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Development and Efficacy of a Bycatch Reduction Device for Wisconsin-Type Fyke Nets Deployed in Freshwater Systems

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Abstract. – **Aquatic biologists throughout the United States use fyke nets to sample fish. Often, these nets have high turtle bycatch and mortality rates, especially when set in extreme environmental conditions. Because a previous study found increased turtle mortality using Wisconsin-type fyke nets, we designed and tested a bycatch reduction device (BRD) for this net type and investigated its ability to reduce turtle bycatch without affecting fish capture. Over 68 net-nights, the BRD significantly reduced turtle bycatch with no significant decrease in fish quantity or richness when compared to a control fyke net with no BRD. We argue that aquatic biologists and managers should consider turtle mortality when sampling fishes and other aquatic organisms. We also suggest that further studies be conducted to develop BRDs for all passive freshwater sampling nets. Further, BRDs that have already been designed and tested and appear effective at reducing turtle bycatch without significantly affecting fish catch, such as ours, should be implemented in freshwater fisheries methodologies. This is the first known BRD developed for freshwater trap nets.**

Key Words. – **Reptilia; Testudines; Trionychidae; Chelydridae; Emydidae; turtle; mortality; fish sampling; fyke nets; bycatch reduction device; turtle excluder device; TED; BRD; USA; Mississippi River**

Aquatic biologists often use fyke nets (otherwise known as trap nets) to sample fish, and many protocols require nets to be set for 24–72 hours (Gutreuter et al. 1995; Hubert 1996). These nets are usually set perpendicular to the shore with the lead fixed to the bank and the hoops of the net completely submerged. Consequently, there is a high rate of turtle bycatch involved with passive fishing techniques (Sullivan and Gale 1999; Michaletz and Sullivan 2002; Barko et al. 2004). Because trapping is often conducted during periods with extreme environmental conditions (e.g., high water temperature during summer months or deep water during spring flooding), turtle mortality can approach 100% because of low dissolved oxygen content and drowning (Barko et al. 2004; Fratto et al. 2008). For example, in 2001, fisheries biologists using hoop nets set for 72 hours to sample 2 reservoirs in southeastern Missouri captured 800 turtles per 100 net-nights with nearly 100% mortality (J. Briggler, Missouri Department of Conservation, unpubl. data). Barko et al. (2004) identified some environmental variables correlated with increased aquatic turtle mortality, including depth of gear deployment and temperature. Unfortunately, these conditions are often unavoidable when fish are sampled, especially when spawning or young-of-the-year fishes are targeted. Hence, revised methodologies and gear modifications should be considered to reduce bycatch and bycatch mortality when deploying passive techniques for fish and other aquatic organisms within waters occupied by turtles.

Similar considerations have been made in oceanic systems. For example, gear modifications were developed for shrimp trawls in the 1980s (Seidel and McVea 1982) and implemented by the National Marine Fisheries Service and commercial shrimp trawlers to reduce loggerhead sea turtle (*Caretta caretta*) bycatch. Crowder et al. (1995) studied the effect of turtle excluder devices (TEDs) on loggerhead turtle strandings and showed that TEDs reduced beach strandings by 44%.

Wood (1997) developed a bycatch reduction apparatus to address mortality in diamondback terrapins (*Malaclemys terrapin*) caught in crab traps, which are passive gear like freshwater trap nets. The bycatch reduction apparatus effectively reduced the number of turtles caught in crab traps and increased the number of harvestable crabs. Roosenburg et al. (1997) developed crab pots that were taller than standard commercial and recreational pots used in the Chesapeake Bay to allow terrapins to surface for air. Roosenburg and Green (2000) also developed bycatch reduction devices (BRDs) for crab pots to reduce terrapin mortality. To date, we know of no similar modifications made to freshwater sampling gears.

The lack of TEDs, bycatch reduction apparatuses, and BRDs on passive fishing techniques, especially in freshwater systems where few species are federally

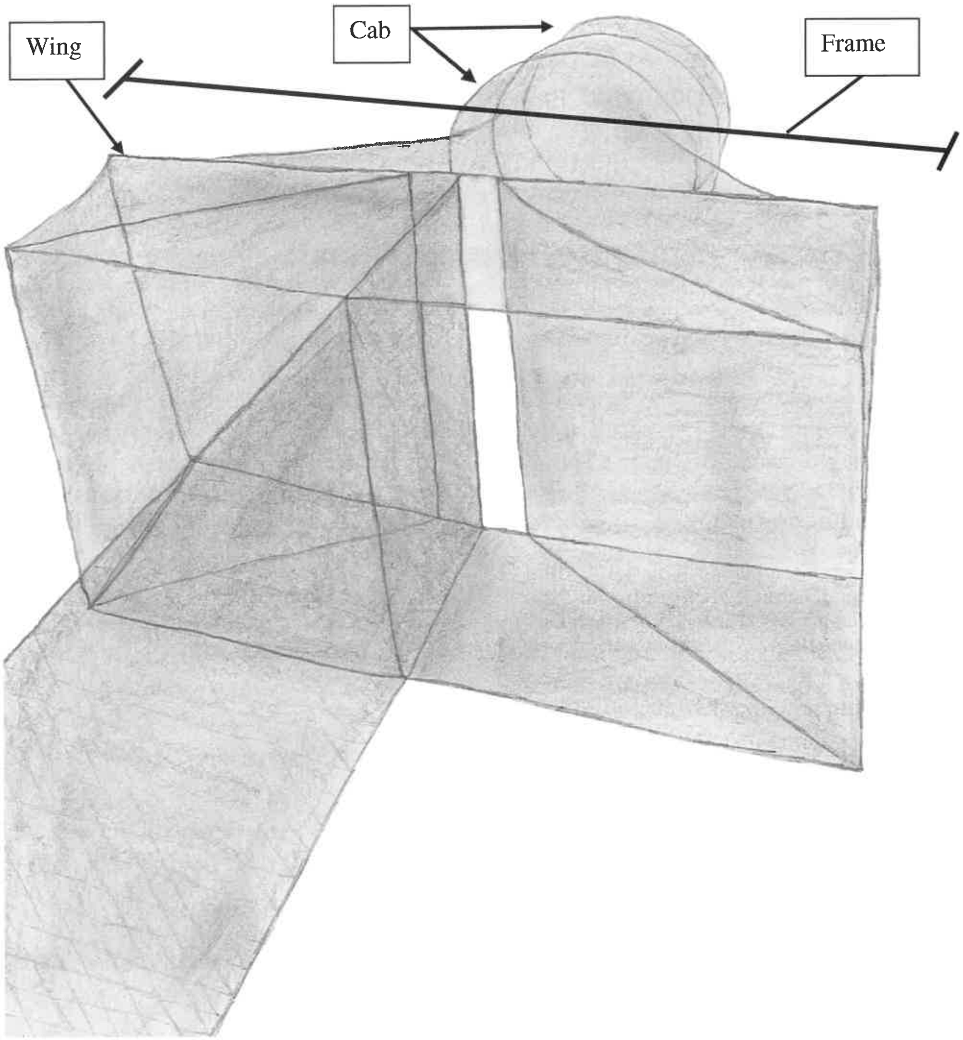

Figure 1. Design of the control Wisconsin-type fyke net with no modifications.

protected, threatens all turtle species. Increased threats occur in areas where fisheries studies and/or commercial fishing are conducted over consecutive years. The increased mortality these species incur can alter population dynamics and sex-based ratios within a population (Roosenburg et al. 1997).

Public attention has focused on charismatic marine turtles because of numerous documented cases of turtle mortality and beach strandings (see Crouse et al. 1987; Magnuson et al. 1990). Also, many turtles in marine environments are listed as threatened or endangered; hence, the federally mandated use of BRDs. Because marine turtles differ markedly in size or shape from target species like shrimp or crab, the development of effective TEDs and BRDs was less problematic. In freshwater systems, turtles are often similar in size to fish species found within their environment. For example, blue catfish, *Ictalurus furcatus*, and common map turtles, *Graptemys geographica*, have similar body widths. Thus, successful BRDs in freshwater systems may depend on unique aspects of turtle and fish behavior rather than size or shape. Barko et al. (2004) reported fyke nets in the middle Mississippi River had higher turtle mortality rates when compared to other sampling gears. Thus, we developed a BRD for this net type to provide aquatic biologists working in river systems a tool to reduce turtle bycatch while not significantly affecting fish species richness and abundance.

Study Site

Our study was conducted in Missouri within 3 river systems: Mississippi River (MSR), Gasconade River, and Missouri River. Sampling was conducted within MSR floodplains and island side channels of Mississippi and New Madrid counties, backwater sloughs of the Gasconade River in Gasconade and Osage counties, the MSR Diversion Channel of Cape Girardeau County, Mingo National Wildlife Refuge of Stoddard and Wayne counties, and behind wing dikes on the Missouri River in Gasconade County. Fisheries studies in Missouri having the greatest turtle mortality were conducted in lowland habitats (J. Briggler, Missouri Department of Conservation, *pers.*

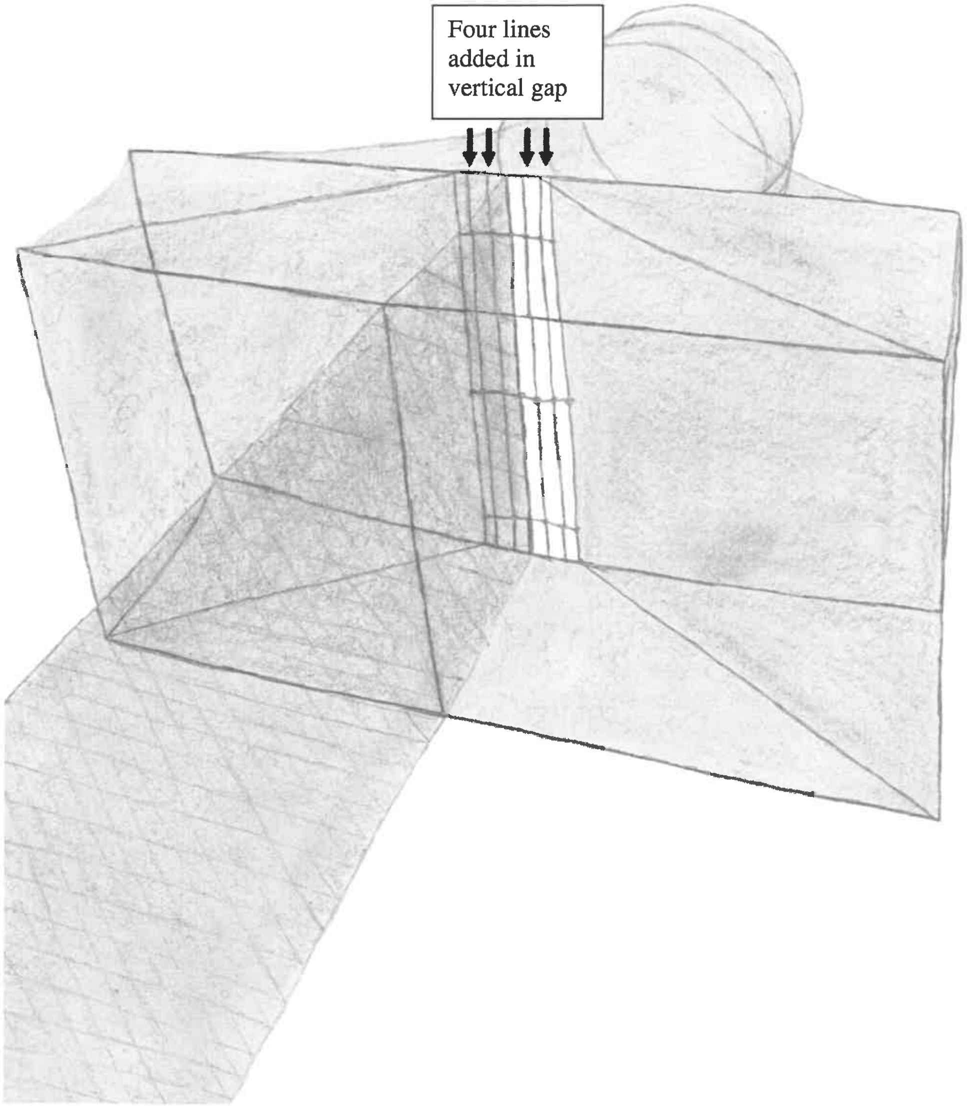

Figure 2. Design of the modified Wisconsin-type fyke net illustrating the pattern of braided rope configuration and placement of modification.

comm., February 2006). Study sites (public and private) greater than 3.2 ha in size were identified using a Geographic Information System (GIS). This minimum size was chosen to provide ample room for paired net sets. Floodplain sites were defined as water bodies within the 100-/500-year floodplain and were composed of levee borrow pits, ditches, blew holes (e.g., scour holes created by openings in the levee), and chutes. Side channels had direct connection to the main river channel annually; whereas, floodplain sites had no connectivity to the main river except during extreme flood events. Sample sites were demarcated into 100-m^2 grids and net placement within each site was chosen using a random number generator.

METHODS

Data were collected from July to October 2005 and from May to July 2006 when water temperature generally exceeded 15°C, presumably ensuring turtle activity (Finkler et al. 2004). The control Wisconsin-type fyke net (Gutreuter et al. 1995) consisted of a lead (15 m long × 1.3 m high), frame, and cab with 19-mm bar mesh (Fig. 1). The frame and cab were 6.0 m long when fully extended and 2 rectangular spring-steel rods (0.9 m high and 1.8 m wide) formed the frame. Two mesh wings extended from the sides of the first frame to the middle of the second frame, forming a 5.1-cm vertical gap. The cab was constructed of 6 steel hoops with a 0.9-m diameter. There were 2 throats on the fyke net, one on the first hoop (40-mm mesh aperture) and one on the third hoop (32-mm mesh aperture). The cod end had a 2.4-m-long drawstring to keep the cod closed with 19-mm bar mesh.

The modified fyke net had two 3.18-mm braided rope vertical lines tied 38 mm apart where the wings came together in the middle of the second frame for a total of 4 lines (Fig. 2). Horizontal lines were added for rigidity at

Table 1. Overall abundance, mean (x), and standard error (SE) of catch per net-night for turtle species captured in modified fyke net and its unmodified control net across all habitats sampled in 2005 and 2006. Mean catch per net-night (abundance $\geq$ 10) was compared using t-tests, and significant results are bolded.

	Modified			Control				
Family and species	N	x	SE	N	x	SE	t	p
Chelydridae								
Common snapping turtle *Chelydra serpentine*	1	0.03	0.03	49	1.44	0.6	−2.32	**0.027**
Kinosternidae								
Common musk turtle *Sternotherus odoratus*	51	1.5	0.88	33	0.97	0.54	0.51	0.610
Emydidae								
Southern painted turtle *Chrysemys picta dorsalis*	8	0.24	0.15	24	0.71	0.45	−0.99	0.330
Common map turtle *Graptemys geographica*	1	0.03	0.03	27	0.8	0.03	−1.47	0.150
Ouachita map turtle *G. ouachitensis*	2	0.06	0.06	2	0.06	0.04		
False map turtle *G. pseudogeographica*	104	3.06	1.58	167	4.91	1.61	−0.82	0.414
River cooter *Pseudemys concinna*	2	0.06	0.04	12	0.35	0.21	−1.35	0.187
Red-eared slider *Trachemys scripta*	156	4.59	2.4	994	29.24	12.44	−1.95	0.060
Trionychidae								
Midland smooth softshell *Apalone mutica*	0	0	0	21	0.62	0.24	−2.59	**0.014**
Eastern spiny softshell *A. spinifera*	6	0.18	0.15	26	0.76	0.25	−2.04	**0.046**

127 mm and 101.6 mm from the bottom and halfway from the top and bottom. Each net was set for 24 hours with the lead tied to the bank, with the remainder of the net running perpendicular from the bank into the water. Each modified net and its paired control were set with $\leq$ 1.5 m depth differences and $\geq$ 100 m apart to reduce bias. After each 24-hour period, nets were relocated to the next random water body. Turtles and fishes were identified to species, counted, measured for length (carapace length [CL] in millimeters for turtles and total length [TL] in millimeters for fish) and released at the point of capture. Because our study focused on the development of an effective BRD, we did not mark any fish or turtle species captured.

During 2005, the modified net and its paired control were set at 10 different sites within the MSR (5 floodplain; 5 side channel). During 2006, the modified net and its paired control were set in the Gasconade River ($n = 6$), Missouri River ($n = 4$), Mingo National Wildlife Refuge ($n = 5$), MSR Diversion Channel ($n = 5$), and floodplains of the MSR ($n = 4$) using the same methodology as in 2005. We conducted 34 paired net sets across all habitats (i.e., 68 net-nights).

Statistical Analysis. — All statistical analyses were performed using SAS v. 9.1.3 with significance assessed at $p = 0.05$ (SAS Institute 2002). Kolmogorov-Smirnov tests were used to assess normality (Lilliefores 1967). Because data transformations (i.e., log, log + 1, square root, sin, cosin, tangent, and 5%–10% trims) were unsuccessful at normalizing the turtle abundance data, we used Wilcoxon rank-sum test to determine if our modified net had an effect on turtle abundance using the mean abundance of each modified and control net (Sokal and Rohlf 1981). To determine if there were differences among mean catch per net-night for each turtle species with an overall abundance $\geq$ 10 (arbitrary sample size restriction) in either the control or modified net, we used t-tests (Steel and Torrie 1980). We also used t-tests to identify differences in mean fish abundance (log + 1 transformed) among the paired nets and mean catch per net-night of each fish species (overall abundance $\geq$ 10 in either the control or modified net) and fish species richness (log + 1 transformed) among the paired nets. Abundance of Lepisosteidae and Centrarchidae fish families were compared using Wilcoxon rank-sum tests because these families are often targeted in fyke nets by aquatic biologists in large, midwestern river systems (Boxrucker and Ploskey 1989; McInerny 1989; Hoffman et al. 1990). Other families were not analyzed because of the low frequency at which they occurred. We analyzed length distributions of both fish and turtles using Kolmogorov-Smirnov 2-sample tests. Fish mortality among net types was compared using a Wilcoxon rank-sum test.

RESULTS

We captured 1686 turtles in 68 net-nights during 2005 and 2006. The control fyke nets captured 80% of the turtles ($n = 1355$), while the modified fyke net captured fewer turtles ($n = 331$; $Z = -3.314$, df $= 1$, $p < 0.001$). There were differences in mean catch per net-night for 3 turtle species (midland smooth softshell, *Apalone mutica*; eastern spiny softshell, *A. spinifera*; and common snapping turtle, *Chelydra serpentina*; Table 1). In 48% of the net-nights ($n = 14$), the modified net captured no turtles; whereas, the control net caught no turtles during 8% of the net-nights ($n = 3$).

Over 68 net-nights, we captured 893 fishes (33 species), with 478 fishes (23 species) captured in modified fyke nets and 415 fishes (29 species) in the control nets. There was no difference in fish quantity (Satterthwaite method of unequal variances; $t = 0.96$, df $= 59$, $p = 0.338$) or fish species richness ($t = -1.42$, df $= 66$, $p = 0.161$) among the modified and control nets. Also, there was no difference in mean catch per net-night for any of the fish species analyzed (Table 2). Much of the fish catch was comprised of Centrarchidae ($n = 625$, 70%) and

Table 2. Overall abundance, mean (*x*), and standard error (SE) per net-night for fish species captured in modified fyke net and its unmodified control net across all habitats sampled in 2005 and 2006. Mean catch per net-night (abundance $\geq$ 10) was compared using *t*-tests and significant results are bolded.

	Modified			Control				
Family and species	*N*	*x*	SE	*N*	*x*	SE	*t*	*p*
Lepisosteidae								
Longnose gar *Lepisosteus osseus*	1	0.03	0.03	4	0.12	0.07		
Spotted gar *L. oculatus*	11	0.32	0.21	12	0.35	0.16	−0.11	0.912
Shortnose gar *L. platostomus*	26	0.76	0.19	85	2.5	0.97	−1.76	0.087
Amiidae								
Bowfin *Amia calva*	6	0.18	0.09	4	0.12	0.06		
Clupeidae								
Gizzard shad *Dorosoma cepedianum*	11	0.32	0.1	15	0.44	0.22	−0.49	0.624
Cyprinidae								
Common carp *Cyprinus carpio*	6	0.18	0.08	8	0.24	0.09		
Bighead carp *Hypophthalmichthys nobilis*	0	0	0	1	0.03	0.03		
Catostomidea								
Bigmouth buffalo *Ictiobus cyprinellus*	0	0	0	1	0.03	0.03		
Smallmouth buffalo *I. bubalus*	0	0	0	7	0.21	0.08		
River carpsucker *Carpiodes carpio*	5	0.15	0.06	9	0.26	0.1		
Black redhorse *Moxostoma duquesnei*	3	0.09	0.09	0	0	0		
Spotted sucker *Minytrema melanops*	1	0.03	0.03	0	0	0		
Ictaluridae								
Channel catfish *Ictalurus punctatus*	0	0	0	9	0.26	0.13		
Blue catfish *I. furcatus*	0	0	0	1	0.03	0.03		
Flathead catfish *Pylodictis olivaris*	0	0	0	1	0.03	0.03		
Yellow bullhead *Ameiurus natalis*	2	0.06	0.04	1	0.03	0.03		
Brown bullhead *A. nebulosus*	0	0	0	2	0.06	0.04		
Black bullhead *A. melas*	1	0.03	0.03	5	0.15	0.15		
Moronidae								
Yellow bass *Morone mississippiensis*	0	0	0	3	0.09	0.06		
White bass *M. chrysops*	2	0.06	0.06	3	0.09	0.05		
Striped bass *M. saxatilis*	0	0	0	4	0.12	0.07		
White bass × Striped bass hybrid *Morone* spp.	0	0	0	1	0.03	0.03		
Centrarchidae								
Largemouth bass *Micropterus salmoides*	5	0.15	0.12	5	0.15	0.12		
Warmouth *Lepomis gulosus*	3	0.09	0.05	1	0.03	0.03		
Green sunfish *L. cyanellus*	0	0	0	2	0.06	0.06		
Orangespotted sunfish *L. humilis*	1	0.03	0.03	2	0.06	0.06		
Longear sunfish *L. megalotis*	60	1.76	0.88	39	1.15	0.57	0.59	0.557
Bluegill *L. macrochirus*	182	5.35	2.05	66	1.94	0.59	1.60	0.118
Redear sunfish *L. microlophus*	14	0.41	0.22	2	0.06	0.06	1.58	0.123
Flier *Centrarchus macropterus*	3	0.09	0.09	0	0	0		
Rock bass *Ambloplites rupestris*	2	0.06	0.04	1	0.03	0.03		
Black crappie *Pomoxis nigromaculatus*	55	1.62	0.61	59	1.74	0.62	−0.13	0.893
White crappie *P. annularis*	68	2	0.94	55	1.62	0.53	0.35	0.726
Sciaenidae								
Freshwater drum *Aplodinotus grunniens*	11	0.32	0.16	7	0.21	0.09	0.63	0.531

Lepisosteidae ($n = 142$, 16%). We also found no difference in the quantity of Centrarchidae ($Z = 1.207$, df = 1, $p = 0.228$) or Lepisosteidae ($Z = -1.866$, df = 1, $p = 0.062$) among control and modified nets.

We found a significant difference in the length distribution of both false map, *Graptemys pseudogeographica*, and red-eared sliders, *Trachemys scripta* ($p < 0.001$, Fig. 3), as well as white crappie, *Pomoxis annularis* ($p = 0.008$, Fig. 4), and bluegill, *Lepomis macrochirus* ($p = 0.003$). However, we found no difference in length distributions of longear sunfish, *Lepomis megalotis* ($p = 0.459$), or black crappie, *Pomoxis nigromaculatus* ($p = 0.4239$). The number of dead fish per net-night was significantly different among control and modified nets ($Z = -2.571$, df = 1, $p = 0.01$) with 16 fish dead in the modified net sets and 100 fish dead in the control net sets.

DISCUSSION

Our data suggest that the modified fyke net did reduce turtle capture when compared with its control without significantly affecting fish quantity or fish species richness. However, the modification was not very effective at reducing turtles of smaller size (i.e., common musk turtles, *Sternotherus odoratus*, and juvenile turtles of various species), likely because the modification was not restrictive enough. Conversely, if the modification was too restrictive, there may have been a decrease in fish quantity or the frequency of larger fish.

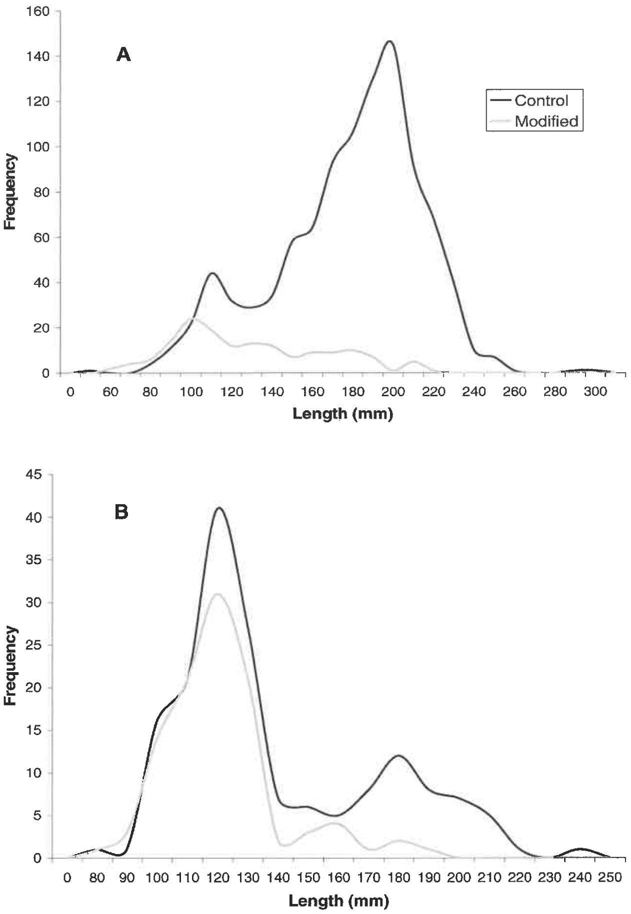

Figure 3. A comparison of length-frequency distributions of red-eared sliders (A) and false map turtles (B) among control and modified nets.

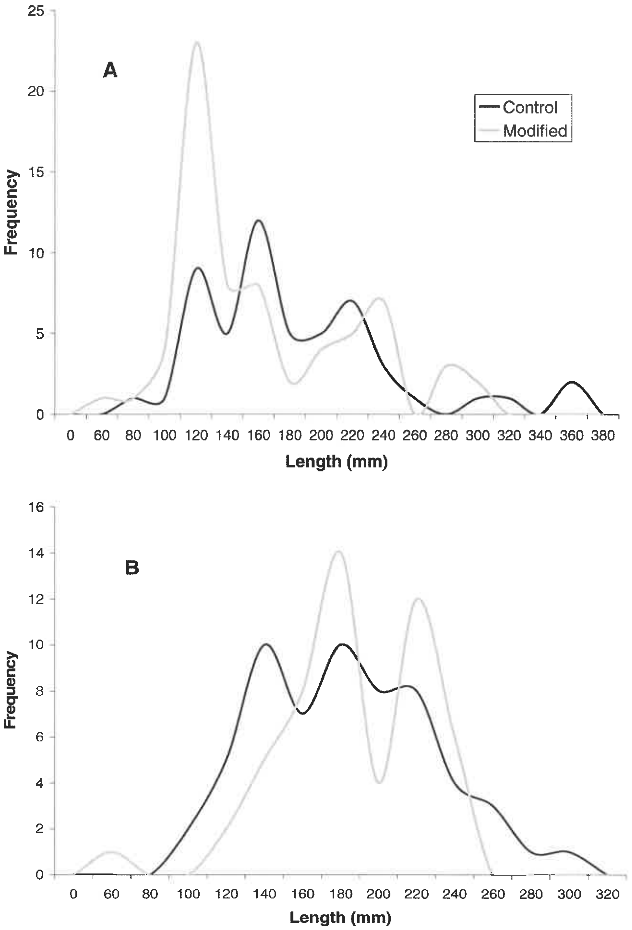

Figure 4. A comparison of length-frequency distributions of white crappie (A) and black crappie (B) among control and modified nets.

When sampling requires nets to be submerged, the application of this modification may prevent high numbers of aquatic turtles from drowning, especially when set in extreme environmental conditions such as high water temperature (Barko et al. 2004). Turtles rely on environmental temperatures to control their internal temperature and metabolism (Pough et al. 1998). Cooler waters and low stress conditions allow turtles to remain submerged for longer periods of time before drowning. When turtles are captured in nets, the stress incurred may raise metabolic rates, creating a greater demand for oxygen (Pough et al. 1998). This becomes problematic when turtles are captured in warm temperatures because the submersion time before drowning is shortened.

Our BRD captured fewer large and small turtles when compared to the control net. A reduction in turtle size is important because few sexually mature turtles will be killed or removed from the population. Turtles are long-lived and growth is slow in most adults (Cagle 1946; Gibbons and Semlitsch 1982; Pough et al. 1998). When high rates of adult or older juvenile turtles are harvested or captured as bycatch in commercial fishing or biological sampling nets, the age structure of these populations cannot remain stable (Congdon et al. 1993, 1994). A study on the demographics of Blanding's turtles, *Emydoidea blandingii*, found that population stability was most sensitive to changes in adult and/or juvenile survivorship (Congdon et al. 1993). One consequence of an unstable age distribution is large density fluctuations in different age groups. Because turtles are long-lived, recovering to a stable age distribution can take many years (Gibbons and Semlitsch 1982).

In regards to the differences in length distributions of bluegill and white crappie among modified and control nets, this shift in the distribution may be a consequence of the greater number of turtles found in the control nets and the increased chance of fish consumption by turtles. Another explanation for these results may be that these fishes avoided nets with greater numbers of turtles as a sort of predator avoidance. There also was a decrease in shortnose gar, *Lepisosteus platostomus*, abundance in the modified nets. Although not significant, the apparent decrease in gar may also help explain the significant difference in length distributions of bluegill and white crappie. Shortnose gar are known to be generalist in their food habits, and they may prey on fishes within the nets (Pflieger 1997). There was also greater fish mortality in the control nets, likely because of increased turtle capture.

Many of the dead fish had missing fins, heads, and other body parts, presumably a result of turtle consumption. Because we found no turtles lodged in the throats of the fyke nets, we do not believe turtles blocked the entrance to these nets and that fish could continuously be trapped. Further, fyke nets used in our study had 2 finger-style throats that were larger than the girths of any of the turtles captured. Because of our findings, we suggest that a reduction in turtle capture within the nets may yield more accurate fish population assessments.

To our knowledge, no papers have been published on BRDs in freshwater systems on passive or active fishing techniques. Further investigation of TEDs and BRDs for freshwater fishing techniques is essential because riverine turtle numbers are declining (Moll and Moll 2000), and turtle mortality figures from commercial fishing are lacking (Barko et al. 2004). These factors are troubling because aquatic turtle habitats, such as rivers, streams, lakes, and other such wetlands, are threatened and declining (Gosselink and Maltby 1990). For instance, floodplains and side channels are becoming disjunct from mainstem rivers because of extensive levee systems, wing dikes, and closing structures (Simons et al. 1975; Buhlmann and Gibbons 1997; Theiling 1999). Bodie and Semlitsch (2000) studied habitat use of lentic and lotic aquatic turtles with the use of radiotelemetry and found that riverine species such as false map and red-eared slider turtles spend most of the year in the Missouri River, but during the warmer months, habitat use was more diverse and included offshore wetlands and even flooded agricultural fields and forests.

Of the 160 freshwater aquatic and semi-aquatic turtle species in the United States, at least 62 require conservation action, and 18 of these are federally endangered (Burke et al. 2000). With these declines and the negative human influence on worldwide turtle populations, incidental mortality by biologists and commercial fisherman using passive sampling techniques should not add to the decline. Our study provides useful information for aquatic managers because our modified nets did not significantly reduce the quantity or richness of fishes captured, yet reduced turtle captures. We suggest further evaluation of this gear in other systems as well as additional research into the development of TEDs and BRDs for other passive and active sampling nets commonly deployed in freshwater systems (e.g., hoop nets). Further, we urge state and federal agencies to support the development, testing, and implementation of these BRDs.

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