Running Head: Juvenile Gag Habitat Use

Title: Habitat use by juvenile gag (*Mycteroperca microlepis*) in subtropical Charlotte Harbor, Florida (USA).

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Abstract

Estuaries play a key role in the juvenile stage of gag (*Mycteroperca microlepis*). The use of estuarine habitats by juvenile gag has been examined in temperate estuaries, which are at the northern limits of the range of this species, but the importance of subtropical estuaries during the early life history of this species has not been studied extensively. Gag were collected in subtropical Charlotte Harbor during routine monthly sampling from January 1996 to December 2002. Juvenile gag were collected using a 21.3-m seine, a 183-m haul seine, and a 183-m purse seine. A total of 738 individuals ranging from 30 to 489 mm standard length (SL) were captured. Most (96%) gag were probably young-of-the-year (<288 mm SL). The majority of juveniles were collected in Gasparilla and Pine Island sounds from April to December, with a few larger individuals captured year-round. The observed period of gag settlement was similar to that in other subtropical and temperate estuaries, but gag in Charlotte Harbor remained in the estuary longer and egressed at a larger size than did gag in other estuaries. Habitat use by juvenile gag within Charlotte Harbor was greatest on shallow seagrass shoals but was also high along mangrove shorelines, which is a habitat not previously reported for gag.

Introduction

Estuaries play a key role in the juvenile stage of gag (*Mycteroperca microlepis*) (Keener et al. 1988). Juveniles have been reported to occur in temperate and subtropical estuaries from Virginia to the northeastern Gulf of Mexico (Hoese et al. 1961, Hood and Schlieder 1992, Koenig and Coleman 1998). This economically important serranid spawns in large aggregations such as those found at traditional West Florida Shelf sites in the Gulf of Mexico primarily during February and March (Collins et al. 1998). The planktonic larvae move into estuaries and settle out at about 15 mm standard length (SL) in the first available habitat, such as polyhaline seagrass beds and oyster shell habitats near inlets and mouths of tidal creeks (Ross and Moser 1995, Mullaney and Gale 1996). As juvenile gag grow rapidly during their estuarine residence, they may also use habitats such as manmade structures including seawalls and jetties (Hastings 1979, Bullock and Smith 1991).

Latitudinal differences in climate appear to affect the duration of estuarine residence and size attained by juvenile gag before they disperse to non-estuarine habitats (Ross and Moser 1995). Juveniles are usually found in North Carolina estuaries from April to September and in estuaries along the northeastern Gulf of Mexico from April to October (Ross and Moser 1995, Koenig and Coleman 1998). The first cold front of fall is thought to trigger their egress to deeper ocean water (e.g., Ross and Moser 1995). In temperate estuaries such as Bogue Sound, North Carolina, gag reach a maximum size of 200 mm SL (Ross and Moser 1995), but in subtropical estuaries such as Tampa Bay, Florida, they can reach sizes of up to 360 mm SL (Hood and Schlieder 1992).

Habitat use by juvenile gag has been examined in temperate estuaries, which are at the northern limits of the range of this species; however, the importance of subtropical estuaries during the early life history of this species has not been studied extensively. Despite the effects of increasing urbanization and the resultant demands for freshwater resources, Charlotte Harbor, a large subtropical estuary in southwestern Florida, supports many suitable habitats for juvenile gag (e.g., seagrass beds, oyster shell habitats). Although juveniles have been collected from seagrass beds within the estuary (Wang and Raney 1971, Hanson et al. 2004), questions regarding aspects of habitat use—especially tropical climate habitats like mangroves—have not been examined. The objective of this study was to use an estuary-wide dataset from a long-term fisheries-independent monitoring program in Charlotte Harbor to examine distribution, seasonality, habitat use, and relative abundance of juvenile gag in a subtropical estuary.

Materials and methods

Study location

Charlotte Harbor is located on the southwestern coast of Florida, and is one of the largest estuaries in Florida. The estuary is separated from the Gulf of Mexico by a series of barrier islands. Two large inlets, Boca Grande Pass and San Carlos Pass, and four smaller inlets allow tidal water exchange. The modal depth of the estuary is 3–4 m, and the deepest point in Boca Grande Pass at 15.5 m (Huang 1966). The climate is subtropical, with average annual rainfall of 127 cm, 60% of which falls between June and September (Taylor 1974). The average water temperature is 25°C, ranging from 12°C to 36°C, and the average salinity is 29 ppt, ranging from 5 ppt to 40 ppt (Poulakis et al. 2003, present study).

Charlotte Harbor supports a variety of habitats that are used by more than 255 species of fish (Poulakis et al. 2004). The two predominant habitats for fishes are seagrass flats and fringing mangroves. Red mangroves (*Rhizophora mangle*), white mangroves (*Laguncularia racemosa*), and black mangroves (*Avicennia germinans*) are the three species of mangroves found in Charlotte Harbor, but red mangroves dominate along the shoreline (143 km^2 fringing mangroves; L. Kish, Florida Fish and Wildlife Research Institute, unpubl. data). Turtle grass (*Thalassia testudinum*), shoal grass (*Halodule wrightii*), and manatee grass (*Syringodium filiforme*) are the most common seagrass species in the estuary (262 km^2; Sargent et al. 1995). Other habitats found in Charlotte Harbor include oyster bars, shoals (areas that are < 0.6 m deep at mean low tide), seawalls, and bridge pilings.

Sample collection

Fish abundance and habitat data collected throughout Charlotte Harbor by the Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute's Fisheries-Independent Monitoring program from January 1996 to December 2002 were analyzed for this study. Monthly stratified-random sampling was conducted during the day by using three different seines (17–26 samples gear^{-1} month^{-1}). The estuary was divided into 1 x 1 nautical-mile cartographic grids (1 nm^2), and grids with appropriate water depths for each seine (< 1.5 m for 21.3 m seine, < 2.5 m for 183-m haul seine, < 3.3 m for 183-m purse seine) were selected as the sampling universe. Using a 10 x 10 cell overlay, each cartographic grid was subdivided into 100 micrograds (0.1 x 0.1 nm), which represented the potential sample sites that were randomly selected without replacement each month.

Samples were stratified by depth and habitat type depending on gear. The 21.3-m center-bag seine (21.3 m x 1.8 m, 3.2-mm stretch mesh) was pulled along shorelines and on shoals away from shore (Poulakis et al. 2003). Samples collected with the 183-m center-bag haul seine (183 m x 3 m, 37.5-mm stretch mesh) were stratified based on the presence or absence of overhanging shoreline vegetation (e.g., fringing mangroves). The seine was deployed by boat, in a rectangular shape (40 m x 103 m) along shorelines and on offshore flats inside the estuary and retrieved by hand (Kupschus and Tremain 2001). The 183-m terminal-bag purse seine (183 m x 5.2 m, 50-mm stretch mesh) was set more than 40 m from the shoreline (Wessel and Winner 2003). All fishes were identified to the lowest possible taxon, enumerated, and measured to the nearest millimeter (SL), and all juvenile gag were released alive in the field. For each sample, bottom type, seagrass species, shoreline vegetation species, and coverage of each were qualitatively measured by visual survey. Water-quality data such as salinity (ppt), dissolved oxygen (mg/l^{-1}), and temperature (°C) were recorded using a hand-held data sonde. A vertical profile of these parameters was taken at the surface (0.2 m below surface) and at each whole meter increment until reaching the bottom (0.2 m above bottom).

Data analysis

The locations of juvenile gag captured in all three gear types were plotted to examine distribution throughout the estuary. Three size-classes were plotted separately (< 100 mm, 101─250 mm, > 251 mm) to explore possible differences in ontogenetic distribution within the estuary. To examine seasonality, length-frequency data were divided into 10-mm size-classes and pooled by month for each gear to examine month of settlement, growth and relative abundance during estuarine residency, month of egress from estuary, and gear selectivity.

Analysis of covariance (ANCOVA) was performed using a general linear modeling (GLM) approach to investigate the influence of water temperature, salinity, water depth, seagrass habitat, bottom type, shoreline type, year, month, and geographic location on the gear-specific relative abundance of gag (PROC GLM; SAS Institute 1998). Water temperature, salinity, and water depth were the covariates (continuous variables) and were ln (x + 1) transformed to stabilize the variance in the data before analysis. The value of each abiotic covariate used in the model is the mean of all readings taken at each sample location. Bottom type (sand, mud, or hard bottom), seagrass habitat, shoreline vs. shoal, year, month, and geographic location (Pine Island Sound vs. Gasparilla Sound) were the class variables (categorical variables) in the model. The seagrass habitat class variable was divided into nine subcategories based on the dominant seagrass species present and the amount of cover provided. A seagrass species was deemed dominant if it composed more than half of the seagrass present in a sample. Seagrass cover was categorized as < 50% or ≥ 50% in each sample. By combining these components, samples were placed into one of the eight subcategories based on either < 50% or ≥ 50% cover by *H. wrightii*, *S. filiforme*, *T. testudinum,* or an equal combination of any two species. The ninth subcategory represented samples with no seagrass present. Samples were excluded from the habitat analysis when the seagrass coverage could not be estimated due to water clarity and depth (n = 20). For the shoreline vs. shoal class variable, "shoreline" was defined as the habitat at the land/water interface (i.e., mangroves, beach, seawall), and "shoal" was defined as areas that were < 0.6 m deep at mean low tide and were at least 5 m from the shoreline (e.g., oyster bar, sand bar).

We constructed a full model that included all class variables and covariates and then simplified it using a stepwise elimination procedure as follows. The variables with the highest p values were removed from the model one at a time until all remaining variables were significant at $\alpha = 0.05$. We report only significant class variables and covariates. Tukey's Studentized Range (HSD) test was used post-hoc to determine where differences occurred in each significant variable (Zar 1999).

Results

A total of 738 juvenile gag, ranging from 30 to 489 mm SL, were caught. Most gag collected (96%) were probably young-of-the-year (< 288 mm SL) based on Hood and Schlieder's (1992) research. Most juveniles were collected in the 183-m haul seine (n = 615) and ranged from 88 to 440 mm. The purse seine collected individuals from 30 to 489 mm (n = 83), and the 21.3-m seine collected juveniles ranging from 30 to 204 mm (n = 40).

Although samples were taken throughout the estuary (note locations of zero catches; Figure 1), gag were collected principally (95%) in polyhaline Gasparilla and Pine Island sounds. Gag were particularly abundant in shallow (< 3.3 m) areas adjacent to Gasparilla and Boca

Grande passes. Distribution of juveniles in Charlotte Harbor did not change as they grew, regardless of size or month. The average salinity where gag were captured was 31.0 ± 0.4 ppt (range = 13–40 ppt).

Gag were collected mainly from April to December, but some individuals were captured in all months (Figure 2). Juvenile gag ranging from 30 to 88 mm were captured in April and May. The cohorts grew and accumulated in numbers during June and July, with the highest number of gag collected in September. Although most individuals were captured from May to December in the haul seine, increasing numbers of individuals were collected in the purse seine in October and November as overall numbers declined in the estuary. Some of the previous years' cohort (> 288 mm SL) were collected year-round (Figure 2). The average water temperature where gag were captured was 27.7 ± 0.3ºC (range = 14.5–33.5ºC).

Data from the haul seine (83% of juveniles collected in this gear) during May to December in Gasparilla and Pine Island sounds were analyzed in more detail using the general linear model. The variables that significantly affected gag abundance were geographic location (Pine Island Sound vs. Gasparilla Sound), year, month, depth, shoreline vs. shoal, and seagrass habitat (ANCOVA; $r^2 = 0.28$; Table 1). In Gasparilla and Pine Island sounds, the annual relative abundance of juvenile gag in 2002 was at least 2.7 gag per haul greater than in other years (Tukey's Studentized Range test; $p < 0.05$) (Figure 3). Gag abundances in Gasparilla and Pine Island sounds were significantly lower in April, May, and December than in June through November (Tukey's Studentized Range test; $p < 0.05$). Gag, were significantly more abundant in Gasparilla Sound than they were in Pine Island Sound (Tukey's Studentized Range test; $p < 0.05$). Mean water temperature and salinity varied little during April to December in either Gasparilla or Pine Island sounds.

In Gasparilla and Pine Island sounds, juvenile gag were collected principally in shallow habitats (< 3.3 m) that contained ≥ 50% seagrass coverage, regardless of seagrass species. These areas were typically on shoals (oyster bars and sandbars) or close to mangrove and beach shorelines (Figure 4). Relative abundance on shoals was 2.9 fish per haul greater than near mangrove and beach shorelines (Tukey's Studentized Range test; $p < 0.05$). Only eight of the shoal samples were on oyster bars (19 gag collected); the other 29 samples were on shoals that had ≥ 50% seagrass coverage (133 gag collected). The majority of sample sites were along mangrove shorelines that had ≥ 50% seagrass coverage, and that is where most of the juvenile gag (n = 226) were collected.

Discussion

Juvenile gag are typically concentrated in polyhaline areas close to passes, and these areas apparently represent the first suitable environments that presettlement gag encounter when they move into estuaries throughout their range (Keener et al. 1988, Ross and Moser 1995). Gag spawn principally during February and March in the Gulf of Mexico (Collins et al. 1988). Larvae remain in the plankton for about 40 days, and juveniles typically settle in temperate estuarine habitats in April and May (Keener et al. 1988, Ross and Moser 1995, Collins et al. 1998). Our data indicate that juvenile gag also moved into subtropical Charlotte Harbor during April and May. Thus, it appears that the timing of recruitment into estuaries is consistent regardless of latitude.

Due to the shape and hydrological regime of Charlotte Harbor (rivers located far from passes and expansive polyhaline sounds), juvenile gag concentrated in high-salinity areas near Gasparilla and Boca Grande passes but also inhabited shallow areas in Gasparilla and Pine Island sounds several kilometers away from the Gulf of Mexico. Previous research determined that juvenile gag in temperate estuaries were concentrated in tidal creeks and seagrass beds near inlets (Ross and Moser 1995, Mullaney and Gale 1996, Koenig and Coleman 1998, Heinisch and Fable 1999). Exclusive use of polyhaline areas in estuaries by different size-classes has typically been attributed to low mobility during estuarine residency (Koenig and Coleman 1998, Heinisch and Fable 1999); however, it is unclear whether distribution is dependent solely upon settlement patterns or if larval survival decreases in lower salinities.

Within the polyhaline areas of estuaries, gag inhabit seagrass beds, oyster-shell habitats, mangroves, seawalls, and jetties (Hasting 1979, Bullock and Smith 1991, Mullaney and Gale 1996, Koenig and Coleman 1998, current study). In Charlotte Harbor, juveniles were collected from a similar variety of habitats, but abundance was greatest on seagrass-covered shoals and mangrove-lined shorelines—the dominant habitats in Gasparilla and Pine Island sounds. In estuaries where seagrasses are absent, juveniles typically have been collected from oyster-shell habitats in high-salinity tidal creeks (Mullaney and Gale 1996). High-salinity habitats that provide structure therefore appear to be preferred by juvenile gag during their estuarine residency throughout their range.

One habitat that has received little attention but yet provides considerable structure and large areas of suitable habitat for juvenile gag, is fringing mangroves. A consistent number (low SE for shoreline, see Figure 4) of juvenile gag were collected along fringing mangroves in this study. The dominant species of fringing mangrove in Charlotte Harbor is the red mangrove, which provides structure for fish assemblages in the form of prop roots and overhanging branches that extend into the water away from the shoreline (Thayer et al. 1987, Ley et al. 1999, Poulakis et al. 2003). Because of the large area (ca. 4120 m^2) and possible multiple habitats encompassed by the haul seine (e.g., seagrass beds, fringing mangroves), the exact habitat where juvenile gag resided could not be determined using this gear. However, a hook-and-line study targeting common snook (*Centropomus undecimalis*), conducted by the Fish and Wildlife Research Institute, captured juvenile gag as bycatch (D.A. Blewett, unpublished data, Fish and Wildlife Research Institute, Charlotte Harbor Field Laboratory). During hook-and-line sampling, juvenile gag were extracted from among prop roots of red mangroves, providing evidence that they use fringing red mangrove habitats.

Studies conducted in temperate estuaries have indicated that the passage of cold fronts in September and October trigger the egress of juvenile gag from estuarine waters to open-ocean waters (Ross and Moser 1995, Koenig and Coleman 1998). Our data showed that juveniles began to decline in abundance throughout Charlotte Harbor from October to December. Before dispersing offshore, juvenile gag appeared to first move to deeper open waters within the estuary during October and November, as indicated by the increased number of juvenile gag captured in the purse seine, which samples deeper habitats away from shore. Although Charlotte Harbor becomes affected by cold fronts in September and October, the effects of those cold fronts are milder than at higher latitudes. Therefore, because juvenile gag remain in subtropical estuaries like Charlotte Harbor longer than they do in temperate estuaries, they may attain relatively larger sizes before egressing.

Movement toward the ocean is enhanced by cold fronts, but these fronts are probably not the only cue used by gag. Previous studies have suggested that a few individuals may begin egressing to open ocean waters before water temperatures are lowered by cold fronts. For example, in Bogue Sound, North Carolina, and St. Andrews Bay, Florida, juveniles were observed along jetties in inlets several weeks before the first cold front (Ross and Moser 1995, Heinisch and Fable 1999). Similarly, near Charlotte Harbor, juvenile gag were observed near rock outcroppings on the Gulf of Mexico side of Boca Grande Pass during August in waters less than 5 m deep (J.P. Casey pers. obs.). It is unknown whether these individuals settled out in these habitats or moved there after first settling in the estuary.

Although most juveniles egress to the Gulf of Mexico during their first winter, some individuals remain in estuaries for a second year or possibly return to their respective estuaries after moving into the Gulf of Mexico (Heinisch and Fable 1999, current study). Heinisch and Fable (1999) hypothesized that some fish remained in temperate St. Andrews Bay, Florida, during the winter because of the great depth (19.8 m) in the inlet, but in Charlotte Harbor young gag have been collected during winter in relatively shallow water (< 3.3 m). Heinisch and Fable (1999) also suggested that larger juveniles migrate to join offshore spawning aggregations and then return to their respective estuaries. Future studies would be necessary to understand the extent to which this may occur in subtropical southwestern Florida. One method that could be used to determine the extent to which young gag move from the estuary to adult spawning aggregations is chemical markers within otoliths (Hanson et al. 2004).

In conclusion, the gag is an economically important reef species that is dependent on estuarine habitats during its early-life stages (Keener et al. 1988). Juvenile gag are distributed in the high-salinity areas of estuaries, and the period of settlement is similar in temperate and subtropical areas. However, gag remain in the estuary longer in warmer climates and egress at a larger size. Habitat use by juvenile gag within the high-salinity areas of subtropical Charlotte Harbor was greatest on shallow seagrass shoals, but mangrove shorelines represent a suitable habitat not previously reported for gag. Interannual variability in gag abundance was evident in Charlotte Harbor, with 2002 having a stronger year-class than in other years during this study.

Variability in young-of-the-year abundances for nearshore fishes may be attributed to fluctuations in factors such as fecundity of the offshore population, larval mortality, larval transport to the estuary due to winds and associated currents, and survival rates within the estuary as a result of changes in river discharge (Keener et al. 1988, Epifanio and Garvine 2001, Tsou and Matheson 2002, Paperno 2002). This study describes specific locations, habitat types, and interannual patterns of abundance within the Charlotte Harbor estuary that can be used to gauge future changes that may result from natural (e.g., stochastic events such as hurricanes) or anthropogenic alterations to water quality, habitat, and freshwater discharge.

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Table 1. The significant ($\alpha < 0.05$) variables identified by the general linear model analysis as contributing to the abundance of juvenile gag captured in the 183-m haul seine in Gasparilla and Pine Island sounds.

Source	df	Sum of squares	*F*	r^2
Model	24	63.54	6.57	0.28
Geographical location	1	2.63	6.50	
Seagrass habitat	8	15.43	4.79	
Shoreline vs. shoal	1	2.72	6.75	
Year	6	17.30	7.15	
Month	7	11.39	4.04	
Depth	1	9.32	23.12	
Error	400	161.18		
Corrected total	424	224.72		

Figure legends

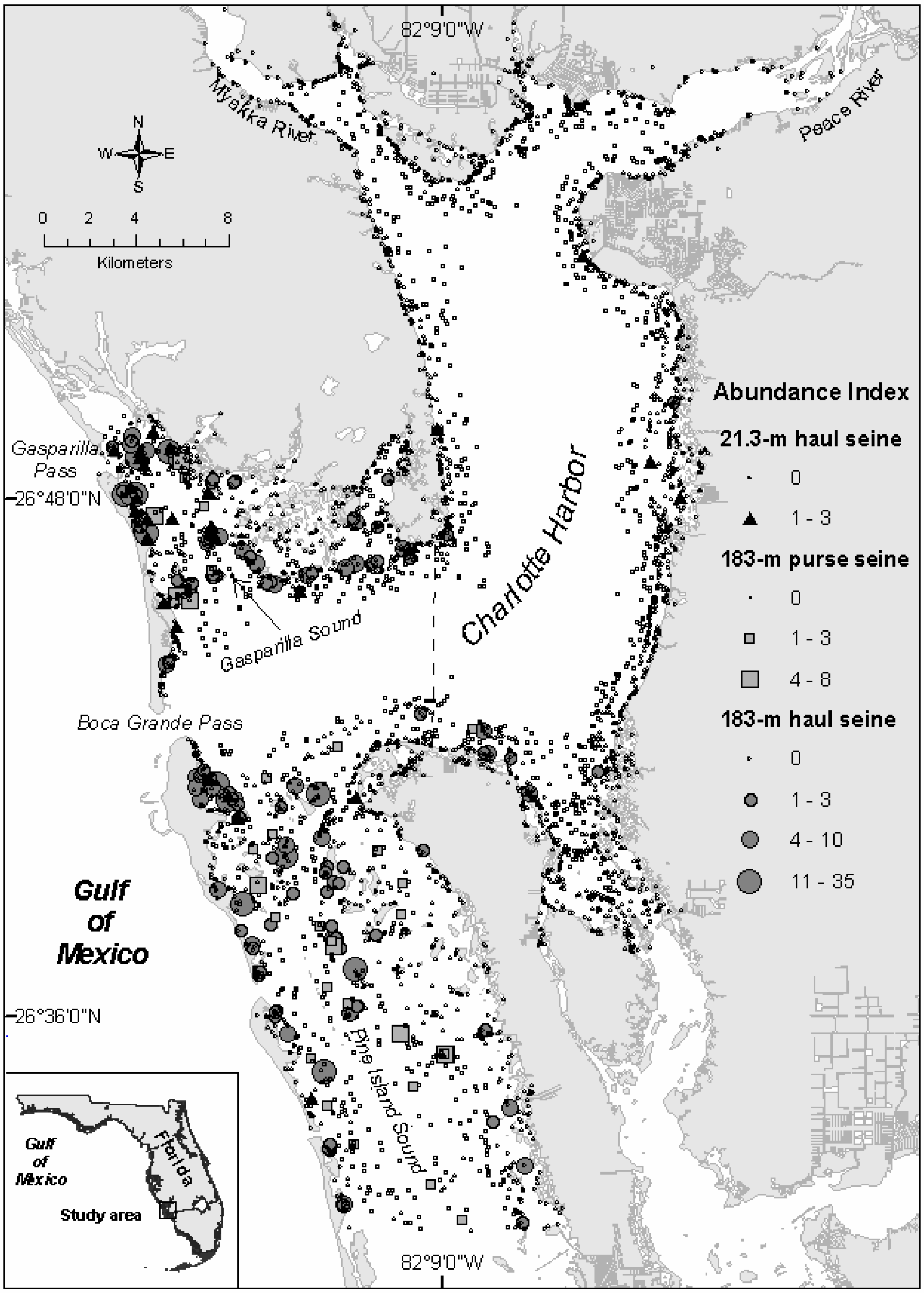
Figure 1. Distribution and relative abundance (abundance index = number of fish $haul^{-1}$) of juvenile gag in Charlotte Harbor, Florida. Samples were collected throughout the estuary, but most (95%) individuals were captured in Gasparilla and Pine Island sounds (areas west of dotted line).

Figure 2. Monthly size distribution of juvenile gag in Charlotte Harbor, Florida (1996–2002). black = 21.3-m seine, white = 183-m haul seine, hatched = 183-m purse seine.

Figure 3. Relative abundance (abundance index = number of fish $haul^{-1}$) of juvenile gag captured in the 183-m haul seine from May to December in Gasparilla and Pine Island sounds (± 1SE).

Figure 4. Relative abundance (abundance index = number of fish $haul^{-1}$) of juvenile gag captured with the 183-m haul seine from May to December (+ 1SE). Shore habitats included mangroves and beach shorelines, and shoal habitats included shallow sandbars and oyster bars. Seagrass percent cover includes up to three of the seagrass species found in Charlotte Harbor. The number in parentheses indicates the number of samples in each habitat.

Figure 1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183-m purse seine
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1 - 3
4 - 8
183-m haul seine
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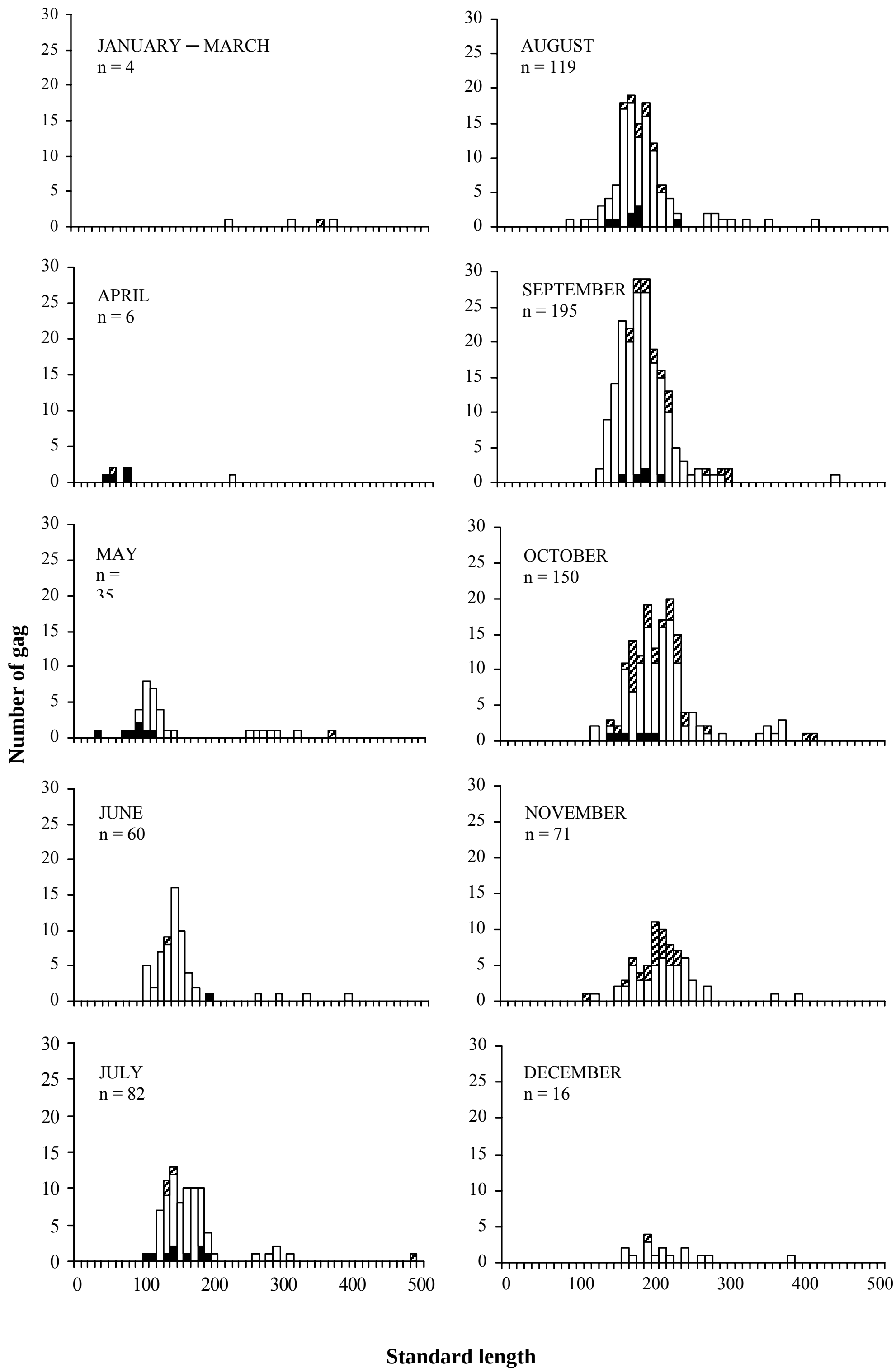
1 - 3
4 - 10
11 - 35
Gasparilla Pass
-26°48'0"N
Charlotte Harbor
Gasparilla Sound
Boca Grande Pass
Gulf of Mexico
-26°36'0"N
Pine Island Sound
Gulf of Mexico
Florida
Study area
82°9'0"W

Figure 2


JANUARY – MARCH
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APRIL
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JUNE
n = 60
JULY
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AUGUST
n = 119
SEPTEMBER
n = 195
OCTOBER
n = 150
NOVEMBER
n = 71
DECEMBER
n = 16
Number of gag
Standard length
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Figure 3

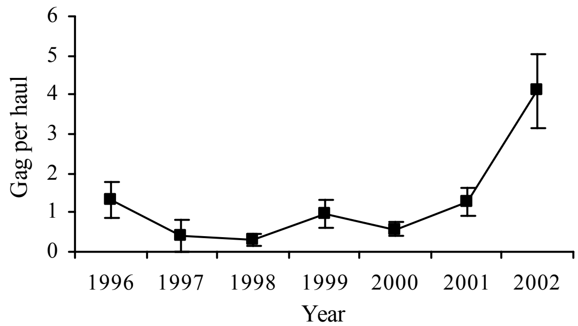
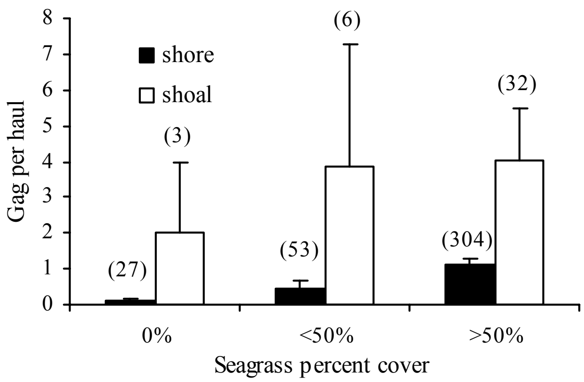


Figure 4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7
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Gag per haul
shore
shoal
(27)
(3)
(53)
(6)
(304)
(32)
0%
<50%
>50%
Seagrass percent cover