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# Refinement of bycatch reduction devices to exclude freshwater turtles from commercial fishing nets

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

KEY WORDS: Non-target species · Small-scale fishery · Catchability · Turtle excluder device · Selectivity · Sunfish · Time-lapse photography



## INTRODUCTION

Bycatch is the inadvertent capture of non-target species and is a major issue in commercial fisheries in marine and freshwater environments around the globe (Saila 1983, Alverson et al. 1994, Raby et al. 2011). Bycatch occurs as a result of overlap in spatial distribution between target and non-target species, and the use of gear lacking the selectivity to differentiate between them. Bycatch reduction devices (BRDs) are modifications to fishing gear that improve selectivity by excluding or freeing bycatch species (Broadhurst 2000). BRDs designed to exclude bycatch species typically exploit size or behavioural differences between bycatch and target species (Broadhurst 2000, Roosenburg & Green 2000). Size selectivity functions simply by physically limiting those individuals that are too large or of the incorrect shape to pass through the BRD (Broadhurst 2000). Behavioural differences can also be exploited to improve selectivity; for example, observations of behaviour around nets can be used for BRD design and placement (Watson 1989, Broadhurst 2000, Harden & Williard 2012). In addition, the propensity

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of a bycatch species to change its orientation when interacting with a BRD may affect the performance of the BRD. Information on size and behaviour can be combined to determine where overlap between target and non-target species is incomplete, and to create a device that capitalizes on that difference to avoid bycatch (Broadhurst 2000).

Many species of freshwater turtles overlap in habitat with fish that are the target of commercial fisheries, which puts these turtles at risk of incidental capture and associated mortality (Barko et al. 2004, Carrière 2007, Larocque et al. 2012a, Drake & Mandrak in press). The need for atmospheric oxygen makes most turtles unable to survive prolonged submergence in warm water. Delayed sexual maturity and naturally high mortality at early life stages limit the ability of most turtle populations to buffer the loss of fecund individuals (Brooks et al. 1991, Congdon et al. 1993, 1994, Bulté et al. 2010). Turtles have benefitted from several BRDs, in both freshwater and marine systems (Broadhurst 2000, Lowry et al. 2005, Fratto et al. 2008a,b, Bury 2011, Larocque et al. 2012b). The development of turtle excluder devices (TEDs) for commercial marine trawl fisheries is a well-known and successful example (Crowder et al. 1995, Broadhurst 2000, Epperly 2003). A simpler TED has been implemented for commercial and recreational blue crab *Callinectes sapidus* fisheries to reduce incidental capture of diamondback terrapins *Malaclemys terrapin* (Bishop 1983, Wood 1997, Roosenburg & Green 2000, Rook et al. 2010, Hart & Crowder 2011, Morris et al. 2011). Most BRDs rely on a size or shape difference between target and bycatch species. In many freshwater fisheries, however, target fish and bycatch turtles may overlap in size (Fratto et al. 2008a), making it difficult to develop effective TEDs. In some marine fisheries where morphological selective criteria alone were not effective, cameras have been used to document the behaviour of bycatch and target species in and around commercial gear to inform BRD design (Favaro et al. 2012). Behavioural differences between fish and turtles could be similarly exploited in BRD development for freshwater fisheries, but very few efforts have been made to observe and quantify freshwater turtle interactions with small-scale fishing gear.

In eastern Ontario, Canada, a small-scale fyke-net fishery operates in freshwater lakes and large rivers (Burns 2007, Larocque et al. 2012a). Fyke nets are passive entrapment nets in which fish movements are obstructed by a long lead line that directs them into a trap (Hubert 1996). The eastern Ontario fishery targets several fish species that vary in size and ecology: small panfish such as sunfish (*Lepomis* spp.) and yellow perch *Perca flavescens* are primary targets, but larger bullheads (*Ameiurus* spp.) and common carp *Cyprinus carpio* are also targeted. The local turtle community likewise varies in size and ecology. For example, the mass of a snapping turtle *Chelydra serpentina* can be 300 times that of a musk turtle *Sternotherus odoratus*. Intermediate in size are the northern map turtle *Graptemys geographica* and the painted turtle *Chrysemys picta*. These 4 turtle species have habitat preferences that put them at risk of capture in areas of eastern Ontario where fyke nets are deployed (Larocque et al. 2012a). Three of these 4 species have a status of 'special concern' with the Committee on the Status of Endangered Wildlife in Canada, with only the painted turtle considered 'not at risk' (COSEWIC 2012).

Previous studies investigating bycatch reduction in the eastern Ontario commercial fishery left several questions unanswered. Larocque et al. (2012b) found that an exclusion BRD with an 8 cm spacing still allowed the capture of large map turtles (with carapace widths larger than 8 cm), while it reduced the capture of small musk turtles (with carapace widths less than 8 cm). This counterintuitive result is difficult to explain given only the physical characteristics of these species and suggests the need for refinement. Behavioural differences between species may inform BRD design and refinement (Sutherland 1998, Renchen et al. 2012). The aims of the present study were to use an adaptive approach to refine a simple exclusion BRD for commercial fyke nets and to evaluate its effectiveness at reducing captures of 4 species of freshwater turtles. First, turtle behaviour when interacting with nets was documented *in situ*. Controlled behavioural experiments were then used to determine the willingness of target and bycatch species to pass through the BRDs under controlled conditions. Finally, the efficacy of the refined design was tested using paired field trials under realistic commercial fishing conditions.

## MATERIALS AND METHODS

### Study area

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

### Nets

Nets and net set methods used in this study were the same as those presented by Larocque et al. (2012a) and mimic those used by commercial fishers in eastern Ontario. Briefly, we used fyke nets constructed of 7 structural rings each with a diameter of 0.91 m attached together with no.15 knotted nylon, 1 inch (2.54 cm) square mesh (2 inch [5.08 cm] stretch; Christiansen's Nets Company). On the second and fourth rings is a throat that directs organisms into the cod end of the net and minimizes escape. These nets were set in pairs connected mouth to mouth by a lead net 10.7 m long and 0.91 m tall, and each net also had 4.6 m long wings set at ~45° angle all made of the same material. The nets were set near shore in shallow water (1 to 2.5 m deep), equipped with floats to provide an airspace, and left to fish for approximately 24 h.

### Evaluating turtle–net interactions *in situ*

GoPro Hero cameras (Woodman Labs) pointing out towards the mouth were deployed inside 98 fyke nets (Fig. 1) from 12 June 2011 to 20 June 2012 and programmed to take 1 high-resolution photo every 5 s for approximately 3.5 h. We reviewed the photos to record the number of interactions/observations for each species of turtle. The observations per unit effort (OPUE) were then compared to the capture per unit effort (CPUE) of the same net over the total soak time. Qualitative observations were also made of the way turtles approach the nets and the way they move around the mouth of the net to inform BRD design and refinement.

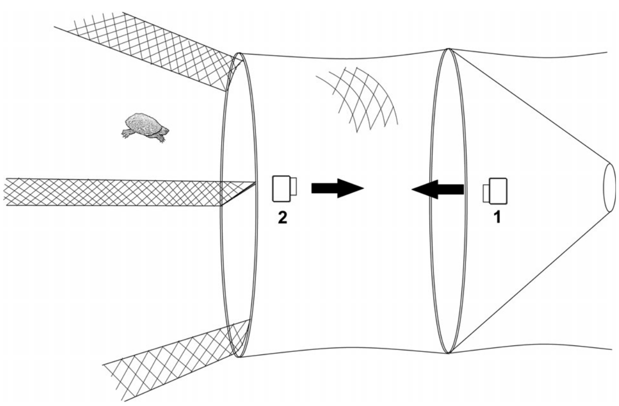


Fig. 1. Mouth of a fyke/hoop net as seen from above showing camera placement for observing pre-capture net–turtle interactions (1) and turtles interacting with the bycatch reduction device affixed to the first throat (2)

### Evaluating constriction BRDs using controlled behavioural experiments

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

These controlled behavioural experiments were conducted from 5 May to 22 June 2012 at water temperatures from 13 to 21°C for turtles and from 15 to 24°C for fish. Both turtles and fish were collected using unmodified fyke nets. Fish trials were run on the day of capture. Turtles were held in open-air ~700 l fibreglass flow-through tanks for 1 to 5 d before the trials. Each turtle or fish was placed in the trial arena for 10 min, and its behaviour was observed from a distance and recorded. Preliminary trials indicated that single *Lepomis* spp. were unlikely to move during a 10 min trial, so 4 individuals were added per trial, and exclusion was recorded as a proportion. No stimulus or bait was used to guide the individuals through the throat or BRDs, relying instead on unsolicited movement in a confined space.

Three treatments were compared using repeated measures on the same individual: painted copper

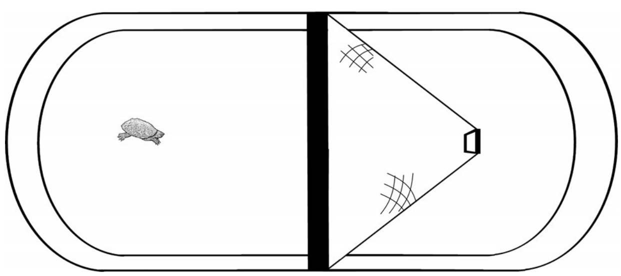

Fig. 2. Arena (as seen from above) used during controlled behavioural experiments to evaluate the effect that constriction bycatch reduction devices (BRDs) of different diameters had on passage rate of representative target and bycatch species present in Lake Opinicon, Ontario, Canada. The arena measures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

piping constriction rectangles with measurements of 22.5 by 5 cm, 22.5 by 8 cm, and an unobstructed throat. Individual order of treatment was randomized. Between treatments, the individuals were placed in a 60 l cooler. Each species was exposed to each order of treatments twice for a total of 12 trials per species. Trials were conducted using target fish (sunfish and bullhead) and bycatch fish (largemouth bass *Micropterus salmoides*), as well as painted, musk, and map turtles. All turtles and fish had dimensions that would allow them to pass through a 5 cm spacing. Only male turtles were used, in an effort to minimize stress on females during the critical spring reproductive season.

## Evaluating constriction BRDs in paired field trials

BRDs with a spacing of 5 cm were affixed to standard fyke nets that were set with floats in the cod end to provide access to air. Nets were set from 7 to 24 September 2011 in water temperatures of 17 to 21.5°C. The first BRD consisted of vertically oriented bars attached across the mouth of the net with a spacing of 5 cm (Fig. 3). The second device was the 5 cm constriction rectangle attached on the inside of the first throat (Fig. 3). Both devices were constructed from 0.5 inch (1.27 cm) diameter copper piping. Nine groups of 3 nets (2 treatments and a control) were set together for roughly 24 h. Cameras were used to monitor the qualitative aspects of turtle–exclusion device interactions using the same methods as the *in situ* turtle–net interactions, but with cameras facing towards the throat (Fig. 1). Pairs of similarly modified nets were fished together connected by a lead net, and the order of treatment was rotated for each set. Upon net retrieval, target and bycatch were identified to species, measured and counted. All animals were returned to the site of capture.

Further field trials were conducted from 29 April to 21 June 2012 with water temperatures ranging from 9.5 to 26°C. The same methods were used as in 2011, but the exclusion bar treatment was eliminated. A

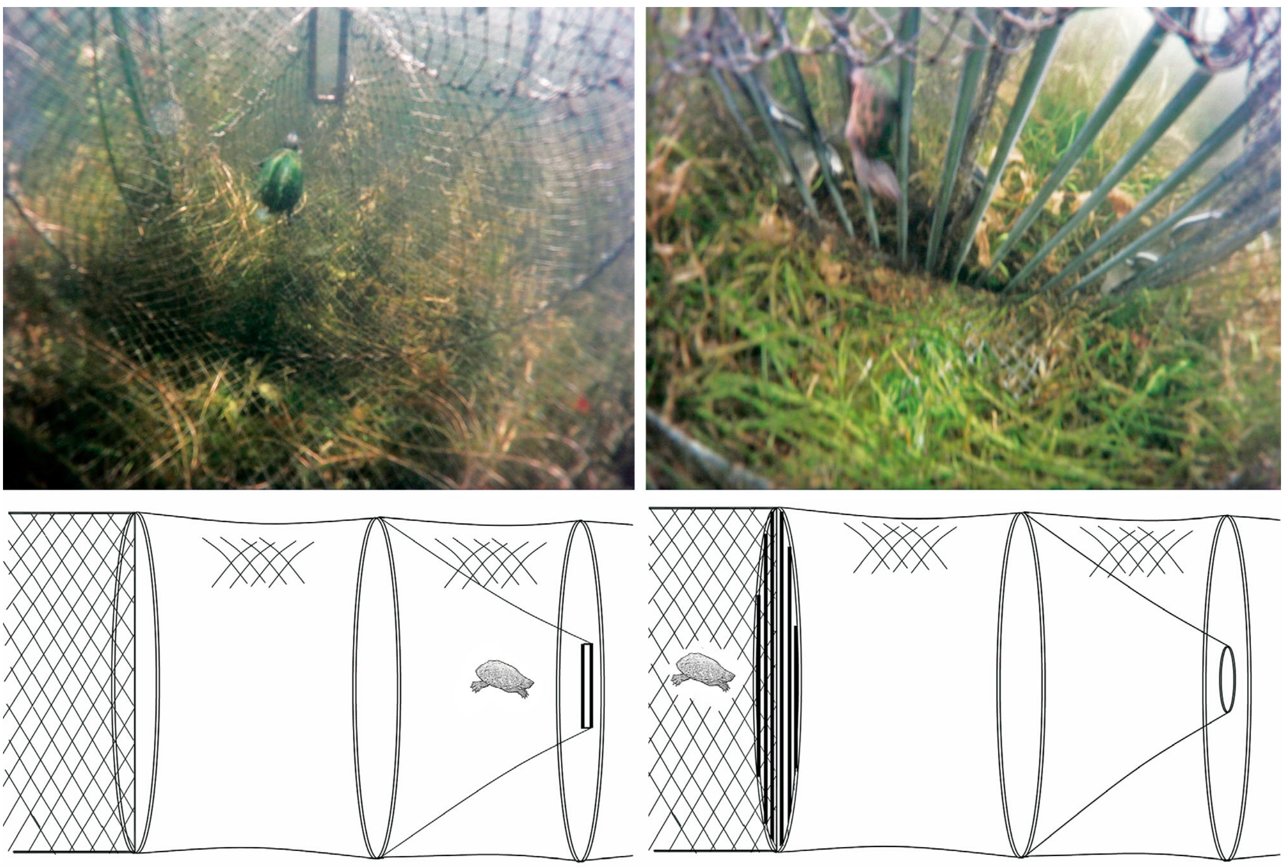

Fig. 3. Constriction rectangle (left) and vertically orientated bars (right) used as exclusion bycatch reduction devices (BRDs) for freshwater turtles in Lake Opinicon, Ontario, Canada. The height of the rectangle is 22.5 cm and the spacing of both BRDs was 5 or 8 cm

total of 22 groups (unmodified controls set with a 5 cm constriction rectangle) were set at 11 sites. Each site was fished twice with treatment order reversed. At least 1 wk was given between sets at a site.

### Statistical analyses

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

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

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

## RESULTS AND DISCUSSION

### Evaluating turtle–net interactions *in situ*

Considering all turtle species combined, camera OPUEs were significantly higher than CPUEs (Fig. 4; $V = 2403$, $p < 0.001$, $r = 0.38$). Wilcoxon signed rank tests indicated that painted turtles ($V = 516$, $p = 0.01$, $r = 0.25$; Fig. 4) and particularly map turtles ($V = 580$, $p < 0.001$, $r = 0.35$; Fig. 4) were observed more frequently than they were captured. However, no such differences were observed for musk ($V = 855$, $p = 0.34$, $r = 0.10$; Fig. 4) and snapping turtles ($V = 45$, $p = 0.32$, $r = 0.10$; Fig. 4), although in the latter case it may be related to smaller sample size. Species composition differed significantly between observation and capture (Fig. 4; $A = 0.03$, $p < 0.001$, where A is a measure of homogeneity (effect size) between pairs). However, no single species appeared to be the main driver of this overall difference. Although all species exhibited higher OPUE than CPUE, the magnitude of the difference varied by species, which suggests some differences in catchability between species.

Catchability is the relationship between the abundance of a species and the efficiency with which a capture method collects that species (Arreguín-Sánchez 1996). The difference between observation (a proxy for abundance) and capture rates for each species is an indication of the likelihood of an individual of that species actually getting caught when interacting with a net. This proportion of captured to observed individuals is deemed the catchability coefficient ($q$; Arreguín-Sánchez 1996). The rate of capture per interaction and the nature of these interactions may provide further insight into the design of BRDs (Bardach & Magnuson 1980). For instance, the

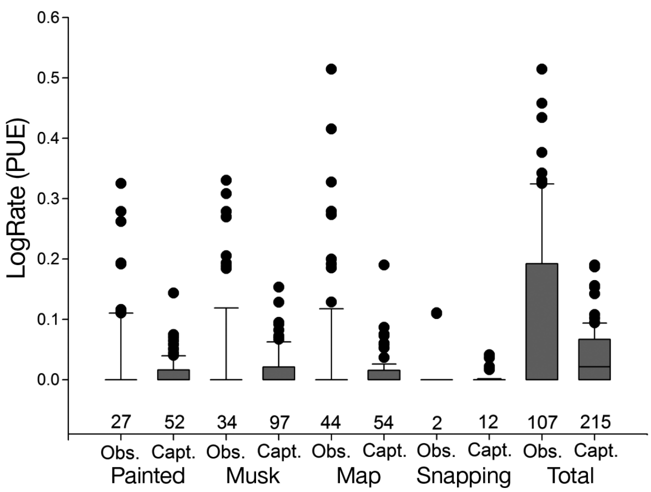


Fig. 4. Logarithmically transformed turtle–net interactions obtained using net-mounted autonomous cameras. Data are observations (obs.) per unit effort (PUE) rate and captures (capt.) per unit effort for the same nets along with sample sizes for each method. The differences between these metrics point to the inter-specific variation of catchability within the turtle community of Lake Opinicon, Ontario, Canada. Boxes represent 25th and 75th percentiles of the population and whiskers the 5th and 95th percentiles. Data outside of these ranges are represented by dots

abundance and catchability of species may point to species that are most at risk of entering nets and allow focused efforts towards these species in particular. Information on the way turtles approach a net may also inform the type and placement of the BRD.

Our observations suggest that the 4 turtle species in Lake Opinicon approach and interact with fyke nets differently. Painted turtles were regularly observed interacting with the nets, but few interactions resulted in capture, suggesting a low catchability ($q = 0.3$; Fig. 4). Painted turtles typically approached along the lead net, swimming above the vegetation. Painted turtles appeared deliberate, swimming directly into the cod end or exiting quickly with minimal contact with the net. Painted turtles often avoided prolonged interactions with nets, turning around upon reaching the mouth of the net or transiting across the mouth to depart on the other side of the lead.

Map turtles had an OPUE nearly 5 times higher than their CPUE, suggesting the lowest catchability of the 4 species ($q = 0.2$; Fig. 4). The behaviour of this species when approaching or interacting with the nets was similar to that of painted turtles, but map turtles tended to approach the net from higher in the water column. Transiting across the mouth of the net was particularly common in map turtles. This may be the cause of the relatively high rates of map turtle captures in nets equipped with 8 cm exclusion bars (Larocque et al. 2012b). By design, these bars impede turtle movement into the mouth of the net, but this has the unintended consequence of making movement around the lead more difficult compared to an unobstructed net, potentially increasing catchability of those turtles able to pass through the BRD. Map turtles that pass through the exclusion device once, in order to transit across the mouth, may then take the path of least resistance and proceed into the cod end of the net instead of passing through the BRD a second time.

Musk turtles had observation rates similar to their capture rates, suggesting higher catchability than map or painted turtles ($q = 0.44$; Fig. 4). Behavioural observations suggest that musk turtles readily entered the mouth of the net. Musk turtles typically approached along the substrate following the lead or wing nets.

Very few snapping turtles were observed or captured during this portion of the study, so an estimate of catchability is preliminary. For snapping turtles, OPUE and CPUE were very similar ($q = 0.95$; Fig. 4). Snapping turtles were only observed twice, and in both cases they interacted with the wings of the net midway in the water column.

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

## Evaluating constriction BRDs using controlled behavioural experiments

Preliminary trials indicated that a model net throat without a BRD did not restrict the passage of turtles over a 10 min period. Video observations revealed that turtles of all 4 species readily turn on their sides to pass through vertically oriented exclusion devices.

The Fisher's exact test revealed differences in the rates of exclusion, where the more restrictive 5 cm device appeared to exclude more turtles than the 8 cm BRD. The 8 cm constriction rectangle did not significantly affect the passage rates of any turtle species (painted: $p = 1$; map: $p = 1$; musk: $p = 0.21$; Fig. 5), bycatch fish (largemouth bass: $p = 1$, Fig. 5) or target fish (bullhead: $p = 0.2$; sunfish: $p = 0.48$, Fig. 5). Reductions generated by the 5 cm device were significant or approached significance for all turtles

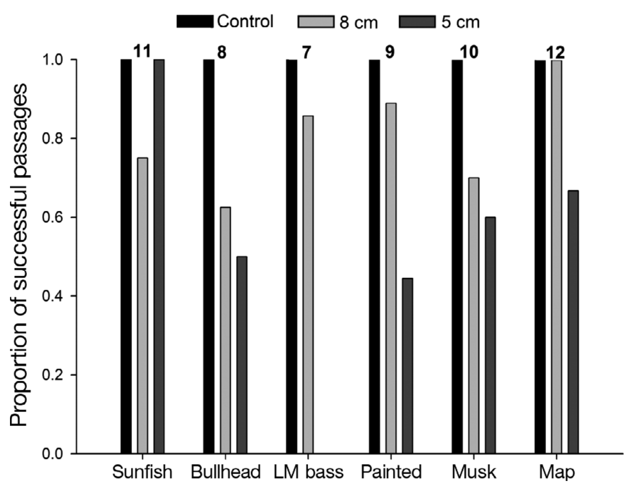


Fig. 5. Successful passage rate through 8 and 5 cm constriction rectangles as a proportion of those individuals which successfully passed through a control in the form of an unconstricted throat. The numbers above the histogram represent the sample size of individuals that passed their respective controls. LM bass: largemouth bass

despite relatively low power (painted: p = 0.03, power = 0.64; map: p = 0.09, power = 0.37; musk: p = 0.09, power = 0.37; Fig. 5). The 5 cm spacing significantly impeded largemouth bass passage rate ($p < 0.001$, Fig. 5), reductions in passage were nearly significant for bullhead (p = 0.08, power = 0.36; Fig. 5), but there was no effect on passage rate for sunfish (p = 1, Fig. 5).

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

Sunfish did not appear to be deterred by the addition of a BRD, with at least 1 sunfish passing through the 5 cm device in all trials. The bullheads, however, appeared to be more averse to passing through BRDs. Of the 7 largemouth bass that passed through the control, 6 also passed through the 8 cm constriction rectangle, but none passed through the 5 cm constriction rectangle. Bullheads and largemouth bass appear to be increasingly excluded by decreased spacing of the exclusion device, but BRDs seem to have little effect on sunfish passage (Fig. 5).

Previous successes in excluding smaller turtles from nets using exclusion devices based on carapace width were likely due to behaviour (Larocque et al. 2012b). Not all species were excluded, however, as painted turtles (8 cm constriction rectangle) and map turtles (8 cm vertical bars) were collected at similar rates between modified and unmodified nets (Larocque et al. 2012b). The willingness of all turtle species tested to turn on their sides to traverse a BRD limits the efficacy of vertically oriented BRDs with large spaces and suggests that a design based on minimum diameter of turtles, such as CH, may be more appropriate. Using CH as a selective criterion, only snapping turtles and large female map turtles could be reliably excluded with an 8 cm device (Fig. 6). The percentages (for adult males and females, respectively) of the Lake Opinicon turtles that can be excluded using a 5 cm device based on CH are 9 and 92% for painted, 2 and 97% for map, 2 and 7% for musk, and 100% for snapping turtles (Fig. 6). These data, along with the minimal apparent effect on the main target species (sunfish), suggest that the 5 cm constriction rectangle may be the most effective BRD to reduce turtle captures while still allowing the capture of target fish.

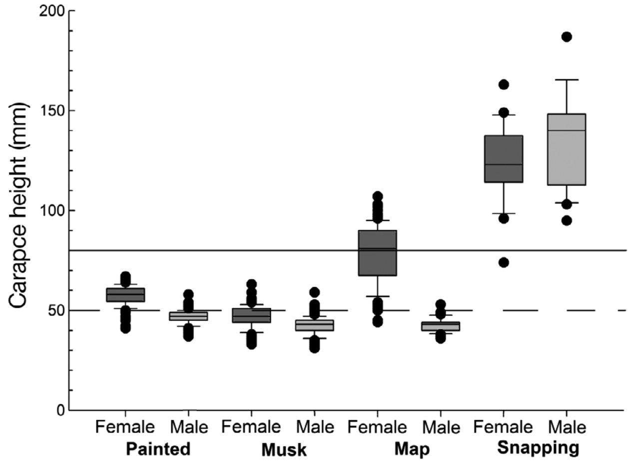


Fig. 6. Minimum diameter (carapace height) of the common turtle species from the Lake Opinicon community and the proportion of each subpopulation which can be excluded by rigid bycatch reduction devices (BRDs) of different spacings. The dashed line represents a BRD spacing of 5 cm and the solid line one of 8 cm. A turtle with a carapace height greater than the spacing would not be physically able to pass through the BRD. Note the increased proportion of the community that would be predictably excluded by a 5 cm BRD. Boxes represent 25th and 75th percentiles of the population and whiskers the 5th and 95th percentiles. Data outside of these ranges are represented by dots

## Evaluating constriction BRDs in paired field trials

In fall 2011, 9 paired net sets (for a total of 18 nets of each treatment) resulted in the capture of 224 fish and 11 turtles in unmodified nets, while 109 fish and 3 turtles were captured in nets modified with 5 cm vertical bars, and 144 fish and 4 turtles were captured in nets modified with a 5 cm constriction rectangle. Both net modifications, bars ($V = 3$, p = 0.08, r = 0.38) and constriction rectangle ($V = 3$, p = 0.08, r = 0.3), tended to reduce turtle captures, but the differences were not statistically significant. Bycatch of game fish also tended to be reduced, but again the differences were not statistically significant for the constriction rectangle ($V = 31$, $p = 0.19$, $r = 0.28$) or vertical bars ($V = 30$, $p = 0.30$, $r = 0.29$). The collection of target fish did not appear to be affected by the constriction rectangle ($V = 61$, $p = 0.30$, $r = 0.23$), but the bars tended to diminish captures, albeit not in a statistically significant manner ($V = 31$, $p = 0.06$, $r = 0.37$). The difference in species diversity collected by control and modified nets was not statistically significant for the bar device ($A = 0.02$, $p = 0.06$) or the constriction rectangle ($A = 0.01$, $p = 0.17$). In total, the control nets collected 8 target fish species, 2 bycatch fish species and 2 turtle species, while the modified nets collected 5 target fish species, 2 bycatch fish species and 2 turtle species.

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

The most obvious difference between the 2 styles of BRD was the ease of use during net deployment and retrieval. The vertically oriented bars were more cumbersome, increasing the time required to set the net. Vertical bars also limited access to the mouth of the net, hindering removal of tangled fish. Conversely, the constriction rectangle had little influence on ease of net use. Because of the important role of user friendliness for fisher adoption of BRDs (Campbell & Cornwell 2008, Nguyen et al. in press), the prevention of turtles from transiting across the mouth of the net and the apparent reduced captures of target fish, we abandoned the use of the vertical bar BRD.

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

The turtle species had varying responses to the BRD. Painted turtles displayed a 92.5% reduction in CPUE between unmodified and modified nets, and those captured had significantly smaller CH (Table 1). The reduction in CPUE was higher than expected from CH alone and likely represents some behavioural exclusion in addition to physical exclusion. CPUE of map turtles was reduced by 92.6%, but there was no difference in CH of individuals captured in modified and control nets (Table 1), which was surprising given that the means are noticeably different (68.2 ± 3.6 and 42.0 ± 0.0 mm for control and treatment, respectively). The device did not appear to have a significant effect on the CPUE for musk turtles even though a 38.3% reduction was observed and the turtles collected were significantly smaller (Table 1). This high capture rate for musk turtles is unexpected based on the success Larocque et al. (2012b) had with 8 cm devices, and is concerning despite the better tolerance of submergence by this species (Stoot et al. 2013). Only 2 snapping turtles were collected, both in unmodified nets. Based on the CH of snapping turtles, it can be assumed that a 5 cm constriction rectangle would exclude the majority, if not all, adults of this species.

The CPUE of target pumpkinseed sunfish was reduced by 22.6% by the 5 cm constriction rectangle compared to an unmodified net, but TL did not differ significantly (Table 1). Bluegill sunfish displayed similar reductions in CPUE (22.7%) in the modified net, but the difference was not significant (Table 1). Bluegill collected in the modified net were significantly larger (Table 1). Brown bullheads were the only target species with a significant reduction for both CPUE and TL (Table 1). A 93.4% reduction in bullhead landings is concerning for fishers as this is an important target species. These ictalurids possess sensitive barbels that may limit their willingness to pass through confined spaces (Ogawa et al. 1997). In addition, the use of metal as a BRD in this study may have reduced the capture of bullheads as they are electrosensitive (Parker & van Heusen 1917, Peters & Bretschneider 1972). The use of a plastic device of the same dimensions may minimize this effect, but further study is needed to address this possibility.

## CONCLUSIONS

Each species in the freshwater turtle community displayed differences in behaviour and catchability, but there were similarities that can be exploited to improve BRD design. Three of the species readily

Table 1. Number, percent of landing, mean size and catch per unit effort (CPUE) along with the corresponding Wilcoxon rank-sum test ($W$) and signed-rank test statistics ($V$) and the relative effect size ($r$) for each species collected using unmodified fyke nets and those modified with a 5 cm constriction rectangle (CR) affixed to the first throat. In total, 44 nets of each treatment were set in Lake Opinicon, Ontario, Canada, from 29 April to 21 June 2012. TL: total length (fishes); CH: carapace height (turtles); NA: not applicable

| Species | Treatment | N | Percent | Mean size in mm (TL or CH) | $W$ | p | $r$ | CPUE (± SE) | $V$ | p | $r$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rock bass | Control | 28 | 2.20 | 217.96 | 365 | 0.40 | 0.20 | 0.04 ± 0.01 | 153 | 0.66 | 0.07 |
| *Ambloplites rupestris* | CR | 31 | 4.29 | 225.97 | | | | 0.03 ± 0.01 | | | |
| Black crappie | Control | 34 | 2.67 | 247.18 | 256 | 0.69 | 0.06 | 0.03 ± 0.01 | 166 | 0.08 | 0.26 |
| *Pomoxis nigromaculatus* | CR | 14 | 1.94 | 238.86 | | | | 0.01 ± 0.00 | | | |
| Bluegill | Control | 248 | 19.50 | 197.59 | 20932 | 0.02 | 0.12 | 0.26 ± 0.05 | 570 | 0.14 | 0.22 |
| *Lepomis macrochirus* | CR | 195 | 26.97 | 199.72 | | | | 0.20 ± 0.05 | | | |
| Pumpkinseed | Control | 479 | 37.66 | 208.26 | 92019 | 0.13 | 0.05 | 0.48 ± 0.05 | 630 | 0.03 | 0.34 |
| *Lepomis gibbosus* | CR | 362 | 50.07 | 207.00 | | | | 0.37 ± 0.06 | | | |
| Yellow bullhead | Control | 29 | 2.28 | 272.24 | 215.5 | 0.24 | 0.18 | 0.03 ± 0.01 | 124 | 0.10 | 0.25 |
| *Ameiurus natalis* | CR | 12 | 1.66 | 264.50 | | | | 0.01 ± 0.01 | | | |
| Brown bullhead | Control | 106 | 8.33 | 299.15 | 547.5 | 0.03 | 0.20 | 0.11 ± 0.03 | 319 | <0.001 | 0.63 |
| *Ameiurus nebulosus* | CR | 7 | 0.97 | 281.57 | | | | 0.01 ± 0.00 | | | |
| Largemouth bass | Control | 202 | 15.88 | 342.41 | 8772.5 | <0.001 | 0.31 | 0.21 ± 0.03 | 789 | <0.001 | 0.64 |
| *Micropterus salmoides* | CR | 61 | 8.44 | 301.49 | | | | 0.06 ± 0.01 | | | |
| Northern pike | Control | 16 | 1.26 | 515.50 | 67 | 0.18 | 0.28 | 0.02 ± 0.01 | 90 | 0.09 | 0.25 |
| *Esox lucius* | CR | 6 | 0.83 | 476.50 | | | | 0.01 ± 0.00 | | | |
| Painted turtle | Control | 53 | 4.17 | 48.98 | 185 | 0.01 | 0.33 | 0.05 ± 0.01 | 366 | <0.001 | 0.64 |
| *Chrysemys picta* | CR | 4 | 0.55 | 43.00 | | | | 0.00 ± 0.00 | | | |
| Musk turtle | Control | 47 | 3.69 | 44.23 | 989.5 | <0.001 | 0.38 | 0.05 ± 0.01 | 164 | 0.22 | 0.18 |
| *Sternotherus odoratus* | CR | 29 | 4.01 | 40.24 | | | | 0.03 ± 0.01 | | | |
| Map turtle | Control | 27 | 2.12 | 68.19 | 46 | 0.11 | 0.30 | 0.03 ± 0.01 | 164 | <0.001 | 0.51 |
| *Graptemys geographica* | CR | 2 | 0.28 | 41.00 | | | | 0.00 ± 0.00 | | | |
| Snapping turtle | Control | 2 | 0.16 | 144.50 | NA | NA | NA | 0.00 ± 0.00 | NA | NA | NA |
| *Chelydra serpentina* | CR | 0 | 0.00 | 0.00 | | | | 0.00 ± 0.00 | | | |
| Total turtles | Control | 129 | 10.14 | NA | NA | NA | NA | 0.13 ± 0.02 | 614 | 0.001 | 0.60 |
| | CR | 35 | 4.84 | | | | | 0.03 ± 0.01 | | | |
| Total target species | Control | 925 | 72.72 | NA | NA | NA | NA | 0.95 ± 0.10 | 770 | 0.001 | 0.50 |
| | CR | 621 | 85.89 | | | | | 0.64 ± 0.11 | | | |
| Total fish bycatch | Control | 218 | 17.14 | NA | NA | NA | NA | 0.22 ± 0.03 | 820 | 0.001 | 0.63 |
| | CR | 67 | 9.27 | | | | | 0.07 ± 0.01 | | | |

turn on their sides when confronted with a narrow space, suggesting that CH is preferable to carapace width when trying to predict which turtles can be physically excluded with a given BRD. Because turtle height is less than turtle width, this will result in BRDs with smaller openings which, in turn, may diminish captures of target fish.

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

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