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Effectiveness of fishing gears to assess fish assemblage size structure in small lake ecosystems

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Abstract Measurement of fish body-size distributions is increasingly used as a management tool to assess fishery status. However, the effects of gear selection on observed fish size structure has not received sufficient attention. Four different gear types (experimental gill nets, fine mesh bag seine, and two different sized mesh trap nets), which are commonly employed in the study area for fisheries surveys, were used to fish in five small (< 200 ha) lakes to evaluate differential catch in terms of species composition and assemblage size distributions. Kolmogorov–Smirnov tests revealed that, out of the five lakes and six comparisons, the four gear types captured fish of statistically similar size distributions in only one instance. Non-metric multi-dimensional scaling followed by a multi-response permutation procedure revealed that the species composition of fish captured by these gears also differs. These results support the notion that multiple gear types should be used to assess body-size distributions as well as fish assemblage composition.

KEYWORDS: body size, gear efficiency, gillnet, seine, species diversity, trapnet.

Introduction

Analysis of species composition is the most common approach in the study of lake food webs. While species composition is important, there is growing interest in using body-size distributions to evaluate aquatic food web structure in both lake and marine systems (Daan *et al.* 2005; Petchey & Belgrano 2010; Emmrich *et al.* 2011). Although variously defined, assemblage size structure is often translated as the distribution of individuals among body size classes regardless of species identity (Boldt *et al.* 2012). Typically, in aquatic systems, there is decreasing abundance with increasing body size (Kerr & Dickie 2001). Owing to the shift from single-species management to community and ecosystem management (FAO 2003; Garcia *et al.* 2012; Law *et al.* 2012), it is increasingly important to use metrics that provide insight into food web structure and function (Jennings & Warr 2003; Berg *et al.* 2011; O'Gorman & Emmerson 2011) as well as for evaluating community responses to disturbance (Daan *et al.* 2005; Sweeting *et al.* 2009; Murry & Farrell 2013). Understanding the size structure and species composition of a system is a step towards these goals.

Gear selection is a critical issue in evaluating fish assemblage composition and size structure. Gears differ in effectiveness in different habitat types and often have size, species and behavioural biases (Hayes *et al.* 1996; Hubert 1996; Knight & Bain 1996; Shoup *et al.* 2003; Peterson & Paukert 2009). Using multiple gears has been advocated as a means to overcome these biases and provide the most robust estimates of assemblage composition because this approach is more likely to provide a more accurate assessment of the size structure of a system (Weaver *et al.* 1993; Knight & Bain 1996; Fago 1998; Shoup *et al.* 2003). However, the pooling of data across multiple gears is analytically challenging (Weaver *et al.* 1993; Peterson & Paukert 2009).

Use of a single gear is insufficient for capturing all species present in a system (Fago 1998), and gear (i.e.

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trap nets) of different sizes may not be sufficient to sample all size classes for some species, e.g., bluegill *Lepomis macrochirus* Rafinesque, largemouth bass *Micropterus salmoides* (Lacepede), black crappie *Pomoxis nigromaculatus* (Lesueur) (Shoup *et al.* 2003). Therefore, it is important to combine multiple gears to ensure that all possible habitats are included when sampling lake fish assemblages (Diekmann *et al.* 2005). While extensive research exists on the gear bias associated with species-specific capture efficiency (Clark & Willis 1989; Kraft & Johnson 1992; Jackson & Bauer 2000), there has been little research conducted on differential catch and gear biases associated with body size and the assessment of the body-size distribution of fish assemblages. For this reason, the primary objective of the present study was to assess differences in assemblage body-size distributions sampled by four types of nets commonly used in surveys of lake fisheries. A secondary objective was to evaluate differences in the species composition of samples using each type of gear. The results of the present study will be used to recommend the best combination of gears for sampling the body-size distributions and species composition (diversity) of fish assemblages in small, north-temperate lakes.

Methods

Site description

Sampling was conducted within the inland lakes of Beaver Island, Michigan, USA, which is located in northeast Lake Michigan, ≈ 51.5 km from Charlevoix, Michigan (Fig. 1). Beaver Island is ≈ 21 km long and 10 km wide and covers an area of 144.45 km^2. Five of the

Table 1. Area (ha) and perimeter (m) of each lake sampled within the inland lakes of Beaver Island, Michigan, USA. Gear effort was fished proportional to lake perimeter. Trap nets were set over night, gillnets were set for 3 h, and seine hauls were broken into small lengths to allow for multiple hauls. The Great Lakes Coastal Wetland Consortium (GLCWC) trap had a 4.8 mm mesh, the bag SEINE had a 1 mm mesh, and the XLTRAP was the largest mesh trap net used

Lake name	Area	Perimeter	GLCWC trap (# 24 h sets)	XLTRAP (# 24 h sets)	Gillnet sets (# 3 h sets)	Seine haul (linear m)
Barney lake	14.3	2512.9	6	1	9.30	210
Greene's lake	23.9	2356.5	6	1	9.30	210
Fox lake	30.9	2902.4	7	1	10.85	245
Font lake	143.7	6572.8	16	2	24.80	560
Lake Geneserath	192.1	8300.4	21	3	32.55	735

Figure 1. Map of Northern Lake Michigan showing Beaver Island, MI USA and its inland lakes.

island's seven inland lakes were sampled, that is, Barney, Greene's, Fox, Font, Geneserath (Table 1). They differ greatly in their dominant habitat types, which include near-shore areas (<2 m deep) of marl flats, sand, rock, vegetated areas and bogs in addition to deeper off-shore areas (>2 m deep), which were present in Fox Lake, Lake Geneserath, and minimally in Barney and Font lakes (for bathymetric maps, see: http://www.michigan.gov/dnr/0,1607,7-153-10364_52261_52964_66796-67550–,00.html).

Fishing gear and data collection

Each lake was sampled once between 25 June and 8 August 2009, inclusive to obtain data on fish species composition and relative abundance (catch–per-unit-effort; CPUE), as well as the fish total length (TL, mm) of all specimens captured with each gear type, both passive and active. The gears used, which included two types of trap net (of different frame and mesh dimensions), experimental gillnets, and a fine-mesh seine, were chosen because they are commonly used for fisheries surveys in Michigan and they can be employed in all habitats present in the five study lakes. Total effort for each gear type was based on lake perimeter length to standardise sampling effort across the five lakes (Table 1).

Passive fish survey methods included gillnets and trap nets (Hubert 1996), and seine netting was the only active fish capture method (Hayes *et al.* 1996). Similar to previous lake (Emmrich *et al.* 2011) and large river (Murry & Farrell 2013) applications to evaluate fish assemblage size structure, experimental 5-panel gillnets ($7.62 \text{ m} \times 5 = 38.1$ m total net length; stretched mesh sizes = 12.7, 25.4, 50.8, 101.6 and 152.4 mm) were used to sample deeper (>2 m in most cases) vegetated, rocky and open (sand, silt, marl) habitats. The gillnets were set for 2–3 h (to minimise mortality) in the deepest parts of the lake.

Near-shore vegetated and open habitats (rock, sand, silt, mud, marl) were sampled using trap nets with two different mesh sizes. The small-mesh trap nets (Great Lake Coastal Wetland Consortium approved nets (GLCWC)) had two different-sized frames (mesh size = 4.8 mm, lead length = 7.3 m, wing lengths = 1.8 m): the smaller frame size (frame dimensions: $0.5 \text{ m} \times 1$ m openings) was used for water depths of 0.25–0.50 m and a larger frame size (dimensions: $1 \text{ m} \times 1.22$ m openings) was used for water depths of 0.50–1.50 m. The largest trap net (XLTRAP; $1 \text{ m} \times 1.524$ m, mesh size = 25.4 mm, lead length = 22.86 m) was used at water depths >1.5 m.

Seine nets (length = 9.14 m, height = 1.63 m, mesh size = 1 mm; centre bag = 1.63 m^3) were used in all habitat types <1.5 m in depth (i.e. sand beaches, marl flats, emergent wetlands and submersed macrophyte beds), with most hauls conducted parallel to the shoreline. Following methods described by Murry and Farrell (2007), the seine was slowly dragged a predetermined distance (30–40 m) and bagged in the water by bringing the poles together and pulling the lead lines along the substrate until the bag was secure. If the seine was hauled through areas of thick submergent or emergent aquatic vegetation, then chains were added to the lead line at both front corners of the bag to help keep the bottom of the seine touching the substratum.

Regardless of capture method, all surveyed fish were held in coolers filled with fresh lake water until they could be enumerated and identified to species. All fish were measured for TL except small (<100 mm TL), highly abundant species, which were subsampled by species and gear set. Gear set refers to one trap net set, gillnet set or one seine haul. Subsampling was carried out by measuring the first 25 randomly selected individuals of a species for each gear set, and the remaining individuals of that species were counted and released. This was repeated for subsequent gear sets (same gear/lake) until 100 individuals were measured, after which individuals of this species were counted. The counted and unmeasured fish were proportionally assigned to individual size classes based on the measured subsamples for each species/gear/lake combination. All subsampled fish were then attributed a length by determining the percentage of each length among measured fish for each gear type in each lake.

Data analysis

A two-sample Kolmogorov–Smirnov test was used to determine whether the size distribution of fish captured in each gear was similar to, or different from, those captured using each other gear type. Individual fish lengths were used to perform the Kolmogorov–Smirnov test conducted in R v 3.0.2. There were a total of six comparisons, and each was preformed independently for each lake to limit the bias that lake factors such as productivity, habitat complexity and species diversity could have on gear selectivity. Because a total of six tests for each lake were conducted, the alpha of 0.05 was Bonferroni correct to 0.0083.

Non-metric, multidimensional scaling (NMDS) was used to compare the species assemblage data (Kruskal 1964; Mather 1976) captured between gears, similar to the approach used by Ruetz *et al.* (2007). Greene's Lake was excluded from this analysis because it contained two species only. Abundance data for each species collected by each gear in each lake were the input data for the NMDS using the Bray–Curtis distance measure (Kruskal & Wish 1978). NMDS analyses were completed using PC-ORD v5.0 (MjM Software, Gleneden Beach, OR, USA). Random starting coordinates in 50 runs of real data and 50 runs of randomized data returned six dimensions. Solution stability was obtained using a maximum of 200 iterations or an instability of 0.00001. A Monte Carlo test was used to determine whether a solution with comparable stress could be obtained by chance alone. Significance was set at $P < 0.05$. Dimensionality of the data set was determined by a scree diagram (stress vs. dimension). Once dimensionality was determined, the analyses were repeated, calculating the number of dimensions suggested by the scree diagram only. Gear and lake were superimposed onto biplots, which presented the two dimensions that explained the most variation in the data set. The blocked, multiresponse permutation procedure (MRBP) was implemented in PC-ORD to test for any differences in species composition measured by each gear (Zimmerman *et al.* 1985; Ruetz *et al.* 2007). Each lake was a block. Euclidean distance measures, natural weighting (n/sum(n)) recommended by Mielke (1984), were used in the MRBP, and median alignment within blocks was performed.

Table 2. The number of fish caught per gear type per lake within the inland lakes of Beaver Island, Michigan, USA. See Table 1 for abbreviations and net details

Lake	Gill	GLCWC	SEINE	XLTRAP	Lake total
Barney	26	648	371	10	1055
Greene's	133	771	45	407	1356
Fox	6	234	450	8	698
Font	70	10640	3220	93	14023
Geneserath	15	5053	2125	75	7268
Gear total	250	17346	6211	593	24400

Results

A total of 24 400 fish, representing 24 species, were captured using all gear types (Tables 2 and 3) in the five lakes. Fox Lake yielded the lowest number of fish (698), and Font Lake yielded the highest (14 023). Gillnets captured the lowest number of fish in all lakes, whereas the small-mesh trap nets captured the highest number of fish in all lakes except Fox Lake (Table 2). All gears were highly variable at capturing fish between lakes. Gears differed in the distribution of sizes they captured across all lakes except for one instance (Fig. 2). The gillnet and XLTRAP captured a similar distribution

Table 3. Species relative abundance (proportion of total catch) sampled in four inland lakes sampled on Beaver Island, Michigan, USA. Columns add up to 1.0

	Species	Barney	Greene's	Fox	Font	Geneserath
White sucker	*Catostomus commersonii*	0.00	0.00	0.00	0.02	<0.01
Northern redbelly Dace	*Phoxinus eos*	0.00	0.00	0.00	0.00	<0.01
Western blacknose Dace	*Rhinichthys obtusus*	0.00	0.00	0.00	0.00	<0.01
Golden shiner	*Notemigonus crysoleucas*	0.00	0.00	0.00	0.00	<0.01
Northern common shiner	*Luxilus cornutus*	0.00	0.00	0.00	<0.01	0.00
Blacknose shiner	*Notropis heterolepis*	0.00	0.00	0.00	0.00	0.09
Blackchin shiner	*Notropis heterodon*	0.00	0.00	0.00	0.00	<0.01
Bluntnose minnow	*Pimephales notatus*	0.00	0.00	0.00	0.18	0.41
Brown bullhead	*Ameiurus nebulosus*	0.01	0.87	0.00	0.01	<0.01
Northern pike	*Esox lucius*	0.01	0.00	0.02	0.00	<0.01
Central mudminnow	*Umbra limi*	<0.01	0.00	0.01	0.00	<0.01
Western banded killifish	*Fundulus diaphanous*	0.22	0.00	0.00	0.00	<0.01
Yellow Perch	*Perca flavescens*	0.13	0.13	0.58	0.39	0.11
Walleye	*Sander vitreus*	0.00	0.00	<0.01	0.00	<0.01
Northern log perch	*Percina caprodes*	0.00	0.00	0.00	0.00	0.02
Central johnny darter	*Etheostoma nigrum*	0.05	0.00	0.00	0.00	0.01
Iowa darter	*Etheostoma exile*	0.03	0.00	0.00	<0.01	<0.01
Smallmouth bass	*Micropterus dolomieu*	0.00	0.00	0.00	<0.01	<0.01
Largemouth bass	*Micropterus salmoides*	0.06	0.00	0.02	0.39	0.02
Pumpkinseed	*Lepomis gibbosus*	0.00	0.00	0.07	<0.01	0.05
Bluegill	*Lepomis macrochirus*	0.47	0.00	0.30	<0.01	0.26
Rock bass	*Ambloplites rupestris*	0.03	0.00	<0.01	<0.01	0.02
Brook stickleback	*Culaea inconstans*	0.00	0.00	0.00	0.00	<0.01
Total species		10	2	8	11	22

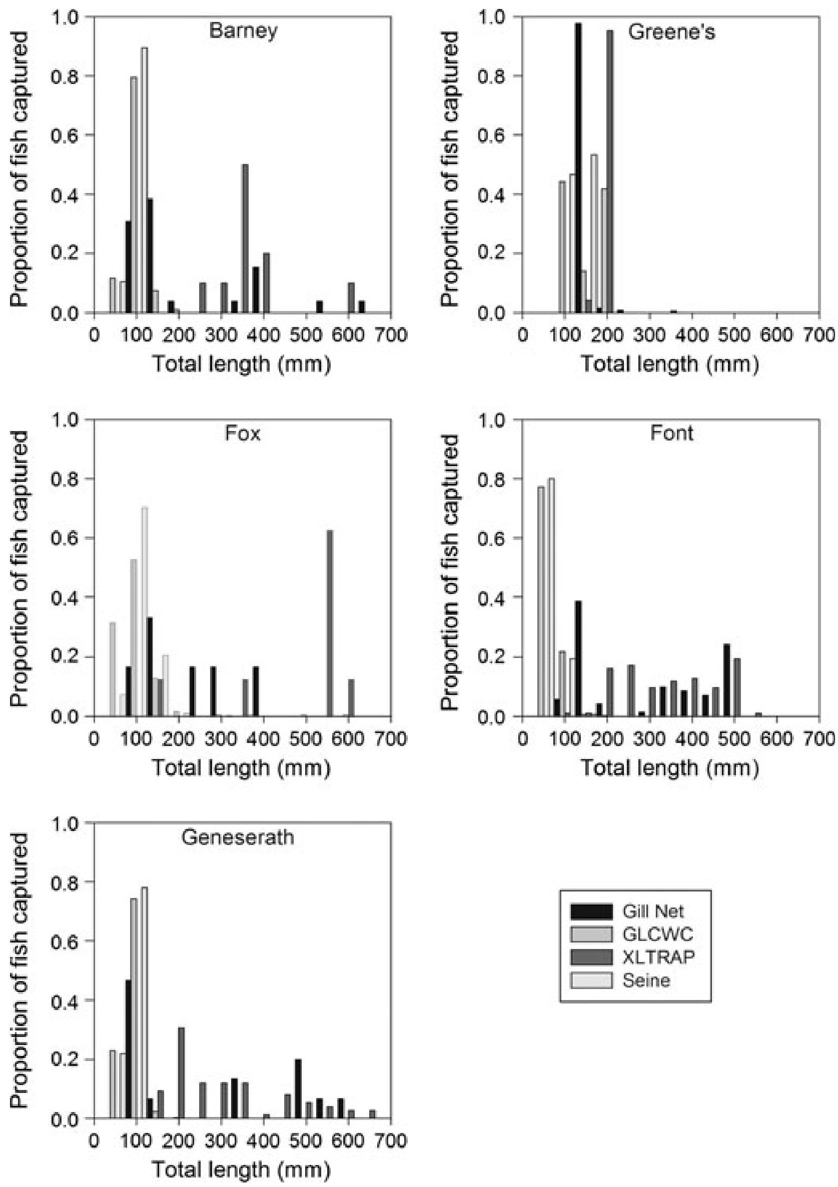

Figure 2. Proportion of fish captured in each gear type in each inland lake of Beaver Island, MI, USA. Data were binned into 50 mm bins to aid in visualisation; however, raw un-binned data were used in the K-S test. Only the XLTRAP and gillnets captured similar distributions (P = 0.0023) all other gears captured significantly different size distributions when compared to one another (P < 0.0083). The total number of tests per lake was six; therefore, alpha of 0.05 was Bonferroni corrected to 0.0083.

of sizes in Fox Lake (D = 0.75 P = 0.0023; all other comparisons P < 0.009 indicating statistically different distributions).

Fish species composition captured by small-mesh trap nets (GLCWC), a fine-mesh seine (SEINE), experimental gillnets (GILL) and large-mesh trap nets (XLTRAP) was different. The first dimension of the NMDS described the most variation (43%) in species composition of any single dimension. The second and third dimensions explained 13 and 34% of the variation, respectively. The third axis in the NMDS was the best discriminator of gear type and contrasted mainly small-bodied species with large-bodied species (Fig. 3). The Monte Carlo test showed that the three-dimensional real solution reduced stress significantly more than could be expected by chance alone (P < 0.02). Stress for this solution stabilized at 7.16 after 67 iterations. The MRBP indicated that there were significant differences in species sampled between gears (Δ = 4.98, T = −4.33, A = 0.22, P < 0.001). Further pairwise comparisons indicated that each

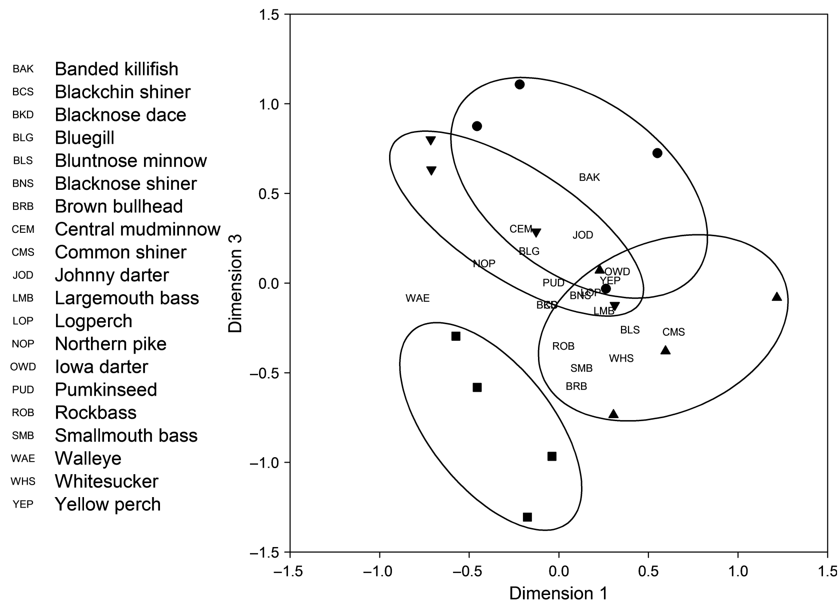

Figure 3. Non-metric multidimensional scaling ordination of fish assemblages captured in the inland lakes of Beaver Island, MI, USA. Gillnets (▲), GLCWC trap nets (▼), Fine-mesh seine (●) and XLTRAP (■) all captured different assemblages of fish species. The circles denote groups that captured statistically different fish species assemblages. Multiple-response blocked permutation procedure was used to analyse differences between gears, and alpha was set at 0.05.

Table 4. Pairwise comparisons of the MRBP for each gear combination for fishing gear types. *T* is the test statistic that describes the differences between groups, *A* is the measure of homogeneity of within groups where one (highest possible value of *A*) is no difference and zero (lowest possible value of *A*) means that heterogeneity within groups is not different then by chance, and *P* is the probability that the defined groups are different from one another (delta is unusual or more extreme given the distribution of deltas) used within the inland lakes of Beaver Island, Michigan, USA

Gears compared	T	A	*P*
GILL vs. GLCWC	−2.088	0.223	0.035
GILL vs. Seine	−1.926	0.155	0.042
GILL vs. XLTRAP	−2.169	0.190	0.036
GLCWC vs. SEIEN	−1.902	0.169	0.047
GLCWC vs. XLTRAP	−2.277	0.259	0.031
SEINE vs. XLTRAP	−2.267	0.248	0.032

gear sampled statistically unique combinations of species abundances (Table 4).

Discussion

Only once did two gear types share a similar size distribution of fish they captured. This supports past studies in which different gear types captured different size distributions of fish. This also supports the idea that multiple gears should be used when sampling for metrics pertaining to whole lake fish assemblages.

Multimesh experimental gillnets appear to be a poor choice for shallow, littoral zone-dominated lakes when only fished during daylight hours (Helfman 1981; Murphy & Willis 1996; Thorpe 1997; Pierce *et al.* 2001). Gillnets captured the lowest number of fish across all lakes. This was most likely a result of factors such as time of day the lake was fished, habitat and location the nets were fished in, and the length of time they were deployed (2–3 h).

A combination of gears targeting small- and large-bodied fishes will provide the most comprehensive assessment of assemblage size structure, but care still needs to be exercised when drawing conclusions from data pooled across gear and habitat types. The smaller gears (e.g. fine-mesh seine and GLCWC) were responsible for the majority of the fish captured, most of which were small- to medium-sized fish. These findings corroborate previous studies in which small-mesh fyke-net captures were dominated by small-bodied and young-of-year fishes (Shoup *et al.* 2003; Ruetz *et al.* 2007). Larger fish were captured in the XLTRAP net more often, and this may be a result of avoidance behaviour by large fish of the small-mesh trap nets, as well as a preference for deeper habitat that could not be sampled by the smaller gears (Shoup *et al.* 2003; Ruetz *et al.* 2007). Small-mesh trap nets sampled water up to 1 m deep, whereas the XLTRAP was employed in water from 1 to 4 m.

Similar to body-size distributions, all gears differed in the species they captured; this strongly supports the need to use multiple gears to sample fish assemblages (Weaver *et al.* 1993; Fago 1998; Shoup *et al.* 2003). Gear-based differences in species composition were most likely the result of differential habitat efficiencies. Factors that can affect habitat-specific gear selection include (but are not limited to) water depth, substratum type, vegetation type and density, and woody and other large debris/structures (Hayes *et al.* 1996; Hubert 1996; Peterson & Paukert 2009).

There are many ways in which a type of fishing gear may be biased or show a capture selectivity for or against certain species or body sizes. Biases may arise from the habitat (Weaver *et al.* 1993; Ruetz *et al.* 2007) and time of day in which the gear is used (Gritters 1994; Pierce *et al.* 2001), fish morphology (Peterson & Paukert 2009) as well as the behaviour of the fish present in the lake (Hayes *et al.* 1996; Hubert 1996) among others. Because of the large number of possible biases, it is difficult to pinpoint one or two gears that would be best suited for all circumstances. Similar to this study, Ruetz *et al.* (2007) found that fyke netting and electrofishing captured different fish sizes and species, but similar total species richness and numbers of total fish. Knight and Bain (1996) found that gillnets of two different mesh sizes captured largely different fish sizes than fine-mesh fyke nets in floodplain settings. Both gears were size selective depending on mesh size, which is similar to results found with trap nets in the present study. The present and previous studies emphasise the need to use multiple gears to sample fish size and/or assemblage structure, even if only one habitat type is being sampled due to the known bias of gear mesh size.

For example, trap nets of multiple mesh and lead size seem to complement each other because they can sample different size ranges and species but are similar (i.e. comparable) in how they fish. As a result of the low capture rate in the present study, it is inappropriate to discuss the utility of multimesh gillnets within a multigear framework, but it is likely that in many situations (i.e. where gillnets are more suitable), experimental gillnets and multiple mesh sizes of trap nets are expected to collect complementary data. However, in an earlier study, gillnets captured substantially different species and sizes than small-mesh fyke nets (Weaver *et al.* 1993). Fine-mesh seine and small-mesh trap nets, when set in appropriate habitats, might intuitively appear largely redundant; however, statistical differences were found in the portions of the fish assemblage they captured in terms of both body-size and species composition. The observed differences in these two seemingly similar gears are likely the result of the seine being an active gear that basically provides an instantaneous sample of the fish in the sampled habitat in that moment and the trap nets passively sampled over a 24-h period.

Because gear efficiencies often differ based on physical habitat and target species characteristics (e.g. behaviour and morphology), the degree to which gears complement one another or become redundant is likely highly variable depending on specific local conditions and underscore the importance of careful and conservative interpretation of multigear data. The perceived efficiency could be related to the abundance of fish being higher in one habitat type vs. another, thus causing a gear type to seem more efficient. These examples show that there is no perfect combination of gear types or any one way that they can be analysed together.

The question of which methods/techniques will yield the most accurate representation of our fisheries has long plagued, and will continue to plague, the mission of resource managers. The problem is exacerbated by the growing movement from single species to assemblage and community management (Garcia *et al.* 2012). The bias associated with any single gear has been well established and is encouraged in many studies, including the present one, but not without the recognition of distinct dangers and drawbacks. Indeed, to date, no one has provided a reliable means of determining comparable effort. Without having equal, or at least comparable effort, all subsequent interpretations will be biased. However, understanding the limits and caveats and taking great care in data interpretation, data derived from multiple gears can be useful for analysing many lake and inter-lake fish populations and community characteristics.

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