted $G = 0.12$, $df = 3$, $P = 1$; map $G = 3.78$, $df = 3$, $P = 0.29$; musk $G = 3.52$, $df = 3$, $P = 0.32$; snapping $G = 1.12$, $df = 3$, $P = 0.77$).

Logistic regression revealed that there were differences in turtle activity through time ($\chi^2 = 58.36$, $df = 1$, $P < 0.001$) and by species ($\chi^2 = 22.8$, $df = 1$, $P < 0.001$). When each species' activity was analyzed in relation to submergence time, painted turtles ($\chi^2 = 53.03$, $df = 1$, $P < 0.001$), map turtles ($\chi^2 = 22.45$, $df = 1$, $P < 0.001$), and snapping turtles ($\chi^2 = 53.49$, $df = 1$, $P < 0.001$) became less active with time (Figure 4). Musk turtles ($\chi^2 = 0.21$, $df = 1$, $P = 0.65$), however, were not less active with time, at least up to 2 h (Figure 4). Three large (>9 kg) snapping turtles were removed from the nets early because of what appeared to be acute distress. Distress was typified by a turtle being passively suspended from the top of the net by its fore-claws with head and neck fully extended, but hanging limply. These reactions occurred 85, 95, and 95 min into the trials. This was preceded by increased activity, which was succeeded quickly (<15 min) by unresponsiveness. All turtles were revived, held for 24 hours, and returned to their point of capture.

Preliminary trials with the PIN-TED

To take advantage of the frequent occupancy of quadrant A, the PIN-TED was positioned in this quadrant. All turtles but one (a painted turtle) were able to escape. All individuals that successfully escaped did so in <1 h, with escape time ranging from 0.9 to 57.1 min (mean escape times: painted: 14.6 ± 4.0 min; map: 9.9 ± 2.4 min; musk: 12.4 ± 2.5 min). Most individuals succeeded in passing through the escape opening shortly after navigating the grid. However, a few individuals were observed passing through the grid, only to return to the terminal end of the net.

Field trials with the PIN-TED

Over 23 paired trials, the nets modified with a PIN-TED collected 2 map turtles while control nets collected 12 turtles of 4 species, which represents a reduction of 83% (Figure 5). The mean CH of turtles in the control nets was

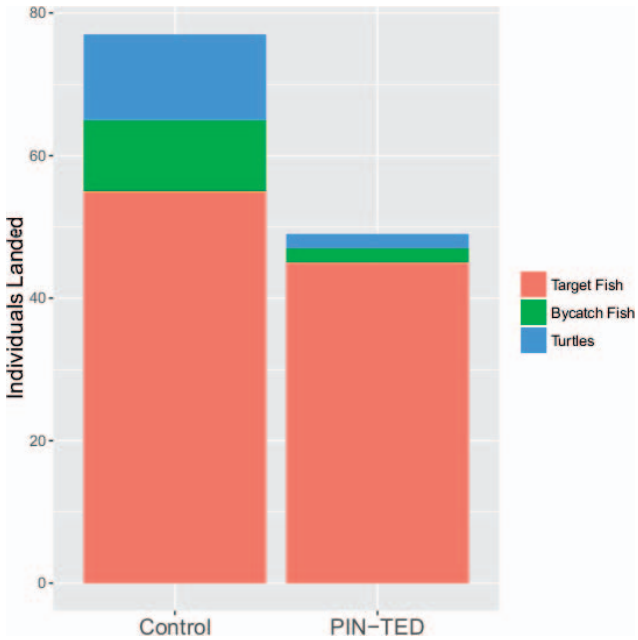

Figure 5. Landings from 23 paired trials of unmodified fyke nets (Control) and of fyke nets modified with a passive in-net turtle escape device (PIN-TED) conducted in Lake Opinicon, Ontario, Canada, from 3 to 12 July 2012 in water temperatures of 23 to 29°C. Captured organisms were categorized into turtles (painted turtle *Chrysemys picta,* northern map turtle *Graptemys geographica,* eastern musk turtle *Sternotherus odoratus,* and snapping turtle *Chelydra serpentina*), target fish (Bluegill Sunfish *Lepomis macrochirus,* Pumpkinseed Sunfish *Lepomis gibbosus,* Black Crappie *Pomoxis nigromaculatus,* Rock Bass *Ambloplites rupestris,* and Bullhead *Ameiurus nebulosus*), and bycatch fish (Largemouth Bass *Micropterus salmoides*). There were differences between overall capture rates and composition between treatments driven by decreases in target fish (18%) and turtles (83%) in the PIN-TED–equipped nets.

82.3 mm, with a range of 41 to 149 mm. Both map turtles collected in the modified nets had CH $>$8 cm (89 and 91 mm). Largemouth Bass *Micropterus salmoides* was the only bycatch fish species collected; 10 Bass were collected in the unmodified nets and 2 in the modified nets, which represents a reduction of 80% (Figure 5). One hundred target fish of five species were collected: 55 from control nets and 45 from modified nets (a reduction of 18%; Figure 5). Sunfish *Lepomis* spp. were the most common species collected (control: 52; PIN-TED: 39) and showed a 25% reduction in the modified nets. Other economically important species were relatively uncommon in both net treatments. No difference in total length of fish was observed between modified and unmodified nets ($W = 12$, $P = 0.75$).

For each species, there was no difference in total capture ($P = 0.13$) or composition ($P = 0.24$) between modified and unmodified nets. However, when species were combined into categories (target fish, bycatch fish, and turtles), differences became apparent for both total numbers ($P = 0.02$) and composition ($P = 0.03$). Paired post hoc comparisons indicated that turtles and target fish were the main drivers of this effect (Table 1). The composition of both unmodified and PIN-TED–equipped nets was dominated by target fish (72% and 91%, respectively), though the unmodified nets collected 18% more in total (55 versus 45 fish). Turtles represented 15% and 4% of captures in unmodified and PIN-TED–equipped nets, respectively, and showed an 83% reduction (12 versus 2 turtles) in total captures in modified nets. If only turtles with a CH $<$8 cm (the maximum size that can pass though the selective grid) were used in our analyses, then no turtles were captured in the modified nets and five were captured in the control nets. These differences remained significant in overall capture numbers ($P = 0.03$) and composition ($P = 0.04$; Table 1). Four additional turtles (two painted and two musk turtles) were recorded inside the modified nets using cameras, but were absent from the nets when they were retrieved. These four turtles were observed using the escape device (Figure 6). The in situ use of the BRD by painted and musk turtles mirrored the observations made in preliminary trials.

Discussion

We observed and quantified behaviors of turtles entrapped in fishing nets and used these data to guide the development of a BRD, which we then tested under field conditions. The males of four turtle species differed in their occupancy of regions within the net. Wood (1997) noted that male and female diamondback terrapins *Malaclemys terrapin* were equally susceptible to drowning in crab pots. We decided to use male turtles only in our experiment because female mortality tends to have greater negative population effects than male mortality. We are unaware of any published research into potential sex differences in behavior of entrapped turtles (but see Brown et al. 2011 for a potential example). We found that male musk and snapping turtles preferentially occupied the anterior part of the terminal end of the net. Painted and map turtles occupied this area as often as the other portions of the net, suggesting that this would be as appropriate as any other location for BRD placement. The area under the throat was also occupied regularly, but it seemed less probable that an escape device at that location would be as effective. Fishing nets are set in various conditions and functionality of a BRD located on the bottom could be hindered by substrate and vegetation. We also found that, although most species can survive prolonged submergence, turtles reduce their activity rapidly after entering the net. After 100 min in the net, turtles had an $\sim$50% probability of being active. The final design coupled these findings with observations that trapped turtles seem to follow seams and edges between parts of the net. Turtles spent a lot of time where the throat joined the terminal end and the cone at the very end of the net. The PIN-TED successfully freed turtles in controlled and in field trials.

We designed the PIN-TED taking into account the concerns of fishers. Fishers tend to dislike chimney-style escape devices because they confine nets to specific

Table 1. A summary of Fisher's exact test comparisons for landings collected during field trials with nets modified with a passive in-net turtle escape device (PIN-TED) paired with unmodified nets. A total of 23 paired trials (~4-h soak times) were conducted in Lake Opinicon, Ontario, Canada, from 3 to 12 of July 2012. We categorized all captures into target fish (Bluegill Sunfish *Lepomis macrochirus*, Pumpkinseed Sunfish *Lepomis gibbosus*, Black Crappie *Pomoxis nigromaculatus*, Rock Bass *Ambloplites rupestris*, and Bullhead *Ameiurus nebulosus*), bycatch fish (Largemouth Bass *Micropterus salmoides*), and turtle (painted turtle *Chrysemys picta*, northern map turtle *Graptemys geographica*, eastern musk turtle *Sternotherus odoratus*, and snapping turtle *Chelydra serpentina*). Fish with a total length <190 mm were excluded from comparisons because this size class is not targeted. Tables A and B represent total captures, while tables C and D include only turtles that have a carapace height <8 cm and would be able to escape through the spacing of the bycatch reduction devices. Tables A and C compare total capture numbers, while Tables B and D compare composition while controlling for sample size (the expected values were generated by taking the proportions of captures from the control net and applying it to the sample size of the PIN-TED equipped net). For each comparison, an odds ratio (Exp (B)) and 95% confidence intervals were generated along with a *P*-value for this estimate. Post hoc comparisons were conducted using the pairwise.table command in the R package "RVAideMemoire" (Hervé 2016).

(A)

			95% confidence interval for Exp (B)	
Comparison	***P*-value**	**Exp (B)**	**Lower**	**Upper**
All	0.019			
Turtle and Bycatch fish	1.000	0.839	0.052	13.558
Turtle and Target fish	0.040	0.206	0.021	0.999
Bycatch fish and Target fish	0.070	4.047	0.802	39.862

(B)

			95% confidence interval for Exp (B)	
Comparison	***P*-value**	**Exp (B)**	**Lower**	**Upper**
All	0.031			
Turtle and Bycatch fish	1.000	0.880	0.050	15.26
Turtle and Target fish	0.048	0.209	0.020	1.135
Bycatch fish and Target fish	0.084	4.194	0.739	43.753

(C)

			95% confidence interval for Exp (B)	
Comparison	***P*-value**	**Exp (B)**	**Lower**	**Upper**
All	0.029			
Turtle and Bycatch fish	1.000	0.000	0.000	13.323
Turtle and Target fish	0.069	0.000	0.000	1.415
Bycatch fish and Target fish	0.070	4.047	0.802	39.862

(D)

			95% confidence interval for Exp (B)	
Comparison	***P*-value**	**Exp (B)**	**Lower**	**Upper**
All	0.043			
Turtle and Bycatch fish	1.000	0.000	0.000	17.6
Turtle and Target fish	0.100	0.000	0.000	2.114
Bycatch fish and Target fish	0.084	4.194	0.740	43.753

depths and are more complicated to set (Nguyen et al. 2013). We decided that an escape device that would function within the confines of the net and would not require additional steps to deploy was needed. The PIN-TED we designed can be set without additional steps in any water depth or condition. Although the PIN-TED adds ~3 kg to the mass of the net, this does not seem to complicate setting and the PIN-TED could be made with lighter components (e.g., plastic or aluminum instead of steel). We also designed the PIN-TED considering the local community of fish and turtles. The main target species of this fishery are small, laterally compressed sunfish that differ markedly in body shape from the dorsoventrally flattened turtles. As such, using differences in shape to free turtles seemed possible. It seemed unlikely, however, that an escape device that would free a very large snapping turtle (up to 17 kg in the local population) would retain target fish. An 8-cm spacing on the selective component of the PIN-TED corresponds to the exclusion BRD spacing used in previous studies in this community (Larocque et al. 2012b) and represents a compromise between bycatch reduction and target retention.

The nets modified with a PIN-TED caught fewer turtles and bycatch fish than unmodified nets. The decrease in target fish captures (18%) is worrying because this could represent a significant loss to fishers and reduce the use and acceptance of the BRD (Nguyen et al. 2013). Further

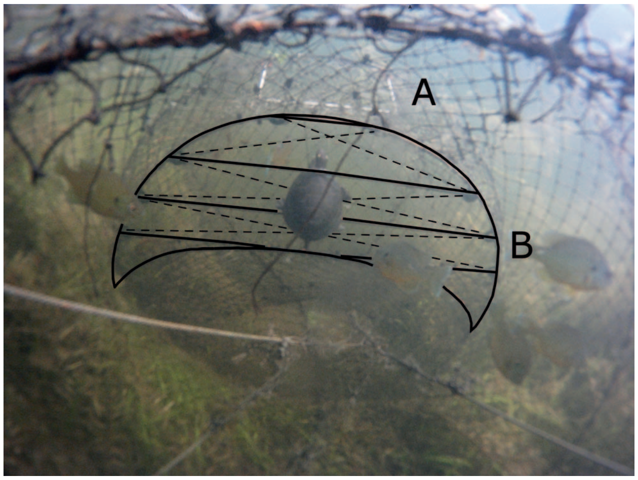

Figure 6. The escape opening (A) and selective grid (B) of the prototype passive in-net turtle escape device (PIN-TED) used in field trials in Lake Opinicon, Ontario, Canada, in July 2012. An adult painted turtle *Chrysemys picta* is passing through the selective grid. The grid has been traced with black lines while tarred twine has been traced with dashed lines.

study is required to better estimate the reductions in bycatch and target fish captures allowed by the PIN-TED. We observed small fish passing through the PIN-TED, but it is difficult to ascertain whether these fish would have met the 190-mm total length minimum mandated by this fishery. Longer trials should be conducted to determine the long-term retention of fish in nets modified with a PIN-TED, and in particular retention of market-sized pan fish.

Field tests of the PIN-TED indicated a large (83%) reduction in turtle captures in modified nets, and we observed two species (musk and painted turtles) successfully using the BRD. Turtles that were retained in the modified nets had carapace heights >8 cm and were therefore unable to pass through the PIN-TED due to the spacing of the selective component. Large turtles, however, are easily excluded with an exclusion BRD (Bury 2011; Larocque et al. 2012b; Cairns et al. 2013). If paired with an exclusion BRD, the PIN-TED would only be required to free small- to medium-sized turtles.

Based on carapace height, an exclusion device with a spacing of 5 cm would exclude most adult female turtles in Lake Opinicon (92% of painted, 7% of musk, 97% of map, and 100% of snapping turtles), but would allow males of several species, as well as juveniles of all species, to pass. Therefore, there is still a need for an escape BRD in addition to any exclusion BRD that is implemented (Cairns et al. 2013). Musk turtles, as the smallest species, are still at risk of entering nets equipped with exclusion BRDs. In addition, in this turtle community, musk turtles have the highest probability of capture if they interact with the net (Cairns et al. 2013). However, we have demonstrated that the musk turtle is also well-suited to self-extraction from entrapment nets using the PIN-TED. Musk turtles do not become easily exhausted (at least, not over several hours in water temperatures up to 24.5°C), occupy a predictable area of the net, and readily use the PIN-TED. Thus, this escape device could be an especially effective part of a bycatch mitigation strategy for this species.

In this study, we were able to determine the region of the net that was used more than others by turtles. We also documented that for most turtles the time available for self-extrication is relatively short because activity diminishes with time. We used this information to guide the development of the PIN-TED. Overall, the PIN-TED was effective at freeing turtles, but requires further testing. In particular, further behavioral observations of females would be helpful to determine whether there are sex differences in escape rate, and retention of target fish should be better evaluated. We feel our PIN-TED used in conjunction with an exclusion BRD could reduce incidental turtle captures in this and other similar fisheries. The PIN-TED, particularly the selective spacing, can be modified to fit other communities and conditions. As such, this PIN-TED may find application with fishery biologists (e.g., for stock assessment or research), small-scale commercial or subsistence fisheries, or wherever fyke nets are set and turtle bycatch is a concern. Finally, affordable commercially available underwater cameras capable of obtaining video or time-lapse imagery are powerful tools for addressing bycatch-related management problems (Struthers et al. 2015). Behavioral information (i.e., conservation behavior; Caro 1998; Sutherland 1998) has much to offer to the development and refinement of BRDs for incidentally captured turtles and other taxa. Exploiting the observed behaviors of target species has been successfully employed in fisheries to increase harvest (Nomura 1980); therefore, the behavior of bycatch species can be used to improve gear selectivity and help design more efficient BRDs (Broadhurst 2000; Wang et al. 2007). By having a priori knowledge of how bycatch organisms behave during capture and retention, we should be able to better plan and implement BRDs and maximize their potential as tools for applied conservation.

Supplemental Material

Reference S1. Burns C. 2007. Biological sustainability of commercial fishing in the inland waters of Kemptville District. Kemptville, Ontario, Canada: Ontario Ministry of Natural R Found at DOI: http://dx.doi.org/10.3996/082015-JFWM-075.S1 (172 KB PDF).

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