Bait type influences on catch and bycatch in tandem hoop nets set in reservoirs

James M. Long [a,*], David R. Stewart [b], Jeremy Shiflet [c], Dane Balsman [d], Daniel E. Shoup [e]

[a] U.S. Geological Survey, Oklahoma Cooperative Fish and Wildlife Research Unit, Department of Natural Resource Ecology and Management, 007 Agriculture Hall, Oklahoma State University, Stillwater, OK 74078, USA
[b] U.S. Fish and Wildlife Service, Division of Biological Sciences, National Wildlife Refuge System, Post Office Box 1306, Albuquerque, NM 87103, USA
[c] Kentucky Department of Fish and Wildlife Resources, 1398 Highway 81 N., Calhoun, KY 42327, USA
[d] Kentucky Department of Fish and Wildlife Resources, 1 Sportsman's Lane, Frankfort, KY 40601, USA
[e] Department of Natural Resource Ecology and Management, Oklahoma State University, 008 Ag Hall, Stillwater, OK 74078, USA

ARTICLE INFO

ABSTRACT

Tandem hoop nets have become the primary gear for sampling channel catfish *Ictalurus punctatus*, but suffer from high incidences of bycatch, particularly aquatic turtles that usually drown as a result. We sought to determine if bait type, ZOTE© soap and ground cheese logs, would influence catch of channel catfish (CPUE and mean TL) and bycatch of fishes and aquatic turtles. We sampled with tandem hoop nets in 13 Kentucky reservoirs (5–73 ha) using a crossover design and two sampling events. We found no difference in channel catfish catch rates between bait types, but mean sizes of fish caught using ZOTE© soap were approximately 24 mm longer compared to cheese. Fish bycatch was similar between bait types, but tandem hoop nets baited with ZOTE© soap caught up to 61% fewer turtles and mortality of turtles that were captured was up to 12% lower than those baited with cheese. Depth of net set, water temperature, and Secchi depth were environmental factors measured that affected catch and bycatch, but varied among species. Using ZOTE© soap as bait in tandem hoop nets appears to be a fairly simple and straightforward method for maintaining high catch rates of channel catfish while minimizing turtle mortality.

Published by Elsevier B.V.

1. Introduction

Entanglement and trapping gears used to capture fish in freshwater systems often result in bycatch (Bettoli and Scholten, 2006; Cartabiano et al., 2015). For example, baited tandem hoop nets are a common entrapment gear used by fisheries biologists to sample freshwater fishes (Fratto et al., 2008), particularly channel catfish *Ictalurus punctatus* (Michaletz and Sullivan, 2002; Stewart and Long, 2012; Bodine et al., 2013). These tandem hoop nets often have high bycatch, particularly aquatic turtles that usually drown. In Longview Lake, Missouri, for example, aquatic turtle bycatch in tandem hoop nets experienced 94% mortality (Sullivan and Gale, 1999) and "hundreds" of dead turtles in the nets reduced channel catfish catch in some lowland impoundments (Michaletz and Sullivan, 2002). The incidental capture and mortality of aquatic tur-

tles is a growing concern among biologists, given that the additional mortality is sufficient to jeopardize turtle populations (Congdon et al., 1994; Midwood et al., 2015). Although efforts to reduce bycatch and associated mortality through gear modifications have been attempted (e.g., excluder devices; Fratto et al., 2008; Larocque et al., 2012), management agencies and commercial fishers would need to replace their current equipment with newly modified gear, which could be expensive. However, bait type has rarely been considered as a potential, inexpensive solution to reduce hoop net-related bycatch even though many bait types (e.g., soybean cake and cheese) have been examined for their effect on catch of channel catfish (Pierce et al., 1981; Flammang and Schultz, 2007). With trotlines, ZOTE© soap virtually eliminated turtle bycatch (Barabe and Jackson, 2011; Cartabiano et al., 2015), suggesting promise when used with tandem hoop nets. At Lake McMurtry, Oklahoma, ZOTE© soap used as bait in tandem hoop nets resulted in similar catch rates and size structure of channel catfish as cheese logs and with lower rates of turtle mortality (Cartabiano et al., 2015). However, this study was limited to only one reservoir, hindering general-

ization to multiple systems, and lacked identification of ancillary environmental variables that might influence results.

We sought to determine if bait type (ZOTE© soap and ground cheese logs) in tandem hoop nets could affect catch and size structure of target channel catfish and bycatch, particularly aquatic turtles. Additionally, we sought to relate environmental factors to catch and bycatch from the use of this gear. If simply changing bait types can limit bycatch while achieving sampling goals and maintaining high efficiency (i.e., personnel time), then wildlife resources can be better conserved.

2. Materials and methods

We chose 13 reservoirs in Kentucky for sampling and set four to six tandem hoop net series (depending on reservoir size) in each of two sampling periods in June 2014 (Table 1; Fig. 1). Tandem hoop net series consisted of three nets per series, each 3.4 m long with 25-mm bar mesh and seven 0.8-m hoops with throats constricted (Michaletz and Sullivan, 2002; Porath et al., 2011). During each sample period, one half of the sites had nets baited with 800 g of ground cheese logs (i.e., 1/3 of a 2.5 kg log per net in the 3-net tandem series; Boatcycle, Inc., Henderson, Texas) and the other half with 800 g ZOTE© soap (two 400-g bars in each net; Fábrica de Jabón La Corona, Mexico). Nets were fished for two days, after which all animals were removed and processed. Nets were then re-set with the opposite bait and allowed to fish another two days (i.e., crossover sampling design with carryover effects where bait A assigned to period 1 at site X may influence catch in period 2 of bait B at site X; Kuehl, 2000). Nets were fished parallel to shore at depths <4 m when possible, but steep slopes sometimes necessitated setting nets perpendicular to shore. At each net set and retrieval, we measured Secchi depth, water depth, and water temperature.

Captured animals were identified to species, enumerated, and fate was recorded (dead or alive). Channel catfish, the target species, were measured (total length, mm) and released 100 m from the site of capture. To determine if bait type influenced catch statistics of target and non-target species, we evaluated catch rates (number of individuals per series) and size structure of channel catfish, relative abundance of bycatch (non-target fishes and turtles), and proportional turtle mortality. We used ($log_{10}(x+1)$) to normalize abundance and length data, and arcsine-square root of proportion of dead turtles. The crossover statistical design accounted for bait sequence based on the interaction effect between period and bait ($\lambda_{c(k-1)}$) using the linear mixed model:

$$y_{ij(h)k} = \mu + \alpha_i + \rho_{ij(h)} + \gamma_k + \tau_{d(i,k)} + \lambda_{c(k-1)} + \varepsilon_{ij(h)k}$$

where α_i is the ith bait sequence effect, $\rho_{ij(h)}$ is the random effect for the jth site within hth lake of the ith bait sequence, γ_k is the kth period effect, $\tau_{d(i,k)}$ is the effect of the bait administered in period k of sequence group i, and $\varepsilon_{ij(h)k}$ is the random experimen-

tal error for the jth site within hth lake of the kth period (Kuehl, 2000). Analyses were conducted using lme4 function within the lmer package in R (Bates et al., 2014), which was followed by a Tukey's Honestly Significant Difference (HSD) test in instances of significance ($P \leq 0.05$). The package lmerTest was used to calculate F and P-values using the Kenward-Rogers approximation to determine denominator degrees of freedom (Kuznetsova et al., 2013).

To measure the effects of bait type and environmental variables on fish catch and bycatch, we used an occupancy modeling approach (i.e., hierarchical Bayesian multi-species mixture model) and estimated detection probabilities (p) as a measure of the gear's ability to capture individual fish species (MacKenzie et al., 2002; Royle, 2004). Only species caught at six or more reservoirs and composing >1% of the total catch were considered to avoid biased parameter estimates of rare species. The model used spatially replicated counts for species k, site i and survey t that is assumed to be a realization of a binomial random variable, denoted as

$$y_{itk} \sim Binomial(N_{ik}, p_{itk})$$

Parameter p_{itk} (detection probability) enables corrected abundance estimates of the target species at sample sites due to incomplete detection (MacKenzie et al., 2002; Royle, 2004). The modeling approach assumes a closed population, which was reasonable given that sites were sampled within a four-day period. Detection probability was represented as a *logit* function of site-level covariates (bait, temperature, Secchi depth, and depth) for species k measured at site i at time t.

The estimated abundance N_{ik} for each fish species was estimated using the same covariates, while accounting for spatial dependency by constructing a hierarchical model that nested sites within lake (Snijders and Bosker, 1999; Gelman and Hill, 2007). Because of over-dispersion in the count data, abundance was assumed to follow a negative binomial distribution. This was accomplished in WinBUGS software (version 1.4; Spiegelhalter et al., 2003) by adding a hierarchical component ε_i with an approximate gamma distribution ($\varepsilon_i \sim gamma(\theta, \theta)$) to a Poisson distribution, such that the resulting probability distribution is marginal to ε_i and θ is the parameter of extra Poisson variation

$$N_{i,k} \sim Poisson(\lambda_{ik}\varepsilon_i).$$

Parameter λ_{ik} was represented as a *log* function of site-level covariates (bait, temperature, Secchi depth, and depth) for species k measured at site i. We did not evaluate candidate models based on a priori hypotheses, but instead were solely interested in functionally significant variables. Models were implemented in WINBUGS software, version 1.4 (Spiegelhalter et al., 2003) using Markov chain Monte Carlo (MCMC) algorithms to generate posterior distributions of the parameters. Diffuse priors (noninformative) were used, models were fit using three parallel chains, and each chain was simulated for 50,000 iterations with a burn-in of the first 20,000

Table 1
Characteristics of Kentucky reservoirs sampled for fish with tandem hoop nets, summer 2014.

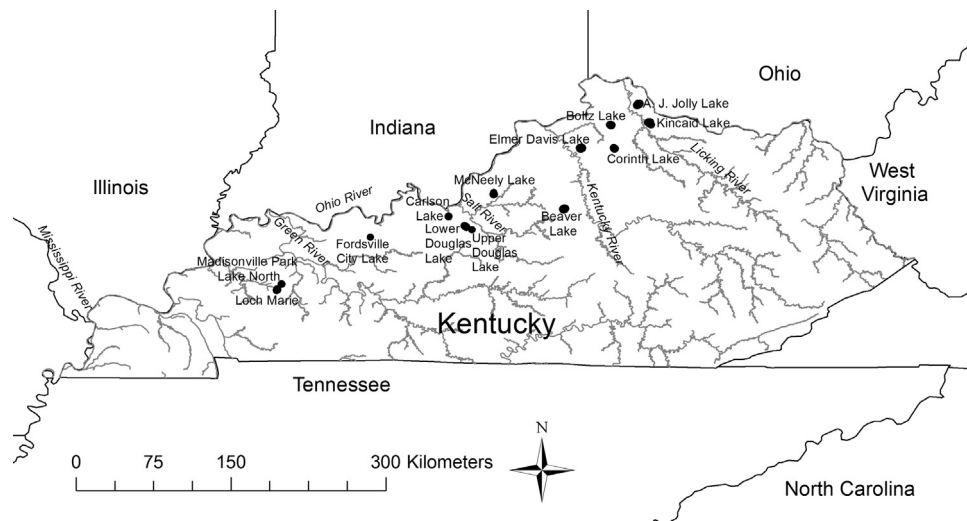| Reservoir	N net series	Surface area (ha)	Mean water temperature (°C)	Mean Secchi depth (cm)
A.J. Jolly	6	71	29.3	77.7
Beaver	6	59	24.4	117.1
Boltz	6	37	28.2	88.6
Carlson	4	6	26.0	167.0
Corinth	6	34	27.1	287.7
Elmer Davis	6	55	24.4	81.2
Fordsville City Park	4	5	25.9	38.0
Kincaid	6	73	29.5	62.5
Loch Marie	6	58	25.5	76.0
Lower Douglas	6	37	28.8	168.0
Madisonville CP South	4	10	25.3	97.0
McNeely	6	21	26.4	156.7
Upper Douglas	4	5	30.2	457.0

Fig. 1. Map of study reservoirs in Kentucky examining the effect of bait type (cheese logs or ZOTE© soap) on catch and bycatch of tandem hoop nets set in summer 2014.

Table 2
Fish species and number captured with tandem hoop nets baited with ZOTE© soap or ground cheese logs in 13 Kentucky reservoirs, summer 2014.

Species	N	Bait	
		Soap	Cheese
Black bullhead *Ameiurus melas*	8	2	6
Black crappie *Pomoxis nigromaculatus*	394	148	246
Blue catfish *Ictalurus furcatus*	24	19	5
Bluegill *Lepomis macrochirus*	1994	1141	853
Brown bullhead *Ameiurus nebulosus*	3	2	1
Channel catfish *I. punctatus*	3042	1613	1429
Common carp *Cyprinus carpio*	1	0	1
Flathead catfish *Pylodictis olivaris*	2	0	2
Gizzard shad *Dorosoma cepedianum*	4	2	2
Green sunfish *Lepomis cyanellus*	10	3	7
Largemouth bass *Micropterus salmoides*	24	16	8
Longear sunfish *Lepomis megalotis*	8	3	5
Redear sunfish *Lepomis microlophus*	384	204	180
Warmouth *Lepomis gulosus*	20	10	10
White crappie *P. annularis*	586	274	312
Yellow bass *Morone mississippiensis*	11	5	6
Yellow bullhead *Ameiurus natalis*	32	23	9
Total	6547	3465	3082

iterations. To determine convergence, we used the Gelman-Rubin diagnostic convergence statistics, examination of chain histories, and posterior density plots (Gelman and Rubin, 1992).

3. Results

Totals of 17 fish and 6 turtle species were collected from the 70 sampling stations at the 13 reservoirs (Tables 2 and 3). The fish catch was mostly the target species, channel catfish ($N = 3,042$, 46% of total catch), but non-target fishes such as bluegill *Lepomis macrochirus* ($N = 1,994$, 30% of total catch), white crappie *Pomoxis annularis* ($N = 586$, 9% of total catch), black crappie *P. nigromaculatus* (n = 394, 6% of total catch), and redear sunfish *L. microlophus* ($N = 384$, 6% of total catch) were regularly caught. Hoop nets with soap ($N = 1,182$; mean = 26.8; SD = 30.6) caught similar numbers of fish bycatch compared to hoop nets baited with cheese ($N = 1,616$; mean = 24.7; SD = 21.5; $F_{1,83} = 0.60$, $P > 0.05$) and tests for carryover ($F_{1,130} = 0.36$, $P > 0.05$), period ($F_{1,5} = 0.09$, $P > 0.05$) and sequence effects ($F_{1,8} = 0.05$, $P > 0.05$) were not significant.

Bait type did not affect catch rates of channel catfish ($F_{1,88} = 0.69$, $P > 0.05$), but did affect mean size of channel catfish captured

($F_{1,43} = 5.29$, $P < 0.05$; Table 3; Fig. 2). Hoop nets baited with cheese caught similar numbers of channel catfish compared to those baited with soap and tests for carryover ($F_{1,124} = 1.50$, $P > 0.05$), period ($F_{1,6} = 0.11$, $P > 0.05$) and sequence effects ($F_{1,7} = 0.33$, $P > 0.05$) were not significant. Hoop nets baited with soap caught slightly larger-sized channel catfish (mean = 344.3 mm TL ± 82.6 [SD]) compared to hoop nets baited with cheese (mean = 320.5 mm TL ± 74.2 [SD]; Tukey HSD $P < 0.01$; Fig. 2). Carry-over ($F_{1,62} = 0.02$, $P > 0.05$), period ($F_{1,43} = 0.19$, $P > 0.05$) and sequence ($F_{1,62} = 0.11$, $P > 0.05$) effects were not significant for mean size of channel catfish captured.

Overall, turtles were caught significantly more often in hoop nets with cheese ($N = 608$; mean = 10.7; SD = 11.6; $F_{1,113} = 16.76$, $P < 0.01$; Tukey HSD $P < 0.01$) than with soap ($N = 332$; mean = 6.9; SD = 9.9) with no significant carryover ($F_{1,98} = 0.54$, $P = 0.46$), period ($F_{1,113} = 2.42$, $P = 0.12$), or sequence effects ($F_{1,125} = 1.19$, $P = 0.28$) (Table 4). The turtle catch was predominately redear sliders *Trachemys scripta elegans* ($N = 572$, 61% of total catch), common musk turtles *Sternotherus odoratus* ($N = 254$, 27% of total catch), and common snapping turtles *Chelydra serpentine* ($N = 83$, 9% of total catch). Only these three turtle species were captured frequently enough to test for mortality differences between bait types. In all cases, mean proportional mortality was greater when cheese was the bait: redear slider ($F_{1,60} = 6.21$, $P < 0.05$; Tukey HSD = 2.63, $P < 0.05$), common musk turtle ($F_{1,57} = 7.82$, $P < 0.05$; Tukey HSD = 3.09, $P < 0.05$) and common snapping turtles ($F_{1,60} = 8.11$, $P < 0.05$; Tukey HSD = 2.92, $P < 0.05$). A significant sequence effect ($F_{1,65} = 5.55$, $P < 0.05$) was detected for common snapping turtles, with higher proportional mortality when cheese was the first bait used at a site (Tukey HSD = 3.03, $P < 0.05$).

Detection probabilities (p) were significantly related to water depth, Secchi depth, water temperature, and bait type for many fish species (Fig. 3). Hoop nets set in shallower water tended to have greater detection probabilities of black crappie, bluegill, and channel catfish whereas white crappie was captured more often in nets set in deeper water. Greater Secchi depth measurements resulted in increased detection probabilities of redear sunfish, and channel catfish and decreased detection of black crappie and white crappie. Higher water temperatures led to lower detection probabilities for all species except white crappie. Detection probabilities for bluegill, and channel catfish increased when hoop nets were baited with soap, whereas the opposite was the case for black crappie and white crappie, where detection probabilities were greater when cheese was the bait.

Table 3
Sample characteristics of Channel Catfish captured using tandem hoop nets baited with ZOTE© soap or ground cheese logs at Kentucky reservoirs, summer 2014. N is the number of nets series in each reservoir for each bait type. Catch per unit effort (CPUE; number of fish per net series per 48-h set).

Reservoir	N net series	Soap		Cheese	
		CPUE (SD)	Mean TL (SD)	CPUE (SD)	Mean TL (SD)
A.J. Jolly	6	20.7 (15.2)	293.0 (54.9)	14.2 (3.9)	312.1 (64.5)
Beaver	6	60.2 (68.1)	355.5 (77.1)	15.3 (8.1)	335.5 (76.7)
Boltz	6	3.0 (3.5)	340.9 (99.8)	12.7 (17.9)	285.1 (59.4)
Carlson	4	43.5 (36.2)	300.1 (59.9)	84.0 (60.7)	302.5 (53.4)
Corinth	6	32.2 (21.9)	324.1 (84.9)	27.3 (19.3)	294.9 (75.1)
Elmer Davis	6	38 (38.4)	302.6 (72.5)	13.7 (9.3)	283.9 (64.8)
Fordsville City Park	4	11.8 (17.7)	326.4 (67.7)	111.0 (21.2)	308.7 (62.9)
Kincaid	6	9.7 (5.6)	312.0 (91.6)	11.3 (12.3)	299.9 (74.8)
Loch Marie	6	55.3 (63.5)	399.0 (59.6)	28.0 (11.2)	389.3 (68.7)
Lower Douglas	6	13.0 (18.0)	410.1 (70.7)	8.0 (4.1)	395 (42.5)
Madisonville CP South	4	2.0 (1.7)	320.5 (99.6)	1.3 (0.6)	407.3 (78.6)
McNeely	6	2.0 (1.4)	292.8 (17.9)	3.8 (3.1)	328.7 (64.7)
Upper Douglas	4	28.3 (43.9)	410.3 (79.6)	19.3 (10.2)	375.2 (82.8)
Total	70	27.8 (37.6)	344.3 (82.6)	22.3 (29.6)	320.5 (74.2)

Table 4
Number of turtles captured (percent dead) by species for tandem hoop nets baited with ZOTE© soap or ground cheese logs in Kentucky reservoirs, summer 2014.

Reservoir	Redear slider		Common musk		Common snapping		Spiny softshell		Common map		Midland painted	
	Soap	Cheese	Soap	Cheese	Soap	Cheese	Soap	Cheese	Soap	Cheese	Soap	Cheese
A.J. Jolly							1 (100)					
Beaver	17 (71)	96 (69)	29 (52)	89 (72)	1 (100)	7 (57)		1 (100)				
Boltz	4 (50)	6 (83)					1 (100)	3 (67)				
Carlson	23 (65)	5 (60)	2 (100)	6 (67)		3 (67)						
Corinth	19 (74)	42 (62)			3 (33)	1 (100)		2 (0)				
Elmer Davis	15 (20)	26 (38)	27 (48)	58 (55)	3 (0)	2 (50)						
Fordsville City Park	1 (100)	2 (50)		3 (67)		7 (43)						1 (0)
Kincaid	3 (67)	8 (75)	7 (71)	21 (81)	13 (85)	7 (57)		2 (100)				
Loch Marie	9 (33)	19 (95)			2 (0)	3 (33)						
Lower Douglas	7 (71)	48 (85)		2 (100)		3 (67)						
Madisonville CP South	80 (100)	30 (93)			7 (43)	12 (58)	5 (80)	8 (88)				
McNeely	39 (87)	35 (29)	2 (50)	3 (100)	2 (50)	6 (50)						
Upper Douglas	5 (80)	32 (100)	4 (100)	2 (100)		1 (100)			1 (100)	5 (80)		1 (100)
Mean	18.5 (68.2)	29.1 (69.9)	11.8 (70.2)	23.0 (80.3)	4.4 (44.4)	4.7 (62.0)	2.3 (93.3)	3.2 (71.0)	1.0 (100.0)	5.0 (80.0)		1.0 (50.0)

4. Discussion

Sampling is most efficient when it produces quality data on the species of interest while limiting bycatch of non-target species, reducing processing time and avoiding needless damage to non-target populations. Turtle bycatch and subsequent mortality can be a major problem with tandem baited hoop nets, which is generally considered the most effective gear for sampling channel catfish (Bodine et al., 2013). We found that baiting tandem hoop nets with ZOTE© soap rather than cheese logs did not meaningfully affect catch statistics of channel catfish (except for slightly larger mean size), but led to the capture 36–61% fewer turtles (leading to dramatically fewer dead turtles) and reduced proportional mortality of turtles that were captured by 1–12%. Although Kentucky has 14 native species of turtles and we only captured 6, (all were species with stable populations; KCWCS, 2013), reducing bycatch mortality for this group can help ensure these species remain stable.

Seasonal differences may further affect catch of target and non-target species, although we did not specifically investigate this. Seasonal effects have been variable for channel catfish catch rates and size structure (Hesse et al., 1982; Michaletz, 2001; Michaletz and Sullivan, 2002; Flammang and Schultz, 2007; Wallace et al., 2011) whereas turtle bycatch and mortality has been consistently higher in comparative warmer seasons (summer vs spring, Michaletz, 2001; spring vs fall, Wallace et al., 2011). Further research is warranted to compare ZOTE© soap to other baits in relation to season to examine its effect on channel catfish catch and turtle bycatch and mortality. However, if protocols currently rely on sampling for channel catfish in summer, results from our study suggest that turtle bycatch can be reduced without sacrificing target fish sample size by using ZOTE© soap as bait, although not all lakes in our study responded similarly.

Inter-reservoir variation was evident for all the catch and bycatch measures we examined, suggesting that our results may differ when applied to any one specific reservoir. For example, from a simple, non-statistical perspective, CPUE of channel catfish in 9 of our 13 study reservoirs was larger when soap was the bait, whereas cheese caught more fish in the remaining 4 (e.g., Boltz Reservoir where mean CPUE was 4× higher with cheese than soap). However, our robust statistical design enabled for detecting patterns in catch and bycatch in spite of this variation, which is inherent in any study involving multiple sampling sites. Furthermore, controlling for site-specific variation, bait order, period, and even cross-over effects were vital for interpreting bait effects, especially for turtle bycatch where we could not estimate detection probabilities.

Detection probabilities for turtles could not be estimated due to their consistently high mortality, especially during the first period of sampling. To estimate detection probabilities from unmarked individuals, one needs a closed population from which to conduct repeat sampling (MacKenzie et al., 2002). Most turtles were dead after the first period, violating model assumptions of a closed population for the second period (i.e., all animals captured during the first period were available for capture during the second period). This phenomenon was particularly notable for common snapping turtles where we found a significant sequence effect. With low abundance and high mortality when captured, the effect of capture and subsequent death during the first period of sampling would have had the largest effect on common snapping turtles
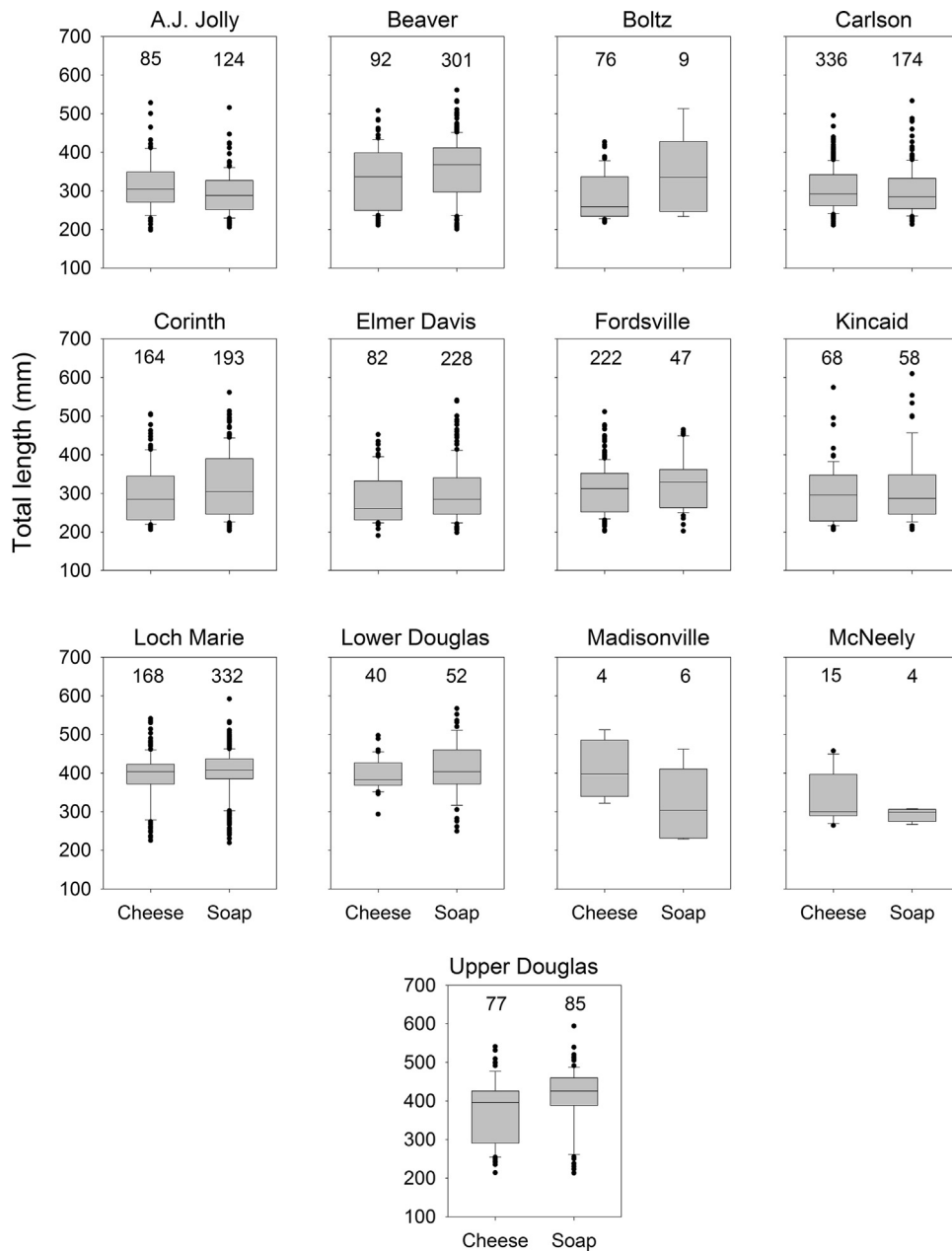
Fig. 2. Box plots of mean TL of Channel Catfish captured from 13 Kentucky reservoirs using tandem hoop nets baited with cheese logs or ZOTE©soap in summer 2014. The shaded box is bounded by the 25th and 75th percentile, with the median bar indicated between. The 10th and 90th percentiles are indicated by error bars and samples beyond these are indicated as dots. Numbers above the box plots indicate number of Channel Catfish captured in that reservoir with that bait.

leading to the significant sequence effect. Common snapping turtle populations were identified as most vulnerable to extirpation due to bycatch mortality in Lake Opinicon, Ontario, Canada compared to other turtle species (Midwood et al., 2015) and our results would suggest this vulnerability can be applied to the species more broadly (e.g., southern U.S. reservoirs).

More precisely, we find a significant sequence effect for common snapping turtle mortality when cheese was the bait, as well as higher mortality of turtles in general, highlighting the role of bait type. A number of studies have been conducted on bait type and turtle catch in nets in an effort to improve population studies of turtles, including the use of frozen fish (Thomas et al., 2008), fish and red meat (Mali et al., 2012), and dog and cat food (Mali et al., 2014). Typical of these studies is the placement of bait such that the scent is available to turtles without the ability to ingest it (Mali et al.,

2014). Thus, it is an implicit assumption that turtles are seeking the bait as a food item. With trotlines, where bait is readily available for consumption, soap has been shown to eliminate turtle bycatch (Barabe and Jackson, 2011; Cartabiano et al., 2015), suggesting turtles are not seeking to eat it as opposed to catfish that are readily caught in this manner. Because turtles are lured to traps with fish, and fish are lured to the traps with bait (including soap), we speculate that turtles are arriving at traps baited with soap mainly after fish are captured (i.e., turtles are lured to the captured fish and not the bait) compared to traps baited with cheese where turtles may be lured to the bait itself in addition to the captured fish. Being lured later would result in less time spent in the trap and a lower potential for mortality. Again, we reiterate that this is speculation as we know of no study that has examined bycatch in this manner, although this line of reasoning could be tested with controlled
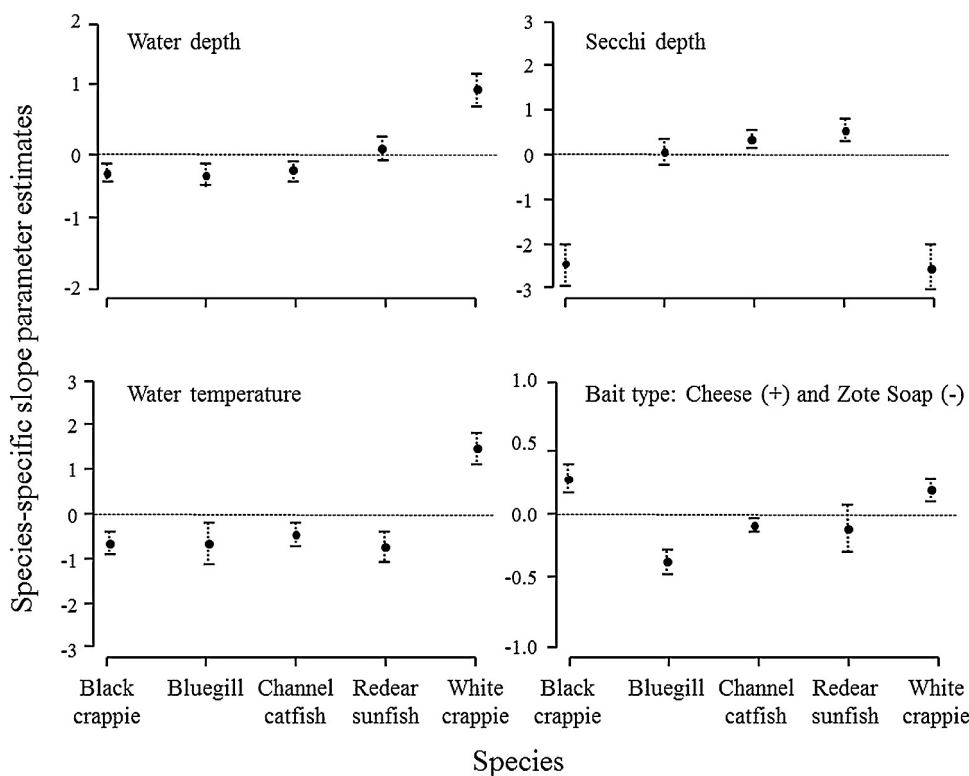
Fig. 3. Species-specific parameter estimates from the hierarchical Bayesian *N*-mixture model relating four functionally significant environmental variables to conditional detection probabilities ($p|N$) of the most commonly captured fish species in tandem hoop nets in Kentucky reservoirs.

studies and a way to precisely measure when a particular organism enters the nets (e.g., action cameras, Struthers et al., 2015).

Environmental factors identified by this study that influence catch and bycatch can be used to further increase catch efficiency (i.e., high target catches with low bycatch) regardless of bait type. Incidental capture of nontarget species can be a concern for anyone, and environmental factors associated with net locations influenced detection of many species. For example, detection of target channel catfish was positively related to shallow, clear, cooler water and these sites could be chosen over others if the goal is to maximize catch of this species, which would likely reduce bycatch of crappie in particular. However, other species such as bluegill, which was our most abundant bycatch fish species, would likely not be affected given similar responses to covariates of detection probabilities as channel catfish.

Tandem hoop nets are considered one of the most accurate and efficient gears for sampling channel catfish populations (Bodine et al., 2013), but bycatch is a common problem that hinders its efficiency (Michaletz, 2001; Flammang and Schultz, 2007; Wallace et al., 2011), to the point that it prevents sampling in some environments (Michaletz and Sullivan, 2002). As stewards of all aquatic resources, it is important that fisheries biologists have tools that allow them to obtain the data they need to manage target organisms without undue harm to non-target species. We demonstrated that tandem hoop nets baited with ZOTE© soap produced similar catch rates of channel catfish compared to cheese logs, but with a slight increase in mean size of fish captured. Additionally, ZOTE© soap significantly reduced turtle mortality, both by reducing the number of turtles captured (by 36–61%) and by reducing the mortality rate of those that were captured (by 1–12%). In situations where bycatch or turtle mortality reduction is important, ZOTE© soap could be a relatively easy substitution for cheese logs while maintaining target species catch rates.

References

Barabe, R.M., Jackson, D.C., 2011. Using soap bait to prevent turtle bycatch on trotlines. In: Michaletz, P.H., Travnichek, V.H. (Eds.), Conservation, Ecology, and Management of Catfish: the Second International Symposium. American Fisheries Society, Symposium 77. Bethesda, Maryland, pp. 563–571.

Bates, D., Maechler, M., Bolker, M., Walker, S, 2014. lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-7. Available: http://cran.r-project.org/package=lme4 (September 2014).

Bettoli, P.W., Scholten, G.D., 2006. Bycatch rates and initial mortality of paddlefish in a commercial gillnet fishery. Fish. Res. 77, 343–347.

Bodine, K.A., Shoup, D.E., Olive, J., Ford, Z.L., Krogman, R., Stubbs, T.J., 2013. Catfish sampling techniques: where we are now and where we should go. Fisheries 38, 529–546.

Cartabiano, E.C., Stewart, D.R., Long, J.M., 2015. Effect of bait and gear type on channel catfish catch and turtle bycatch in a reservoir. J. Freshw. Ecol. 30, 407–415.

Congdon, J.D., Dunham, A.E., Van Loben Sels, R.C., 1994. Demographics of common snapping turtle (*Chelydra serpentine*): implications for conservation and management of long-lived organisms. Conserv. Biol. 7, 826–833.

Flammang, M.K., Schultz, R.D., 2007. Evaluation of hoop-net size and bait selection for sampling channel catfish in iowa impoundments. North Am. J. Fish. Manage. 27, 512–518.

Fratto, Z.W., Barko, V.A., Pitts, P.R., Sheriff, S.L., Briggler, J.T., Sullivan, K.P., McKeage, B.L., Johnson, T.R., 2008. Evaluation of turtle exclusion and escapement devices for hoop-nets. J. Wildl. Manage. 72, 1628–1633.

Gelman, A., Hill, J., 2007. Data Analysis Using Regression and Multi-level/Hierarchical Models. Cambridge University Press, Cambridge, UK.

Gelman, A., Rubin, D.B., 1992. Inference from iterative simulation using multiple sequences. Stat. Sci. 7, 457–511.

Hesse, L.W., Zuerlein G., Newcomb, B., DeVore (Retelsdorf) L.A., 1982. The relationship of hoop net mesh size to channel catfish catches. Pages 40–43 in Hesse, W., (Ed.) The Missouri River channel catfish. Nebraska Game and Parks Commission, Nebraska Technical Series Report No. 11, Norfolk.

Kentucky's Comprehensive Wildlife Conservation Strategy (KCWCS), 2013. Kentucky Department of Fish and Wildlife Resources, #1 Sportsman's Lane, Frankfort, Kentucky.

Kuehl, R.O., 2000. Design of Experiments: Statistical Principles of Research Design and Analysis, second ed. Duxbury Press, Pacific Grove, California.

Kuznetsova, A., Brockhoff, P.B., Christensen, R.H.B., 2013. lmerTest: Tests for random and fixed effects for linear mixed effect models (lmer objects of lme4 package). R package, version, 2. 0-0. Available: http://cran.r-project.org/web/packages/lmerTest/index.html (September 2014).

Larocque, S.M., Cooke, S.J., Blouin-Demers, G., 2012. A breath of fresh air: avoiding anoxia and mortality of freshwater turtles in fyke nets by the use of floats. Mar. Freshw. Res. 22, 198–205.

MacKenzie, D.I., Nichols, J.D., Lachman, G.B., Droege, S., Royel, J.A., Langtimm, C.A., 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83, 2248–2255.

Mali, I., Brown, D.J., Jones, M.C., Forstner, M.R.J., 2012. Switching bait as a method to improve turtle capture and recapture success with hoop net traps. Southeast. Nat. 11, 311–318.

Mali, I., Haynes, D., Forstner, M.R.J., 2014. Effects of bait type, bait age, and trap hours on capture success of freshwater turtles. Southeast. Nat. 13, 619–625.

Michaletz, P.H., Sullivan, K.P., 2002. Sampling channel catfish with tandem hoop nets in small impoundments. North Am. J. Fish. Manage. 22, 870–878.

Michaletz, P.H., 2001. Evaluation of channel catfish sampling methods in small impoundments. Missouri Department of Conservation, Federal Aid in Sport Fish Restoration, Project F-1-R-50, Study I-36, Job 1, Final Report, Jefferson City.

Midwood, J.D., Cairns, N.A., Stoot, L.J., Cooke, S.J., Blouin-Demers, G., 2015. Bycatch mortality can cause extirpation in four freshwater turtle species. Aquat. Conserv.: Mar. Freshw. Ecosyst. 25, 71–80.

Pierce, R.B., Coble, D.W., Corely, S., 1981. Fish catches in baited and unbaited hoop nets in the upper Mississippi river. North Am. J. Fish. Manage. 1, 204–206.

Porath, M.T., Pape, L.D., Richters, L.K., Pope, K.L., Pegg, M.A., 2011. Influence of throat configuration and fish density on escapement of channel catfish from hoop nets. In: Michaletz, P.H., Travnichek, V.H. (Eds.), Conservation, Ecology, and Management of Catfish: the Second International Symposium. American Fisheries Society, Symposium 77. Bethesda, Maryland, pp. 563–571.

Royle, J.A., 2004. N-mixture models for estimating population size from spatially replicated counts. Biometrics 60, 108–115.

Snijders, T.A.B., Bosker, R.J., 1999. Multilevel Analysis: an Introduction to Basic and Advanced Multilevel Modeling. Sage Publications, London, UK.

Spiegelhalter, D.J., Thomas, A., Best, N., Lunn, D., 2003. WinBUGS User Manual Version 1.4. University of Cambridge Institute of Public Health, MRC Biostatistics Unit, Cambridge, UK.

Stewart, D.R., Long, J.M., 2012. Precision of channel catfish catch estimates using hoop nets in larger Oklahoma reservoirs. North Am. J. Fish. Manage. 32, 1108–1112.

Struthers, D.P., Danylchuk, A.J., Wilson, A.D.M., Cooke, S.J., 2015. Action cameras: bringing aquatic and fisheries research into view. Fisheries 40, 502–512.

Sullivan, K.P., Gale, C.M., 1999. A comparison of channel catfish catch rates, size distribution, and mortalities using three different gears in a Missouri impoundment. In: Irwin, E.R., Hubert, W.A., Rabeni, C.F., Schramm, H.L., Coon, T. (Eds.), Catfish 2000: Proceedings of the International Ictalurid Symposium. American Fisheries Society, Symposium 77. Bethesda, Maryland, pp. 293–300.

Thomas, R.B., Nall, I.M., House, W.J., 2008. Relative efficacy of three different baits for trapping pond-dwelling turtles in east-central Kansas. Herpetol. Rev. 39, 186–188.

Wallace, B.C., Weaver, D.M., Kwak, T.J., 2011. Efficiency of baited hoop nets for sampling catfish in southeastern U.S. small impoundments. In: Michaletz, P.H., Travnichek, V.H. (Eds.), Conservation, Ecology, and Management of Catfish: The Second International Symposium. American Fisheries Society, Symposium 77. Bethesda, Maryland, pp. 581–588.