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TRADE-OFFS BETWEEN GEAR SELECTIVITY AND LOGISTICS WHEN SAMPLING NEKTON FROM SHALLOW OPEN WATER HABITATS: A GEAR COMPARISON STUDY

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Abstract: We compared logistical issues and the catch composition, density, and size structure of nekton samples collected with a drop sampler, benthic sled, and a fine mesh cast net in shallow non-vegetated habitats of Galveston Bay, Texas. Approximately 16 cast net replicates were collected and sorted for every one drop or benthic sled sample. The drop sampler collected the greatest number of species and provided the highest density estimates for the majority of crustaceans and small demersal fishes; the sled provided comparable density estimates for penaeids and small demersal nekton, while under-representing more mobile fishes. Densities of small benthic nekton were underestimated by the cast net, but it provided the highest density estimates for larger and mobile fishes. Within the selectivity constraints of each gear, the sled and cast net provide viable alternatives to the drop sampler for sampling particular nekton from shallow open water habitats.

Key words: gear efficiency; drop sampler; benthic sled; cast net; salt marsh

Introduction

All sampling gears and techniques used to estimate population and community parameters (e.g., composition, abundance, size structure) in aquatic environments have biases or selectivities that influence their efficiency. Gear efficiency can be defined as the proportion of target organisms within a sample area that is successfully quantified, and combines the efficiency with which a gear captures or encloses the target organisms, and the recovery efficiency of those organisms from the gear (Kjelson and Colby 1977). Defined this way, gear efficiency directly relates to the accuracy of the parameters being estimated and is thus of particular interest to ecologists in designing and executing field studies (Rozas and Minello 1997). In practice, however, gear efficiency is very difficult to measure since no gears provide a complete picture of the organisms actually present in a sampling area. Accordingly, most studies testing or comparing gears present estimates of recovery efficiency and/or comparisons of population or community parameter estimates among gears or among species (e.g. Connolly 1994, Beesley and Gilmore 2008). Such studies, while rarely measuring true gear efficiency, form useful foundations for comparisons of population or community parameters among studies using different gears (Rozas and Minello 1997). They are also important for evaluating the relative efficiency of new or modified gears in reference to other widely used gears for sampling particular target nekton (Stevens 2006), or for comparing the relative efficiency of a particular gear in sampling a variety of nekton (Lyons 1986, Parsley et al. 1989).

Among the wide variety of gears used to sample nekton from shallow—water habitats, those considered to provide more quantitative measures of density and species composition are also logistically the most difficult to operate (e.g. Kushlan 1974, Kneib 1991). Gears such as pop nets (Connolly 1994) and drop samplers (Zimmerman et al. 1984) rapidly and securely enclose a consistent area and allow for the efficient removal or recovery of trapped organisms. However, such gears typically involve expensive and complicated construction, specialized equipment and/or large numbers of personnel for deployment, and are time consuming to operate (Rozas 1992). In contrast, simple and easily deployed gears such as seine nets and trawls often significantly underestimate density or abundance for many species of nekton (Lyons 1986, Parsley et al. 1989, Allen et al. 1992). The result is that in many circumstances there is a trade—off between the gear efficiency and logistical constraints in their use for the collection of sufficient numbers of replicates. Gear selection must be based primarily on suitability for addressing the objectives of a study such that results can be reliably interpreted and that observed patterns are not simply artifacts of the sampling gear (Rozas and Minello 1997, Connolly 1999). Logistical issues are important to consider because they affect the cost of implementing a sampling program and the ability to achieve sufficient sample size and replication for valid statistical comparisons.

Estuarine systems across the northern Gulf of Mexico are usually dominated by salt marshes and shallow open water, but open water habitat generally covers more area and may contribute significantly to the support of many species (Minello et al. 2008, Fry 2008). The drop sampler was developed (Zimmerman et al. 1984) to allow comparative sampling of

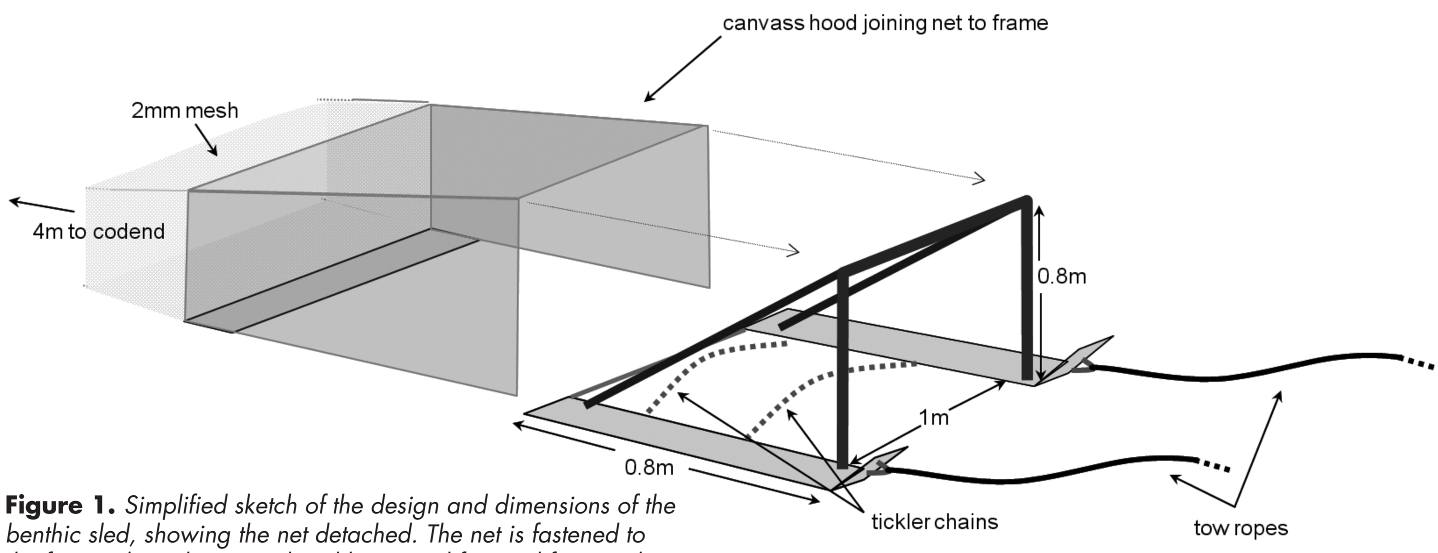

Figure 1. *Simplified sketch of the design and dimensions of the benthic sled, showing the net detached. The net is fastened to the frame along the vertical and horizontal forward frame, along each skid and to the cross—bar at the rear of the two skids.*

nekton in a range of marsh habitats including shallow open water and the vegetated marsh surface. While this sampler appears to be highly efficient, and one of the few gears suitable for sampling in dense vegetation, it is time—consuming to deploy, requires specialized equipment, requires at least three personnel to operate, and it potentially collects large amounts of detritus that increases laboratory sorting time. Accordingly, we explored alternatives for sampling in shallow open water habitats where options for collecting quantitative nekton samples are more varied. In this study, we compared the usefulness of a benthic sled and a fine mesh cast net with the drop sampler.

Materials and Methods

Gear descriptions

The gears to be tested and compared include a drop sampler (Zimmerman et al. 1984, 1986), a benthic sled, and a cast net. A detailed description of the drop sampler and the technique for deploying it is provided by Zimmerman et al. (1984). The drop sampler is an open—ended fiberglass cylinder with a metal skirt around the base, is 1.82 m in diameter, 1.2 m high, and encloses an area of 2.6 m^2. It is suspended from a boom on the front of a shallow draft aluminum boat and moved into position quietly by personnel in the water, ensuring minimal noise and that no shadow is cast over the site to be sampled. Once in position, the drop sampler is released and falls rapidly to enclose the sample area. The sampler is pressed firmly into the mud to form a seal and all water is pumped out. Animals are collected by dip nets or by hand from within the enclosed area, or accumulated in a 1mm nitex mesh cod—end through which the water from the sampler is pumped. The sampler is then reattached to the boom and hoisted with a winch in preparation for the next sample. Occasionally, due to the nature of the substrate, it is not possible to fully drain the drop sampler with the pump, and in such cases, the sample is abandoned as unsuccessful since all animals may not have been cleared from the enclosed area. During this study, the drop sampler was operated from a 5.5 m aluminum boat with 3 crew, the minimum number for efficient operation.

Our benthic sled was based on a design by Rooker and Holt (1997) with a 1 m wide by 0.8 m high aluminum frame on two 0.8 m long skids (Figure 1). Two tickler chains between the skids of the sled are designed to drive sedentary or buried nekton up into the mouth of the trailing net. The location of the forward tickler chain halfway along the skids ensures that nekton driven up into the water column by the chain are already enclosed by the hood of the net (Figure 1). The net is a 4 m long cone shape of 2 mm nitex mesh. Captured nekton accumulate in a 1 mm nitex mesh cod—end at the end of the net. The sled was hauled by 2 operators using 10 m long ropes attached to each skid. After positioning the sled at the beginning of a sample area, the operators moved to the endpoint of the sled haul along a semi—circular path away from the area to be sampled to minimize disturbance of the area. Each haul was terminated by lifting the sled mouth vertically clear of the water to ensure all trapped nekton were accumulated in the cod—end. Following this approach, when hauled for 10 m the sled sampled an area of 10 m^2, albeit with some disturbance at each end of the area sampled.

Until recently, cast nets were rarely used as sampling tools for nekton in shallow waters, apparently due to a belief that they are unreliable for providing estimates of even relative abundance of various nekton. However, several recent studies indicate that cast nets are at least as effective as other commonly used gears in providing relative density and species composition estimates (Webb and Kneib 2002, Stevens 2006, Johnston et al. 2007, Sheaves et al. 2007). The drawstring cast net used in our study was 4.88 m (16 feet) in diameter with a 4.8 mm (3/16") monofilament mesh (stretched measurement). Although theoretically the maximum area sampled by a net of this diameter would be 18.70 m^2, repeated tests involving casting the net on land found the functional area sampled was much smaller but consistent at 6.74 ± 0.09 m^2 (n = 30). In the field, only successful casts were included as replicate samples. A cast was deemed successful if it was visually estimated by the operator to have opened to ≥85% of functional sampling area, it did not snag on debris during retrieval, and no shadow was cast over the area to be sampled prior to deployment (Johnston and Sheaves 2008). The cast net was deployed by one person from the water, with an assistant to help sort the samples and record data. Both the sled and cast net teams sampled on foot and used small (1.3 x 0.6 m) buoyant plastic sleds to transport the gear and accessory equipment. The operators of each gear remained constant throughout the study, and all personnel were experienced with their respective gear types.

Study site and sampling design

We sampled shallow water habitats in the marsh complex of Gangs Bayou on the bayside of Galveston Island, Texas (Figure 2), during 2 trips, 15 October 2007 and 13 May 2008. Both trips allowed for the comparison of sample composition, species density, and nekton size structure among gears, while the design of Trip 1 also allowed a direct comparison of logistical issues in the deployment, collection, and processing of samples with each gear. Additionally, while temporal replication was not deemed necessary since we see no reason that the relative efficiency of the gears would vary through time, the two trips allowed us to sample important fishery species which do not occur year—round; namely white shrimp (*Litopenaeus setiferus)* which dominate in the fall (Trip 1), and brown shrimp (*Farfantepenaeus aztecus*) during spring (Trip 2).

On Trip 1 we designated 3 embayments in the lower part of the bayou as our sample sites (Figure 2). The 3 sites were simultaneously sampled with one gear per site during each of 3 sampling periods, such that each site was sampled with each of the 3 gears. For each sampling period the cast net and sled were operated continuously to collect as many replicates as possible during the time taken to collect 6 drop samples (about 1.5 h) before being rotated to the next site for the next sampling period. During rotation each site was left undisturbed for 20—30 min before commencement of the next sampling period. The order of gears used at a site was randomized. Replicate samples were collected 5 m into open water from the edge of the marsh vegetation; either the cast net or drop sampler centered 5 m from the marsh, or the sled towed for 10 m parallel to the vegetation 5 m into open water. Prior to sampling, we used aerial image site maps to randomly locate individual replicate sample locations with a minimum separation of 10 m, and each replicate was allocated to a particular gear randomly. Replicates located adjacent to benthic sled tows were a minimum of 10 m from either end of the sled tow. If a cast net or drop sample was deemed a failure, the replicate location was abandoned and the operators moved on to the location of the next replicate. This design allowed for a gear to operate within a site without interference or disturbance caused by other gears, and each gear to subsequently sample undisturbed replicate locations within each site. For each replicate, the time at which the gear was deployed was recorded, along with the water depth at the sample location and at the nearest point of the adjacent marsh edge. In the laboratory, all nekton were identified and enumerated, and total length (TL), carapace length (CL), or carapace width (CW) was measured to the nearest mm. The time taken to sort each sample also was recorded.

During Trip 2 we grouped replicates within locations, with each gear collecting a single replicate at each of 15 locations throughout the broader Gangs Bayou marsh complex. This design helped to overcome potential spatial and temporal confounding associated with tide state or time of day. Replication was limited to n = 15 per gear because, with this

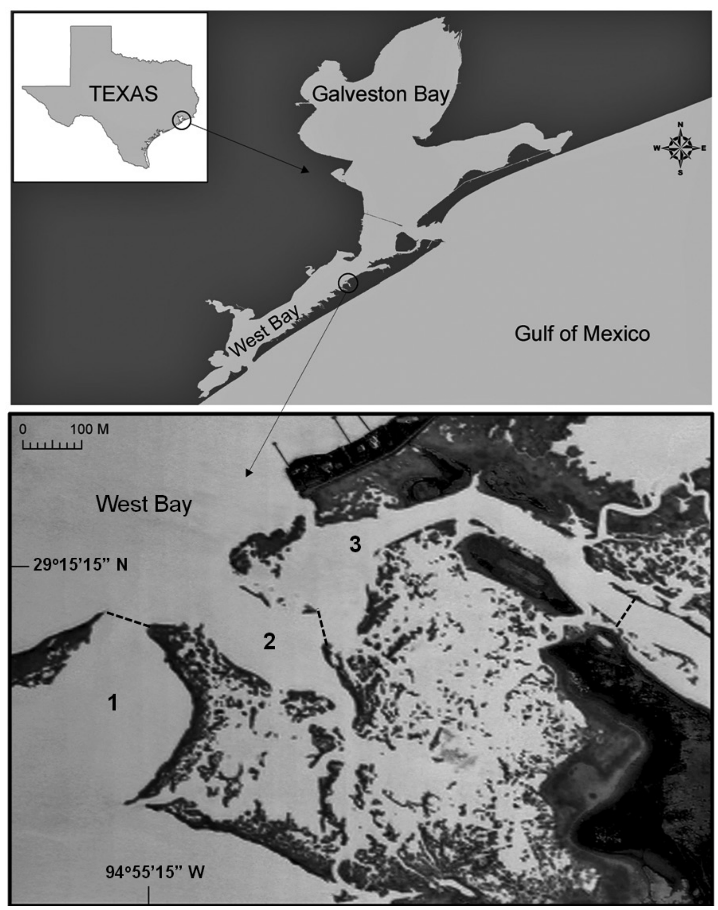

Figure 2. *Study site in Gangs Bayou, Galveston Island, Texas. Numbers and dashed lines in lower panel indicate the three embayments sampled during Trip 1. Sampling during Trip 2 was conducted throughout this and the immediately adjacent areas of Gangs Bayou.*

design, 15 samples represented a full field day with the drop sampler. A location consisted of an 85 m section of relatively uniform marsh edge. Each gear was deployed 5 m from the marsh edge as per Trip 1. To minimize and randomize any interference or disturbance between gears during positioning and deployment, gears were deployed 25 m apart in a random order in each location and the direction of the sled tow was also randomized. At each location, deployment of the cast net and drop sampler and commencement of the sled tow occurred simultaneously after operators positioned the gears while minimizing disturbance of the site. All cast net and sled samples were successfully collected, but one drop sample had to be discarded because of a failure to completely empty the cylinder with the pump. As a result, 14 samples were analyzed from each gear type during Trip 2. The time and water depth at each replicate and water depth at the edge of the adjacent marsh were recorded.

Data analysis

Univariate comparisons of the densities of abundant taxa (those contributing >2% of total catch) were conducted for each trip. For Trip 1 (n = 6 spp.), we used Latin Squares ANOVA to account for the confounded effects of site and time since each site was sampled by each gear during different sampling periods (Hicks 1973). For Trip 2 (n = 4 spp.), univariate comparisons were performed by blocked 2–way ANOVAs with gears blocked within sites. Density data for all taxa were log (x+1) transformed to improve homogeneity of variances. We used Fisher's Protected LSD post-hoc tests to compare gear density estimates when ANOVA's detected a significant effect of gear. The size structures of white shrimp and bay anchovy (*Anchoa mitchilli*; Trip 1), and brown shrimp (Trip 2), were compared among gears via paired Kolmogorov–Smirnov tests. Individuals of the other abundant taxa spanned narrow size ranges and formal comparisons of their size structures were not performed.

We also applied multivariate Classification and Regression Tree (mCART) analysis to compare species composition and densities among gears and sites for each trip (De'ath 2002). mCARTs are a powerful tool for exploring patterns in assemblage structure in data that are unbalanced, contain many zeros, and have potential for high-order interactions (De'ath 2002). Comparisons of both densities and composition were performed on log transformed data to minimize the influence of highly abundant taxa on the analyses, and the composition analysis was performed on relative density data (proportion of total sample). To avoid rare species driving the final models, only those taxa that occurred in >10% of replicates were included in the analysis (n = 12 taxa for Trip 1 and 11 for Trip 2). The trees presented were chosen based on the minimum + 1 SE rule; the smallest tree with a cross–validation error within 1 SE of the tree with the minimum cross validation error (Breiman et al. 1984).

Results

Field sampling and laboratory processing time, Trip 1

A total of 18 drop, 26 benthic sled and 40 cast net replicates were collected during Trip 1 (Table 1). The mean (± 1 SE throughout) time required to collect a sample was 14.3 (± 1.6) min for the drop sampler, 10.9 (± 0.8) min for the sled, and 7.3 (± 0.3) min for the cast net. Therefore, in the time taken to collect 6 open–water drop samples, between 8 and 10 benthic sled samples and between 11 and 16 cast net samples were collected. Samples collected by the drop sampler and benthic sled contained more animals and large quantities of debris and detritus; consequently the sorting of these samples in the laboratory was time consuming and averaged 251 ± 71 min for the drop samples and 264 ± 62 min for the sled samples. In contrast, the cast net provided relatively clean samples containing fewer nekton and laboratory sorting time averaged 9.5 ± 1.3 min per sample (Table 1).

TABLE 1. *Replication, catch summary and replicate handling time for 3 gears used to sample nekton for 4.5 h from shallow open waters in Gangs Bayou, Galveston Island, 15 October 2007. ? = minimal variation, no accurate estimate.*

	Gear		
Parameter	**Drop**	**Sled**	**Cast**
Replication			
n	18	26	40
replicate area (m^2 ± 1SE)	2.6 ± 0	10 ± ?	6.7 ± 0.1
total area sampled (m^2)	46.8	260	268
Total catch			
n	1246	3803	1511
mean density (n/m^2 ± 1SE)	26.6 ± 5.4	14.6 ± 3.1	5.6 ± 0.7
# of taxa	25	20	24
# exclusive taxa	5	3	10
Handling time (mean min/rep ± 1SE)			
field	14.3 ± 1.6	10.9 ± 0.8	7.3 ± 0.3
laboratory	251 ± 71	264 ± 62	9.5 ± 1.3
Total handling time/rep (hr:min)	4:25	4:35	0:17

Nekton composition and abundance

During Trip 1, 6,560 individuals from 38 taxa of nekton were collected in a pooled total of 84 samples. The samples were numerically dominated by white shrimp (54.8%) and bay anchovy (24.5%) (Table 2). We also collected small numbers (< 0.5% of total catch) of the portunid crab *Callinectes similis* and other fish species (*Dasyatis sabina, Synodus foetens, Mugil cephalus, M. curema, Menidia martinica, Syngnathus scovelli, Chloroscombrus chrysurus, Oligoplites saurus, Eucinostomus*

TABLE 2: *Comparison of species composition and density estimates (n/m²) for abundant species (> 0.5% from either trip) among cast net, drop sampler, and benthic sled on two field trips to Gangs Bayou, Galveston Island. Letters in parenthesis indicate homogeous subsets determined from univariate comparisons of abundance for the most abundant species sampled during Trip 1 (6 spp.) and Trip 2 (4 spp.). See Table 1 for details of replication during October 2007. For May 2008, n = 14 replicate samples for each gear.*

Group		**October 2007**				**May 2008**			
taxon	**common name**	**cast net**	**drop**	**sled**	**total n**	**cast net**	**drop**	**sled**	**total n**
Decapod Crustacea									
Penaeidae									
Farfantepenaues aztecus	brown shrimp	<0.1	0.1	0.1	34	2.0 (a)	3.5 (a)	2.1 (a)	614
Litopenaeus setiferus	white shrimp	1.7(a)	8.8 (b)	10.5 (b)	3595	—	—	—	0
Sergestidae									
Acetes sp.		<0.1 (b)	2.4 (a)	1.2 (a)	425	—	—	—	0
Palaemonidae									
Palaemonetes pugio	daggerblade grass shrimp	0	<0.1	<0.1	3	0.1	0	0.2	29
Palaemonetes spp.	grass shrimp	0	<0.1	0.1	29	—	—	—	0
Portunidae									
Callinectes sapidus	blue crab	<0.1 (c)	1.5 (a)	0.3 (b)	163	0	0.1	<0.1	9
Fishes									
Engraulidae									
Anchoa mitchilli	bay anchovy	3.2 (b)	8.7 (a)	1.3 (c)	1609	0.2 (a)	1.7 (a)	0.4 (a)	139
Clupeidae									
Brevoortia patronus	Gulf menhaden	<0.1	0	0	1	31.6 (a)	11.8 (b)	0.1 (b)	3334
Atherinopsidae									
Menidia beryllina	inland silverside	0.3	<0.1	0	91	0.7 (a)	1.6 (a)	<0.1 (a)	129
Sparidae									
Lagodon rhomboides	pinfish	<0.1	<0.1	0	9	0.5	0.5	<0.1	68
Sciaenidae									
Bairdiella chrysoura	silver perch	—	—	—	0	0.3	0	0.1	44
Leiostomus xanthurus	spot	<0.1	0.1	<0.1	7	0.1	0.4	<0.1	28
Sciaenops ocellatus	red drum	0.1 (b)	0.7 (a)	0.3 (b)	138	—	—	—	0
Gobiidae									
Ctenogobius boleosoma	darter goby	0 (c)	1.6 (a)	0.3 (b)	145	<0.1	0.8	0.2	59
Gobiosoma bosc	naked goby	<0.1	0.3	0.2	70	—	—	—	0
Microgobius gulosus	clown goby	0	0.7	0.1	61	—	—	—	0
M. thalassinus	green goby	<0.1	0.8	0.1	78	—	—	—	0

argenteus, *Cynoscion arenarius*, *C. nebulosus*, *Micropogonias undulatus*, *Bollmannia communis*, *Gobionellus oceanicus*, *Citharichthys spilopterus*, and *Symphurus plagiusa*) not listed in Table 2. The drop sampler sampled the smallest total area (46.8 m²) and the lowest total number of individuals (1,246) but collected the greatest number of taxa (25) and the highest total nekton densities from its 18 replicate samples (Table 1). Five of the taxa collected by the drop sampler (small crabs and benthic fishes) were not collected in either of the other gears (Table 2). The highest densities for 21 of the 38 taxa collected during Trip 1 were sampled by the drop sampler. The 26 replicate benthic sled tows sampled an area of 260 m² and collected the greatest number of individuals (3,803) and the lowest number of taxa (20). Three taxa (1 individual each) were sampled only by the sled, and the sled provided the highest density estimates for 5 of the 38 taxa collected during Trip 1. The 40 cast net samples covered a similar area to the sled (about 270 m²), and collected 1,511 individuals from 24 taxa (Table 1). The cast net sampled 10 taxa not collected by the other gears, primarily mobile and/or larger fishes including 19 mullet (*M. cephalus* and *M. curema*) and 5 sand seatrout (*C. arenarius*) (Table 2). Twelve of the 38 taxa collected during Trip 1 were sampled in the highest density by the cast net.

mCART analysis revealed that while the cast net tended to sample lower densities of most taxa compared to the drop and sled (Figure 3b), the composition of the cast net and drop samples were quite similar, both containing a higher

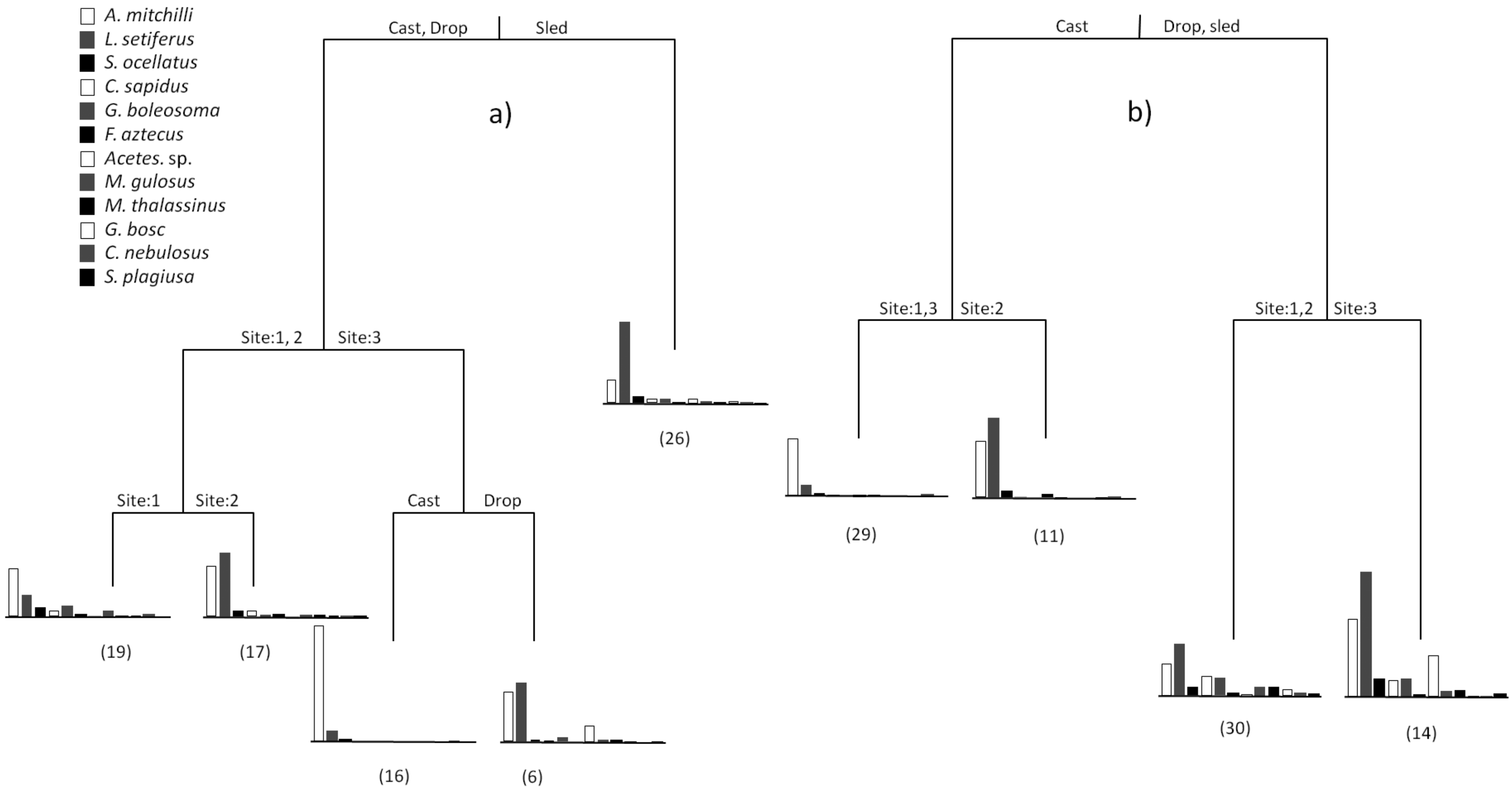

Figure 3. *Multivariate Classification and Regression Trees comparing a) the composition, and b) (log) density of nekton samples among sites and gears, for taxa appearing in >10% of replicates during Trip 1. Bars from left to right in histograms on each leaf follow species names top to bottom in legend, and indicate a) relative abundance, and b) log density. Values in parenthesis are the sample size (number of replicates) forming each leaf. See Table 2 for full species names.*

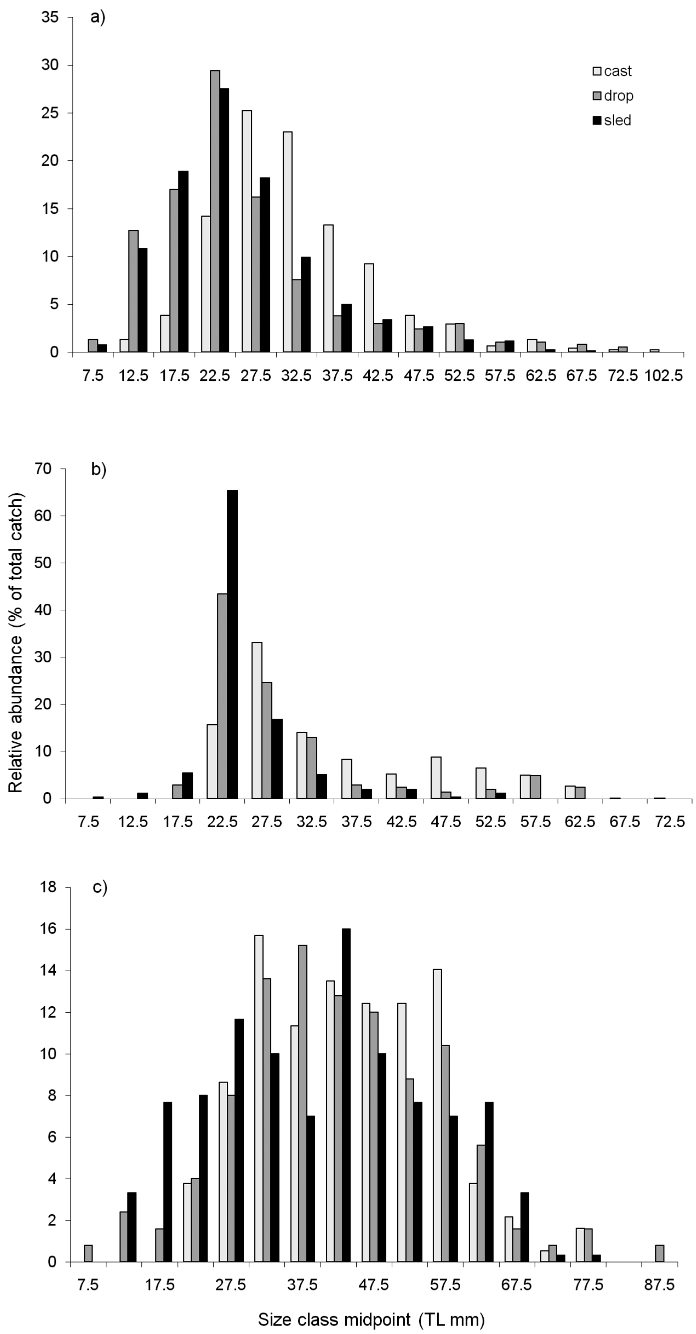

Figure 4. *Comparison of relative abundance within size classes among gears for a)* Litopenaeus setiferus*, and b)* Anchoa mitchilli *during Trip 1 (October 2007) and c)* Farfantepenaeus aztecus *on Trip 2 (May 2008). Note the discontinuous final size class in a).*

proportion of bay anchovy than the sled samples (Figure 3a). In both trees, the further splits by site indicate that nekton composition and density varied more among sites (embayments) than between gears within sites.

White shrimp were sampled in significantly higher densities (mean/m^2 ± 1SE) by the drop (8.8 ± 3.1) and sled (10.5 ± 2.5), than by the cast net (1.7 ± 0.4) ($F_{2,77}$ = 15.78, p = 0.0001) (Table 2). The cast net underrepresented small white shrimp (<30 mm) (Figure 4a) resulting in a size-frequency distribution significantly different from that sampled by the drop and sled (Kolmogorov—Smirnov, p < 0.01 for each comparison). When the densities of only larger (≥ 30 mm) white shrimp were compared, the cast net again sampled the lowest mean density (1.08 ± 0.31) compared to the drop (1.86 ± 0.72) and sled (2.61 ± 0.69), however only the difference between the cast net and sled was significant ($F_{2,77}$ = 5.19, p = 0.008). Among the other abundant species sampled during Trip 1, red drum (*Sciaenops ocellatus*), blue crab (*Callinectes sapidus*), darter goby (*Ctenogobius boleosoma*), and *Acetes* spp. all showed significant gear effects with the drop ≥ sled ≥ cast net (Table 2). In contrast, the bay anchovy densities were drop (8.7 ± 2.6) > cast net (3.2 ± 0.5) > sled (1.3 ± 0.3) ($F_{2,77}$ = 12.59, p = 0.0001). The cast net again under—represented small individuals (<20 mm TL) but provided the highest density estimates for larger bay anchovy (>35 mm TL) (Figure 4b). Both the drop and sled effectively sampled small individuals, while the sled under—represented larger anchovies.

During Trip 2 4,498 individuals from 24 taxa were collected from the 42 samples analyzed (Table 2). Nekton were numerically dominated by Gulf menhaden *Brevoortia patronus* (74.1%), and brown shrimp (13.7%). We also collected small numbers (< 0.5% of total catch) of cephalopods (*Loligo* sp.) and other fish species (*Elops saurus, S. foetens, M. cephalus, M. curema, Orthopristis chrysoptera, C. arenarius, C. spilopterus, Paralichthys dentatus,* and *Sphoeroides parvus)* not listed in Table 2. The cast net sampled 19 taxa. Of these, 4 were not sampled by either the drop or sled, and comprised two individual unidentified clupeids, two *Anchoa* sp., one white mullet *M. curema* and one summer flounder *Paralichthys dentatus*. Seven of the 24 taxa collected during Trip 2 were sampled in the highest density by the cast net, 16 had the highest density in drop samples, while one was sampled in the highest density by the sled. Seventeen taxa were collected by the drop sampler, with one individual each of the sand seatrout, and an unidentified juvenile sciaenid representing the 2 taxa not sampled by the other gears. The benthic sled collected 15 taxa, all of which were sampled in at least one of the other gears. mCART analyses revealed that during Trip 2 both nekton densities and species composition varied more between sites than among gears within sites (Figure 5). There was a weak gear effect at some sites where the composition of the cast net samples was dominated by Gulf menhaden, while the drop and sled samples were dominated by brown shrimp and bay anchovy but contained few menhaden (Figure 5a).

The cast net sampled significantly higher densities of Gulf menhaden (31.6 ± 13.4) than either the sled (0.1 ± 0.1) or drop sampler (11.8 ± 9.6) ($F_{2,26}$ = 8.82, p = <0.01), while the densities of the other two abundant taxa from Trip 2, inland silverside (*Menidia beryllina)* and bay anchovy, were not significantly different among gears (Table 2). Mean brown

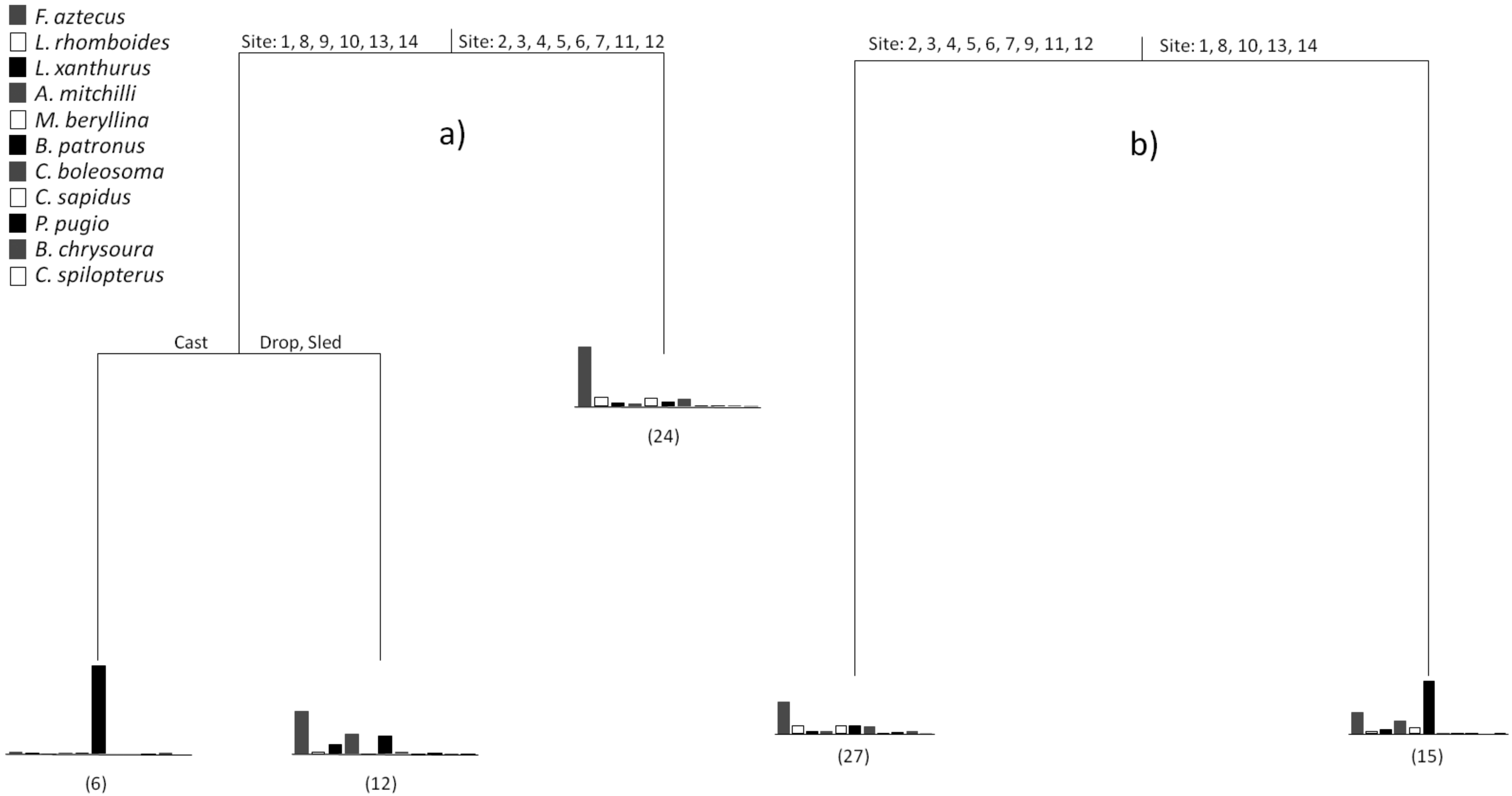

Figure 5. *Multivariate Classification and Regression Trees comparing a) the composition, and b) (log) density of nekton samples among sites and gears during Trip 2. Bars from left to right in histograms on each leaf follow species names top to bottom in legend; e.g., tall bar in histogram for the left-most leaf in 5a represents B. patronus. See figure 3 caption for full details and Table 2 for full species names.*

shrimp density estimates were 3.5 ± 1.1 from the drop sampler, 2.1 ± 0.5 from the sled, and 2.0 ± 0.4 from the cast net (Table 2), but these differences were not significant. As for white shrimp during Trip 1, the cast net underrepresented smaller brown shrimp (< 25 mm TL), and the difference in size structure between the cast net and sled was significant (Kolmogorov—Smirnov, $p < 0.01$) (Figure 4c).

Discussion

Sampling logistics

Drop samplers have been used to estimate nekton densities across a variety of shallow—water estuarine habitats (e.g. Howe et al. 1999, Minello and Rozas 2002, Shervette and Gelwick 2008). Testing in a cleared marsh pond stocked with a known number of shrimp indicated that the sampler provides accurate density estimates for penaeid shrimp in open waters (Zimmerman et al. 1986). Deployment of the drop sampler requires a boat that is modified with a boom and winch to hoist the sampler and a pump to drain water from the sampler (Zimmerman et al. 1984). Three experienced personnel were able to collect a drop sample in shallow open water in an average of around 15 min. There is minimal opportunity for reducing sampling time with the drop sampler because most of the factors influencing sampling time are related to gear characteristics and the environment being sampled rather than logistical issues of the sampling methodology or number of personnel. Water depth affects the time to pump water from the sampler, particularly for large—volume drop samplers. Substrate type and depth affect the ability to form a complete seal with the sampler necessary to drain water from the enclosure. For example, fine detritus present in many Louisiana marshes can make a seal difficult, particularly in deeper water where water pressure pushing up through the substrate is higher. The presence of oyster shell, gravel, or woody debris also can prevent the formation of a good seal with the substrate. If a complete seal cannot be formed and maintained for long enough to drain and clear the enclosure, the sample is abandoned as unsuccessful, using up valuable time for the collection of successful replicates. However, in the present study this occurred for only one of the 33 drop samples deployed and was thus of minor significance.

The nature of the substrate also influences the difficulty in finding and collecting trapped animals from successfully drained drops. The pump intake is usually screened to prevent damage from larger items, however thick detritus can rapidly block the screen, so regular cleaning adds to sample collection time. Finally, laboratory processing time is greatly extended for samples containing large amounts of detritus. Despite these issues limiting replication, the drop sampler is one of the few gear types generally successful across a range of substrates including heavily vegetated habitats.

The benthic sled is efficiently operated by 2 personnel, and it took around 10 min per replicate sample. In shallow water habitats, operators can tow the sled by hand, negating the need for a boat if sites are accessible by road. Water depth and substrate type had a minimal effect on sample collection time in our study, but at sites with abundant fine detritus the sled net can become clogged rendering it ineffective. The detritus collected in the fine-meshed net also increases the sorting time needed in the laboratory.

The cast net was the most rapidly deployed gear of the 3 tested, taking on average a little over 7 min per sample in the field. It provided relatively clean samples of fewer nekton than the other gears, and thus sorting time in the laboratory was also rapid. Similar to the sled, water depth has a negligible effect on replicate time, while obstructions on the substrate such as oysters or woody debris may snag the net, rendering it ineffective. Experienced operators can collect replicate samples of relatively consistent sampling area (Johnston and Sheaves 2008, this study), however the area sampled could potentially vary among operators. Consequently, the functional area sampled should be measured for each operator/net. Sampling time per replicate can be reduced further by the use of a small boat to move more rapidly among sites and to use as a platform for more easily throwing the net. Using our sampling protocols, about 16 cast net replicates were collected and processed for each drop or sled sample.

While the logistical issues discussed above must be considered, they are ultimately of secondary importance compared to selecting a gear that will provide reliable data to address the objectives of a study. Regardless of ease of use, a gear with biases or artifacts that interact with treatments is inappropriate and should not be used (Peterson and Black 1994). While sampling gear can be used to measure relative abundance, there is always the concern that gear efficiency will vary with environmental factors or habitat characteristics of interest, and this concern is heightened when efficiency is low (Rozas and Minello 1997, Connolly 1999).

Nekton composition

The three gears provided broadly similar views of the nekton composition and relative abundance from the shallow, non-vegetated, open—water habitats sampled. During Trip 2, the catch composition and density varied more among sites than among gears within sites, with the exception of a few sites where the cast net sampled large numbers of Gulf menhaden. The distribution of maximum density estimates among gears for the more abundant taxa indicates that each gear has varying efficiency across the nekton assemblage, i.e., each gear samples certain components of the nekton assemblage better than the other gears and other components of the assemblage (Allen et al. 1992).

Despite the broad similarities, there were important differences in assemblage composition among gears. The drop sampler provided the highest density estimates for the majority of demersal crustacea and small fishes including the gobiids and small sciaenids, and was also effective at sampling some of the pelagic fishes such as atherinids, clupeids, and engraulids. The cast net generally sampled the greatest densities of larger and or mobile/pelagic taxa such as the atherinids, carangids, clupeids, and mugilids, while underrepresenting small benthic nekton such as many of the crustacea and gobiids. The benthic sled, while providing the highest density estimates for few taxa, often provided similar density estimates to the drop sampler for demersal crustacea, gobiids, and sciaenids, while capturing few of the more mobile/pelagic fishes.

Higher densities in the cast net of mobile pelagic nekton such as Gulf menhaden suggest gear avoidance of the drop sampler and sled. In particular, this species appeared to simply avoid capture by the slowly-towed benthic sled. The drop sampler also estimated significantly lower densities of Gulf menhaden than the cast net. Despite efforts to minimize disturbance of the sample site, some nekton may respond to the approach of the boat and personnel by moving out of the area thus avoiding capture. In addition, the smaller sample area of the drop sampler in relation to the cast net may increase avoidance at the time of gear deployment.

The cast net data underrepresented smaller size classes of some abundant taxa, and this result was likely related to the larger mesh size of the cast net allowing smaller enclosed animals to escape. The high density estimates of large, mobile, and pelagic fishes along with the under representation of more sedentary taxa also suggests that some of the underrepresented taxa in the cast net escape from the net during recovery after casting, rather than that they avoid being enclosed. After deployment, the draw strings on the cast net gradually purse the lead line of the net to trap enclosed nekton. During this process there may be multiple opportunities for enclosed nekton staying close to, or buried in, the substrate to escape beneath the lead line, while fishes such as mullet and menhaden remain in the water column and are securely enclosed. Substrate type and topography are likely to affect the probability of escape of benthic associated taxa, and thus sampling areas with variable substrates may result in variable catch efficiency of the cast net more so than the drop or sled.

Trade-offs

The 4.8 mm (3/16”) mesh cast net used was the smallest meshed commercially produced net we could find. The low SE values associated with the nekton density estimates from the cast net, particularly during Trip 1 where a higher level of replication was achieved, suggests a relatively stable efficiency of the gear, even if it consistently under samples smaller nekton which escape through the net mesh. Based on the available cast nets and the density and size structure estimates from this study, it is clear that cast nets are not a useful sampling tool if estimates of the density of the smallest size classes of nekton are required. However, where the focus of the study is on larger nekton in shallow open water habitats with similar substrates, cast nets provide an easily deployable and inexpensive alternative that allows vastly greater replication than more complex gears.

The benthic sled and the drop sampler provided similar density estimates for white shrimp, brown shrimp, and a range of small and sedentary nekton. When total replication time (field, lab, and personnel) is considered, the sled requires marginally less effort. Given the requirement of a specially modified vessel and trained personnel to deploy the drop sampler, the benthic sled described here may be a useful alternative for researchers sampling small nekton from open water habitats where abundant detritus does not render it ineffective. The sled seems particularly effective at sampling penaeid shrimp across the size range found in estuarine habitats, and Stunz et al. (2002) reported density estimates of red drum collected with a benthic sled that were similar to those from a drop sampler. Use of the sled is partially limited due to its inability to provide the discrete samples from specific microhabitats which can be collected with the drop or cast net. Decreasing the sled tow length to much less than 10m would likely result in significant site disturbance during gear positioning and deployment.

Despite sampling the smallest area, the drop sampler collected the highest number of taxa and provided the highest density estimates for the greatest number of taxa over the two trips, highlighting its high efficiency relative to other gears (Rozas and Minello 1997). It also has the distinct advantage over many other gears of being able to sample in a variety of habitats including heavily vegetated habitats such as dense sea grass beds and the vegetated marsh surface (Zimmerman et al. 1984, Howe et al. 1999, Shervette and Gelwick 2008). Given the significance of such habitats to a variety of nekton of ecological and economic importance, it is clearly advantageous to have a sampling gear such as the drop sampler that provides high (and therefore the most accurate) density estimates across a number of habitats.

Shallow water nekton assemblages typically show very high spatio—temporal variability. Many studies examining this fauna require comparisons among a range of locations and times. In such cases, the slight loss of accuracy in density estimates for some species obtained with the cast net relative to the more time consuming gears may be outweighed by the ability to collect a vastly greater number of replicates. For example, the differences among gears in density estimates of bay anchovy were proportionally similar for Trip 1 and Trip 2, yet these were only significant during Trip 1 when a much greater level of replication was achieved. In many cases the limits on replication with the more complex gears, and subsequent limits on statistical power to detect important differences among treatments, may render these gears unsuitable despite higher efficiency in sampling some components of the nekton assemblage. Conversely, the differing efficiency of each of the gears tested, and indeed of all sampling gears, suggests that despite the obvious logistical constraints, the best representation of the shallow water nekton assemblage as a whole may be obtained by combining data across multiple gears.

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