DEVELOPMENT OF A DROP RING SAMPLING PROTOCOL FOR JUVENILE FISHES IN GUNSTON COVE

2007 Mini-study Report to Fairfax Department of Public Works

by

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Introduction

Shallow vegetated habitats in tidal waters are critically important because they may serve as a refuge (Kemp et al. 1984, Ruiz et al. 1993) and reduce predation mortality for juvenile fishes (Stunz & Minello 2001), but these habitats are notoriously difficult to sample effectively with standard survey gears such as seines and trawls. Studies have demonstrated not only that seine and trawl efficiency is reduced by the presence of vegetation but also that variability in catch rates is higher in vegetated compared to non-vegetated areas (Rozas & Minello 1997). In Gunston Cove, the standing crop of submerged aquatic vegetation (SAV) has increased to record high levels over the past two decades. Although SAV growth signifies improving water clarity and declining eutrophication, some of the long-term monitoring sites for seine and trawl surveys within Gunston Cove have been adversely impacted. Inefficient sampling or non-sampling of vegetated habitats may generate a biased view of juvenile fish abundance and long-term recruitment dynamics from survey data.

In this mini-study, we evaluated the efficacy of a trap gear to efficiently quantify juvenile fishes in vegetated habitats. This device, called a drop ring (or Wegener ring, Wegener et al. 1973), has been shown to have high catch efficiency for juvenile fishes and other nekton (>95%; Rozas & Minello 1997). In addition, this type of sampling device has been used to study shallow vegetated habitats in other areas, and the results have provided valuable long-term monitoring data to support shallow water habitat restoration (Minello and Rozas 2002, Rozas et al. 2007) and evaluate anthropogenic freshwater diversions on tidal systems (Rozas et al. 2005). The objectives of this mini-study were to: 1) evaluate drop ring sampling as a supplementary approach to better quantify juvenile fish abundance within the cove; 2) determine the effects of vegetation on long-term seine and trawl sampling stations; and 3) develop a protocol to incorporate drop ring sampling into regular surveys of Gunston Cove.

Methods

We employed a completely randomized sampling design based upon SAV distribution data from USGS and VIMS aerial surveys and NOAA bathymetry and shoreline data. Sites were randomly selected from a 10 m grid of 10279 possible sampling locations at depths <1.5m. Due to the extensive coverage of SAV only a small proportion of the grid was outside of areas predicted to have SAV. In practice, all the samples that were collected contained at least some SAV; therefore, it was not possible to compare vegetated with un-vegetated habitats as originally proposed. Thus, variation in SAV biomass density was correlated with density of fish and invertebrates quantified in the samples. To ensure independence between samples, the 10 m grid size was selected based upon the length of the boat used to deploy the drop ring (~5 m) and typical GPS accuracy (WAAS enabled) obtained in Gunston Cove (~5m). The order of sample collection was randomized to reduce bias associated with a given day or tidal cycle, and all the samples were collected during daytime between 17 July and 18 August 2007 – a period when SAV biomass is typically at peak levels. Due to shipping delays for materials to construct the boom framework and drop ring and contractor delays to outfit the boat with the drop ring framework, sampling from throughout the field season was not possible; therefore, a more intensive sampling effort was conducted during this one mid-season period.

The drop ring was constructed from a high density polyethylene tank (0.8 m diameter) reinforced with circular galvanized pipes and a ring of galvanized sheet metal for cutting into the settlement. A boom with a block and tackle system suspended the drop ring above the water forward of the bow. The drop ring was loaded for deployment prior to approaching the sampling location. A quick-release shackle allowed the drop ring to free-fall into the water, rapidly enclosing the area to be sampled. From proximity of approximately 50 m, sample sites were approached slowly without the use of a motor. Once the site was reached (as determined by the GPS), we conducted a short pause (15 to 30 seconds) to allow nekton in the area to resume normal activity before deploying the drop ring. Once it was determined that the drop ring made uniform contact with the sediment, the crew would push the drop ring into the sediment to a depth of at least 15 cm to create a water tight seal.

The sample was obtained from the drop ring with a combination of dip nets and by pumping the water out of the drop ring (see Figure 1). Water that was pumped from the ring was filtered through a plankton net to retain any organisms that passed through the pump. The pump was designed to pass particles up to 1.5 inches in diameter (this device is sold commercially as a trash pump), and damage to any organisms that passed through the pump was negligible. SAV obtained in the sample was vigorously shaken in a bucket to remove invertebrates and small fishes. It was then identified and weighed with a digital hanging scale in the field to the nearest 0.01 lbs. All remaining organisms and debris were fixed in formalin (10%) or ethanol 95% for subsequent identification in the lab.

In the laboratory, fish and invertebrates were sorted from the debris and identified to the lowest possible taxon with the aid of dissection microscopes. The abundance of many of the invertebrate taxa was exceptional, and necessitated a sub-sampling approach. We constructed a large-scale Motodo-style sample splitter that could hold an entire sample. The sample was homogenized by stirring, and a ¼ sub-sample was obtained for processing invertebrates. Prior to sample splitting, the entire sampled was sorted to obtain all fish > 20mm SL and large mollusks >20 mm shell height (gastropods) or length (bivalves). Numbers in each taxon reported here, represent either actual totals or expanded totals based upon a randomly selected ¼ sub-sample.

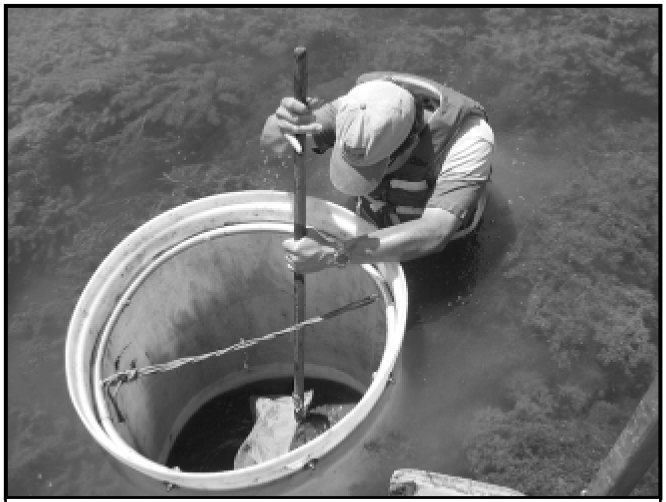

Figure 1. Photograph demonstrating sample collection with a drop ring in Pohick Bay. Note the high density of SAV in the area surrounding the drop ring. In this picture, the water has been pumped out of the drop ring and any remaining organisms are being collected with a dip net.

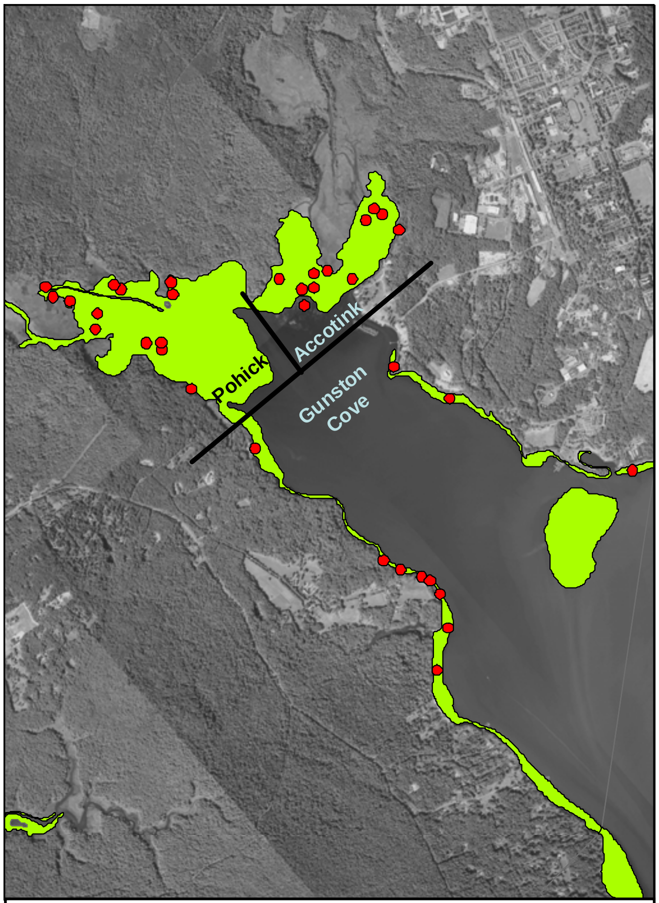

Figure 2. Aerial image of Gunston Cove demarcating drop ring sampling locations (red dots) digitized SAV bed boundaries (green areas), and geographic zones used to identify Pohick Bay, Accotink Bay, and Gunston Cove. Mosaic of aerial photography and SAV coverage data provided by VIMS SAV mapping program.

Some unexpected problems were encountered during the fieldwork. Sporadically, the sediment at the bottom of the drop ring would erupt from water pressure. When this happened before the entire sample could be obtained, the partial sample was discarded and the next random sample was attempted. In addition, some random samples were in locations that were too deep/shallow or had obstructions. When this happened, the closest location where the drop ring could be deployed was chosen for the sample. In one instance, the sample location was far outside the 2006 SAV coverage boundaries (see Figure 2 in Accotink Bay). This sample was still within an SAV bed and represented the closest location to the predetermined site. Further, some samples were lost from decomposition of organisms within the sample jars. This affected 2 of the sampling days from the middle of the sampling period when it was determined that concentration of fixative was insufficient. In part, this was due to unexpected high water content of debris and sediment in some of the samples. This problem was eliminated when we began using a higher fixative concentration and lower sample to fixative volume ratio. Although counts of fish and invertebrates from the degraded samples were made, the densities were unexpectedly low, especially for small bodied organisms, and condition of organisms was poor. Because numbers from the degraded samples were likely to be biased, they are not included here. Consequently, only 35 samples were available for analysis (n=13 from Pohick Bay, n=11 from Accotink, n=11 from Gunston Cove margins).

As described above, contemporaneous sampling of standard seine stations with the drop ring could not be conducted throughout the field season. In order to provide an assessment of juvenile fish density at seine stations and make comparisons with adjacent SAV habitats sampled via drop ring, seine catch efficiency was evaluated opportunistically at three times (early season on May 17th and May 31st and late season on August 30th) and at all 3 standard seine survey sites, twice at ancillary site, 4A, plus 4 additional randomly selected sites for a total of 15 seine efficiency trials. This was accomplished with the use of a second seine that was used to block off the standard seining area. The standard seine was then deployed according to survey protocol. The block seine was twice as long and had a mesh size that was half as large, which allowed size selectivity to be evaluated. Once the standard seine gear was retrieved, the block seine was retrieved and all fish were enumerated and measured from each respective gear. Catch efficiency was estimated as the proportion of the total catch in the standard seine. Size and species effects were evaluated, and mean catch efficiency values were applied to samples that were obtained as part of the standard monitoring. To calculate density from these samples, seine geometry (distance offshore and distance along shore) was recorded to determine the area swept. Density comparisons between seine stations and drop ring sampling were limited to Pohick and Accotink Bays (seine stations 4, 4B, and 6) and the period in which drop ring sampling occurred. Within the time frame of drop ring sampling, 3 rounds of regular monitoring were conducted, and each seine sample from this period was treated as single observations to estimate density in seine habitats. For comparison, seine catches from the regular monitoring (and not the catch efficiency trials) were analyzed.

Results

Drop Ring: Fishes

A combined total of 269 individual fishes, comprising 11 species, were enumerated in drop ring samples during this mini-study. The sizes ranged from 6 mm to 269 mm standard length, with the overwhelming majority of fishes represented by small individuals: 50% < 32 mm SL and 75% <41 mm SL. The 9 largest fishes were American eels (*Anguilla rostrata*), ranging in size from 79 to 269 mm SL.

The four most common fishes in drop ring samples were banded killifish (*Fundulus diaphanus*), tessellated darter (*Etheostoma olmstedi*), white perch (*Morone americana*), and gold fish (*Carrassius auritus*). Whereas banded killifish and tessellated darter were comprised of a mixture of adults (primarily) and juveniles, all white perch captured were juveniles, making them the most common juvenile fish in SAV during this period. Observed densities (per square meter) were calculated and means were compared between three different areas in Gunston Cove: Pohick Bay, Accotink Bay, and the margins of Gunston Cove proper (Figure 2). For the dominant species, significant differences between areas were only found for banded killifish (Figure 3, overlap of standard errors with means indicates a non-significant difference). Banded killifish density was significantly lower in the margins of Gunston Cove (0.4 per square meter) than in the bays, and there were no differences between Pohick and Accotink bays (combined: 2.5 per square meter). Mean densities for all other species were < 0.5 per square meter.

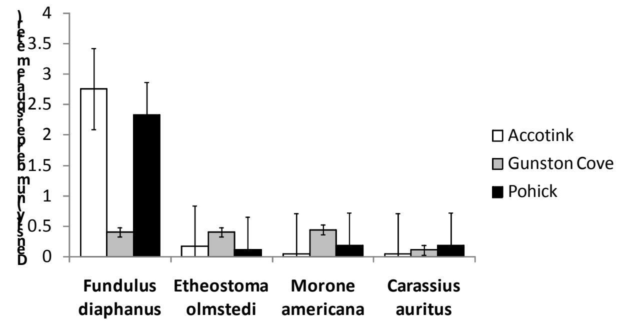

Figure 3. Mean densities by area of the four most common fishes in drop ring samples. Standard errors of the means are also plotted.

Fishes present in lower abundances in drop ring samples, were brown bullhead (*Ameiurus nebulosus*) , American eel (*Anguilla rostrata*), blue-spotted sunfish (*Enneacanthus gloriosus*), mummichog (*Fundulus heteroclitus*), pumpkinseed (*Lepomis gibbosus*), bluegill (*L. macrochirus*), and spottail shiner (*Notropis hudsonius*). The densities of these varied greatly between areas within Gunston Cove (Figure 4); however, comparisons are difficult to make due to the low numbers that were encountered. Combining areas, the overall densities of American eel and pumpkinseed were highest (both: 0.09 per square meter) followed by brown bullhead (0.08 per square meter) and mummichog (0.07 per square meter). The other species were present at densities ≤ 0.04 per square meter. SAV densities from these samples ranged 3 orders of magnitude, from 1.8 to 1883 grams per square meter, and pair-wise correlations (spearman rank test) with fish density revealed no significant positive coefficients for the three most abundant species (banded killifish, tessellated darter, and white perch). Correlations with SAV were not considered valid for the other fish species because the frequency of occurrence was less than 25%.

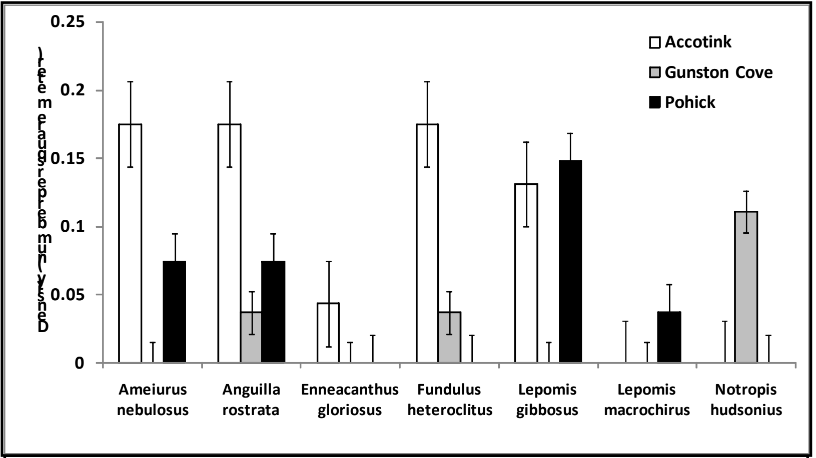

Figure 4. Mean densities by area of seven fish species in drop ring samples. The four most common species are presented in Figure 3. Standard errors of the means are also plotted.

Drop Ring: Invertebrates

Estimated combined total of invertebrates from drop ring samples was 193,215 individuals representing 19 different groups. These 19 groups were comprised of (in order of decreasing abundance): native gastropoda (primarily Hydrobiid snails, but also small numbers of Physid snails, Planorbid snails, and *Elimia* sp.), amphipoda (primarily family Gammaridae), Chironomidae larvae (midges), *Corbicula fluminea* (invasive Asian clam), odonata (dragonfly and damselfly nymphs), trichoptera (caddisfly larvae), annelida (mostly leeches but also some polycheate and oligocheate worms), *Bellamya japonica* (invasive Japanese mystery snail), other crustaceans (primarily crayfishes, but also some *Paleomonetes* sp. grass shrimp and isopod crustaceans), and Unionidae (native bivalves).

Density of native gastropods was higher than for any other taxon, and at approximately 764 individuals per square meter, mean density was highest in Accotink Bay (Figure 5). This was significantly higher than in Pohick Bay (356 per square meter) or in the margins of Gunston Cove (135 per square meter), and Hydrobiid snails were the primary constituent. Amphipods were second only to native gastropods in density with mean values ranging from 108 to 257 per square meter. All other taxa were present at densities <50 per square meter (Figures 5 and 6).

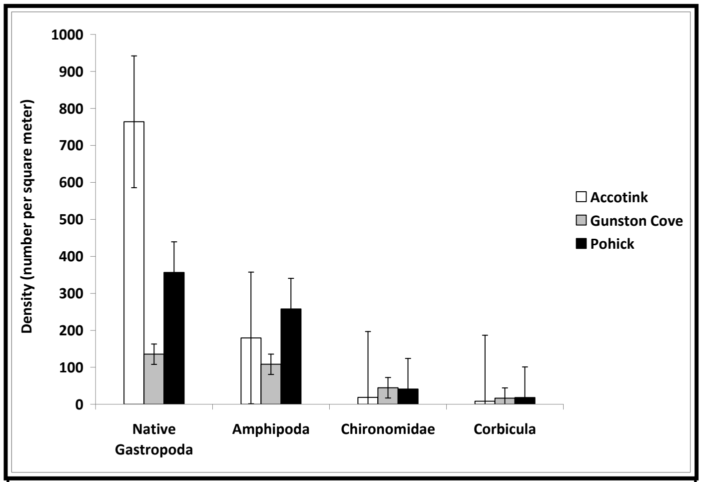

Figure 5. Mean densities by area of the 4 most common invertebrate taxa in drop ring samples. Standard errors of the means are also plotted.

There were two notable patterns in the invertebrate data. One in which densities were similar between areas, and this pattern applied to Chironomidae, *Corbicula*, Trichoptera, non-amphipod crustaceans, and native bivalves (Figures 5 and 6). A second pattern occurred where higher mean densities were observed in the bays (Pohick and Accotink) when compared to the margins of Gunston Cove proper. This second pattern was evident for native bivalves, amphipods, odonata, annelid worms, and *Bellamya* (Figures 5 and 6). Pair-wise correlations (spearman rank test) between invertebrate taxa and SAV density revealed no significant coefficients for any of the groups examined.

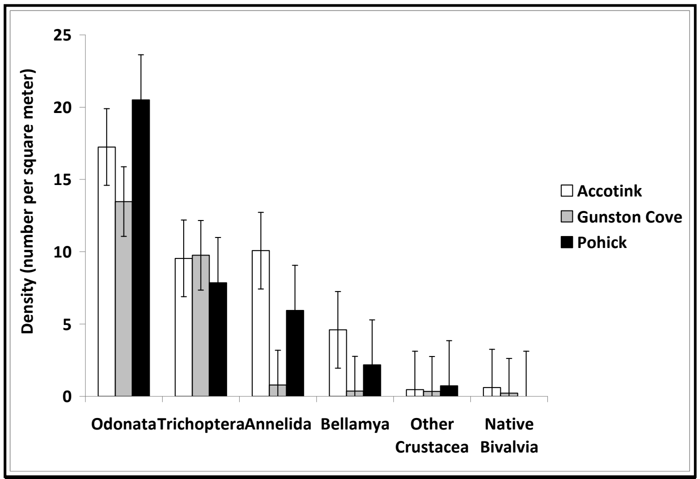

Figure 6. Mean densities by area of 6 invertebrate taxa observed in drop ring samples. The 4 most abundanct taxa are presented in Figure 5. Standard errors of the means are also plotted.

Seine Catch Efficiency

In the seine efficiency trials, a total of 4419 fishes were captured representing 28 species, and 44% of all individuals were captured in the standard survey gear. The majority of fishes captured were between 40 and 150 mm standard length (Figure 7). The low catch efficiency and small overall numbers of fish at sizes <40 mm SL are due primarily to small fish that can escape through the mesh of the nets. Decline in frequency of larger fish (>150 mm SL) in the catches is due to the lower natural abundance as well as greater avoidance capabilities.

Some of the species were present at only one site on one date or only small numbers were captured (n<25); therefore, data in these situations was not considered useful for estimating catch efficiency. Of these, species present at low abundance included: northern snakehead (*Channa argus*, n=1), bay anchovy (*Anchoa mitchilli*, n=1), striped bass (*Morone saxatilis*, n=2), channed catfish (*Ictalurus punctatus*, n=3), black crappie (*Pomoxis nigromaculatus*, n=6), American eel (*Anguilla rostrata*, n=7), goldfish (*Carrasius auritus*, n=8), common carp (*Cyprinus carpio*, n=10), gizzard shad (Dorosoma cepedianum, n=20), eastern mosquitofish (*Gambusia holbrooki*, n=22), yellow perch (*Perca flavescens*, n=24), blue spotted sunfish (*Enneacanthus gloriosus*, n=24), and mummichog (*Fundulus heteroclitus*, n=24). High abundances of blueback herring (*Alosa aestivalis*, n=875), Atlantic menhaden (*Brevoortia tyrannus*, n=88), and American shad (*A. sapadissima*, n=58) were observed, but these species were only captured one time at a single site. For the small fish category (<40 mm SL, n=223), species were pooled and the seine had low catch efficiency (28%) as expected due to escapement through the mesh (Figure 8). By comparison, although there were fewer fish in the large category (>150 mm SL, n=130) catch efficiency was higher (45%). For other species that were encountered more frequently (medium size category between 40 and 150 mm SL, Figure

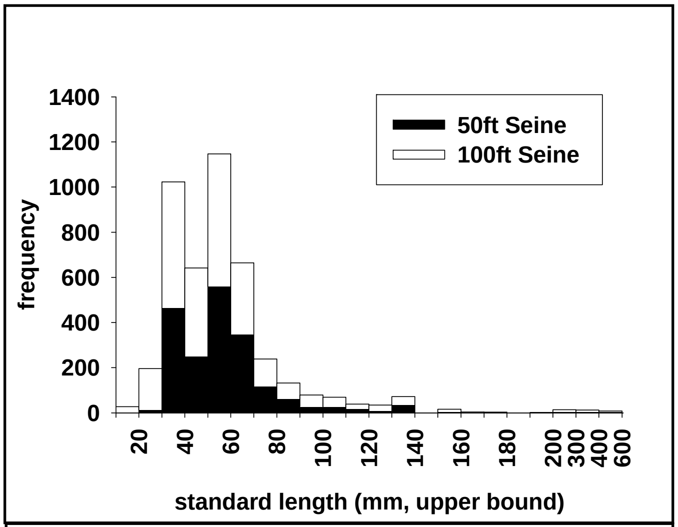

Figure 7. Length distribution histogram of fishes captured in the seine efficiency trials. Verticals bars are demarcated by the two different seine gears.

8), high variability in catch efficiency was observed with a marginally non-significant effect of species (ANOVA: p=0.07). The overall pooled catch efficiency for the medium size category was 49%. The catch efficiency (CE) values for individual species ranged from 22% for bluegill (*Lepomis macrochirus*) to 79% for spottail shiner (*Notropis hudsonius*). Bluegill and spottail shiner were 2 of the 5 most abundant species which included: banded killifish (*Fundulus diaphanus*, CE=54%), pumpkinseed (L. gibbosus, CE=31%), and white perch (*M. americana*, CE=41%).

Due to narrow size ranges or insufficient numbers at larger sizes, effects of body size on catch efficiency were difficult to examine. To facilitate analysis of size effects in at least two groups, sunfishes (genera *Lepomis* and *Enneacanthus*) were pooled together due to similar body shapes. A linear regression of catch efficiency on size (10mm binned categories) was then conducted for both sunfishes and banded killifish. Size effects were not detected for sunfish, but a significant increase in catch efficiency with size was detected for banded killifish (p<0.001). The trend indicated that catch efficiency increased approximately 1% with each mm increase in size. To determine whether the smallest size categories were driving this trend, a reduced data set removing fish <50 mm SL was analyzed and the slope of the regression remained constant and significant. Thus, mean catch efficiency for banded killifish ranged between 36% for the 40 to 50 mm SL size category and 89% for the 80 to 90 mm SL category.

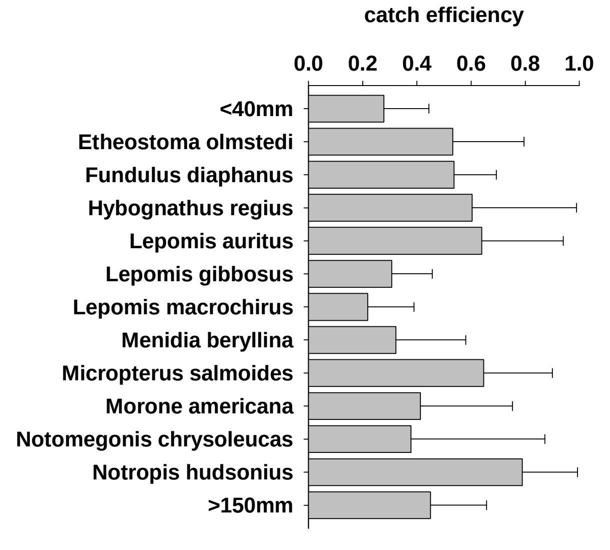

Figure 8. Catch efficiency of the standard seine gear by species (and size groups for the largest and smallest). Species captured in low abundance (n<25) or at low frequency of occurrence (present at 1 site) are not show. Confidence bars are based upon arcsine transformed means.

Comparison of Fish Catches Between Drop Ring and Seine Samples

To better understand relationships between shoreline habitats sampled with seines and SAV habitats sampled with drop rings, densities of fishes common to both gears were compared and examined. Primarily due the much larger area sampled by the gear (0.8 versus 256 square meters), species richness in seine samples was always higher than in drop ring samples. Based upon frequency of occurrence in the drop ring samples, 3 common species were selected for density comparisons: banded killifish, tessellated darter, and white perch. In seine samples, catches were adjusted for catch efficiency (size effects not considered due to need for greater sample size; see discussion) and density was estimated from area swept using geometry measurements from seine deployments. These estimates were then expanded based upon either 2006 SAV bed area from VIMS and USGS surveys (2007 data were still not available at the time of writing this) or linear shoreline length estimates from representative areas of Pohick and Accotink bays. Although estimates may change substantially depending upon the total area used for SAV and shoreline habitat, the total abundance of all three species was over 1 to 3 orders of magnitude higher in SAV than in shoreline habitats of Pohick and Accotink bays (Table 1). Estimates are somewhat biased for tessellated darter because this species was not captured in seines during this period, but was present in drop ring samples. Still, similar densities of white perch in both habitats were offset by the larger area of SAV habitat, resulting in a much greater total abundance of white perch in SAV. For banded killifish, density in SAV habitat was 6-fold higher, and this difference resulted in a 132-fold greater estimate of total abundance in SAV habitats compared to shoreline habitat in this system.

Table 1. Summary of density and total abundance estimates for 3 common species in 2 habitats from Gunston Cove. Shoreline density estimates are based upon fixed seine stations and a zone 15.24 m wide and 3966 m long. Area of SAV bed coverage in Pohick and Accotink bays was based upon areal survey data and constituted 1.3 million square meters.

	SAV		Shoreline	
	Density (m^{-2})	Total (millions)	Density (m^{-2})	Total (millions)
Fundulus diaphanus	2.53	3.302	0.41	0.025
Morone americana	0.12	0.157	0.16	0.010
Etheostoma olmstedi	0.14	0.183	0.00	0.000

Discussion

In the most recent decade, SAV habitats within Gunston Cove have become widespread and represent nearly all of the available shallow areas (<1.5 m) important to juvenile fish productivity in this system. For many juvenile and small adult fishes, these extensive SAV beds provide additional areas for refuge, feeding and reproduction; therefore, abundance indices based solely upon shoreline seine sampling may exhibit trends that are contraindicative. Based upon the results of this mini-study, drop ring sampling appears to be a highly effective approach for quantifying juvenile and small adult fishes in vegetated habitats. In particular, the two historically dominant fish species, banded killifish and juvenile white perch, were frequently captured in drop ring samples, providing useful data for determining density and abundance of these species in SAV habitats. Notably, the total abundance of these two species in SAV habitats was one to several orders of magnitude higher than what was present in shoreline habitats sampled with a seine. Other species present in drop ring samples demonstrated a fish assemblage that is comparable to what has been observed in other adjacent areas of the Potomac (Killgore et al. 1989) and other tidal freshwater systems in Chesapeake Bay (Serafy et al. 1988). Killgore et al. (1989) noted that higher fish densities occurred in areas with intermediate SAV density and a mix of SAV species as compared to those areas with dense Hydrilla. In the present study, Hydrilla was the overwhelmingly dominant SAV species; therefore, a similar comparison cannot be made.

The efficiency of the drop ring sampling was not evaluated here, but previous work this type of device indicates a high catch efficiency for juvenile fishes and other nekton (~95%; Rozas and Minello 1997). No adjustments to drop ring catches were made in the calculations of density from the drop ring samples; therefore, the results here should be considered minimum values. In addition, there were many species present in seine catches that were never observed in drop ring samples. Although one explanation is that these species were not present in the SAV habitats, an alternative explanation is that these species (many of which are larger than what was captured by the drop ring) avoid the gear. Jordan et al. (1997) evaluated a similar type of drop ring that was deployed by hand, and found that approximately 17% of fishes (mostly larger individuals) could avoid the gear. For those species that occurred infrequently in drop ring samples, gear avoidance and/or low natural abundance may have influenced the results. Additional sampling effort combined with a catch efficiency study similar to Jordan et al. (1997) would be needed to determine the relative importance of each factor.

The limited seine catch efficiency study presented here not only provided a way to compare SAV and shoreline habitats but may also be applied to the historical seine data from the regular monitoring. One caveat is that the total abundance estimates from the fringing shoreline area of Pohick and Accotink Bays is based upon fixed station sampling, and any unique characteristic of these stations will tend to present a biased view of the overall fish assemblage in this habitat. The range of catch efficiency values and high variability between species was consistent with other studies that tested beach seines in freshwater for similar species in the presence of similar vegetated habitats (Parsley et al. 1989, Peirce et al 1990, and Holland-Bartels and Dewey 1997). As catch efficiency varies between species (and potentially between different size classes of some species) the raw catch data from beach seines presents a biased view of the shoreline fish assemblage. The application of catch efficiency estimates on a species and size class basis would reduce such bias, and additional work to refine catch efficiency estimates is needed. In particular, the size effects on catch efficiency for the dominant banded killifish should be confirmed with additional trials. With the reasonable assumption that catch efficiency is consistent between years within a species, fixed station sampling still provides a valuable index of abundance through time.

In addition to structural refuge and spawning substrate, high densities of fishes in SAV of Gunston Cove can also be linked to the macroinvertebrate community. Higher densities of many of the fishes were elevated in Pohick and Accotink bays, and this was coincident with elevated densities of potential prey resources such as amphipods, dragonfly and damselfly nymphs, and annelid worms. The macroinvertebrate assemblage of SAV in a different tidal freshwater area of the Potomac was examined by Thorp et al. (1997) who results were qualitatively similar. The most prominent difference between Thorp et al. (1997) and this work was the presence of the Japanese mystery snail, which warrants close attention as a relatively new invader in this system. Otherwise, high densities of Hydrobiid snails and other native gastropods plus high densities of amphipods appear to characterize and dominate SAV habitats in shallow tidal fresh waters of the Potomac River.

Recommendations

1) Based upon the importance of SAV beds to the 2 historically dominant species in the survey, drop ring sampling should be incorporated into the regular fish monitoring using a stratified random sampling design: targeting Pohick and Accotink bays and the margins of Gunston Cove if resources are available.

2) The seasonal development and senescence of SAV is a factor that could not be evaluated in this study, yet this process may have important consequences to changes in the distribution and abundance of fishes in the cove. Therefore, efforts to extend temporal domain of drop ring sampling in shallow water habitats should be considered.

3) The lack of some species, especially larger species, from the drop ring samples should be studied to determine whether these species are avoiding the drop ring gear or are simply absent from SAV habitats.

4) Valuable conversions and comparisons of seine catch data were possible from the catch efficiency trials, but inferences were limited due to low sample size. Thus, additional seine catch efficiency trials are warranted.

5) The earliest record of the Japanese mystery snail in the Potomac was from GMU in 1993 (USGS invasive species online database), and since that time no monitoring of the species has occurred. The high numbers in drop ring samples and anecdotal evidence indicates that the species is thriving in Gunston Cove, but its population trend is unknown. As this species may have both negative (e.g., displace native species) and/or positive (e.g., improve water clarity) effects, periodic assessments of its abundance and distribution should be compared to other native gastropods and associated macroinvertebrates.

Literature Cited

Holland-Bartels, L. and M.R. Dewey. 1997. The influence of seine capture efficiency on fish abundance estimates in the upper Mississippi river. Journal of Freshwater Ecology 12:101-111.

Jordan, F., S. Coyne, and J. C. Trexler. 1997. Sampling fishes in vegetated habitats: Effects of habitat structure on sampling characteristics of the 1-m2 throw trap. Trans. Am. Fish. Soc. 126:1012-1020.

Kemp, W.M., W.R. Boynton, R.R. Twilley, J.C. Stevenson, and L.G. Ward. 1984. Influences of submersed vascular plants on ecological processes in upper Chesapeake Bay. pp. 367–394 in V. Kennedy (ed.). The Estuary as a Filter. Academic Press, New York.

Killgore, K.J., R.P. Morgan, and N.B. Rybicki. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac river. North American Journal of Fisheries Management 9:101-111.

Minello, T.J., L.P. Rozas. 2002. Nekton in the Gulf Coast wetlands: fine-scale distributions, landscape patterns, and restoration implications. Ecological Applications 12-441-455.

Parsley, M.J., D.E. Palmer, and R.W. Burkhardt. 1989. Variation in capture efficiency of a beach seine for small fishes. North American Journal of Fisheries Management 9:239-244.

Pierce, C.L., J.B. Rasmussen, and W.C. Leggett. 1990. Sampling littoral fish with a seine: corrections for variably capture efficiency. Can. J. Fish. Aquat. Sci. 47:1004-1010.

Rozas, L.P., and T.J. Minello. 1997. Estimating densities of small fishes and decapod crustaceans in shallow estuarine habitats: a review of sampling design with focus on gear selection. Estuaries 20:199-213.

Rozas, L.P. T.J. Minello, I. Munuera-Fernandez, B. Fry, and B. Wissel. Macrofaunal distributions and habitat change following winter-spring releases of freshwater into the Breton Sound estuary, Louisiana (USA). Estuarine Coastal and Shelf Science 65:319-336.

Rozas, L.P., T.J. Minello, R.J. Zimmerman, and P. Caldwell. 2007. Nekton populations, long-term wetland loss, and the effect of recent habitat restoration in Galveston Bay, Texas, USA. Mar. Ecol. Prog. Ser. 344:119-130.

Ruiz, G.M., A.H. Hines, and M.H. Posey. 1993. Shallow water as a refuge habitat for fish and crustaceans in non-vegetated estuaries: an example from Chesapeake Bay. Mar. Ecol. Prog. Ser. 99: 1–16.

Serafy, J.E., R.M. Harrell, and J.C. Stevenson. 1988. Quantitative sampling of small fishes in dense vegetation: design and field testing of portable "pop nets". Journal of Applied Ichthyology 4:149-157.

Thorp, A.G., R.C. Jones, and D.P. Kelso. 1997. A comparison of water-column macroinvertebrate communities in beds of differing submersed aquatic vegetation in the tidal freshwater Potomac river. Estuaries 20:86-95.

Stunz, G.W., and T.J. Minello. 2001. Habitat-related predation on juvenile wild-caught and hatchery-reared red drum *Sciaenops ocellatus* (Linnaeus). Journal of Experiment Marine Biology and Ecology 260:13-25.

Wegener, W., D. Holcomb, and V. Williams. 1973. Sampling shallow water fish populations using the Wegener ring. Proceedings of the Southeast Association of Game and Fish Commissioners 27:663-674.