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HABITAT USE BY JUVENILE GAG, *MYCTEROPERCA MICROLEPIS* (PISCES: SERRANIDAE), 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, Florida, 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 collected in 4,480 samples. Most gag (96%) were probably young-of-the-year (< 288 mm SL). The majority of juveniles were collected in polyhaline 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 reported 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. Relative abundance of juvenile gag within Charlotte Harbor was greatest on shallow seagrass shoals but was also high along fringing 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). The species ranges from New York to Brazil, including the entire Gulf of Mexico (GOM), and juveniles have been reported to occur in temperate and subtropical estuaries from Virginia to the northeastern GOM (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 GOM, primarily during February and March (Hood and Schlieder 1992, 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 manmade habitats like 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 GOM 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, maximum reported size does not exceed 200 mm SL (Ross and Moser 1995), but in subtropical estuaries such as Tampa Bay, Florida, gag can reach 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, Fitzhugh et al. 2005), questions regarding aspects of habitat use, especially use of tropical climate habitats like mangroves, have not been examined. Thus, 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, located on the southwestern coast of Florida, is one of the largest estuaries in Florida and is separated from the GOM 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 is 15.5 m in Boca Grande Pass (Huang 1966). The climate is subtropical, with infrequent freezes and distinct wet and dry seasons. Mean annual rainfall is 127 cm, 60% of which falls between June and September (Taylor 1974), whereas mean water temperature is 25°C, ranging from 12°C to 36°C, and mean salinity is 29 psu, ranging from 5 psu to 40 psu (Poulakis et al. 2003, present study).

Charlotte Harbor supports a variety of habitats that are used by at least 255 species of fish (Poulakis et al. 2004). The 2 predominant habitats for fishes are seagrass flats and fringing mangroves. Red mangrove (*Rhizophora mangle*), white mangrove (*Laguncularia racemosa*), and black mangrove (*Avicennia germinans*) are the 3 species found in Charlotte Harbor, but red mangroves dominate along the shoreline (143 km^2; Poulakis et al. 2003). 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, sandy shoals (areas away from shore that are ≤ 0.5 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 3 different seines. Between 17 and 32 samples were completed each month for each gear, with effort distributed equally throughout the study area. 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 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). This 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 at least 40 m from the shoreline and was retrieved with the aid of a motorized hydraulic system (Wessel and Winner 2003). All fishes were identified to the lowest possible taxon and enumerated. Up to 40 fishes were measured to the nearest millimeter SL, and all juvenile gag were released alive in the field. The bottom type, seagrass species, shoreline vegetation species, and coverage (%) of each sample were qualitatively measured. Salinity (psu), dissolved oxygen ($mg\,l^{-1}$), and water temperature (°C) were recorded with 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 captured juvenile gag were plotted by gear type to examine distribution throughout the estuary. Three size-classes were plotted separately (≤ 100 mm, 101 ≤ 250 mm, and ≥ 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 and year for each gear to examine month of settlement, growth and relative abundance during estuarine residency, month of egress from estuary, and gear selectivity.

The gear type and areas within Charlotte Harbor where gag were most abundant were analyzed further by analysis of covariance (ANCOVA), which was performed by using a general linear modeling (GLM) approach, to investigate the influence of water temperature, salinity, water depth, overall seagrass coverage, bottom type, shoreline type, year, month, and geographic location on the gear-specific relative abundance of gag (PROC GLM; SAS Institute 1988). The relative abundance of gag was $\ln(x + 1)$ transformed before analysis.

Water temperature, salinity, water depth, and overall seagrass percent coverage 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 was the mean of all readings taken at each sample location. We tested for parallelism in the model by plotting each covariate against gag relative abundance to ensure similar slopes.

Bottom type (i.e., sand, mud, oyster), shoreline vs. shoal, year, month, and geographic location were the class variables (categorical variables) in the model. Samples were excluded from all habitat analyses when the overall seagrass coverage could not be estimated due to poor water clarity or water depth (3.5% of all samples). The geographic location variable included data west of the dotted line in Figure 1 and was defined as areas north of Boca Grande Pass (Gasparilla Sound) and south of Boca Grande Pass (Pine Island Sound). 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 ≤ 0.5 m deep at mean low tide and were at least 5 m from the shoreline (i.e., 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. The variables with the highest P values were removed from the model one at a time until all remaining variables were significant at $\alpha = 0.01$. The significance level of 0.01 was used to minimize the possibility of Type I error. We report only significant class variables and covariates in the results. 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 collected in 4,480 samples (Table 1). Most gag (96%) were probably young-of-the-year (< 288 mm SL), based on data presented in Hood and Schlieder (1992). Most juveniles were collected in the 183-m haul seine ($n = 615$) and ranged from 88 to 440 mm SL (mean = 183 mm). The purse seine collected individuals ($n = 83$) ranging from 50 to 489 mm SL (mean = 204 mm), and the 21.3-m seine collected juveniles ($n = 40$) ranging from 30 to 204 mm SL (mean = 138 mm).

Although samples were taken throughout the estuary (note locations of zero catches in Figure 1), gag were collected principally (95%) in polyhaline Gasparilla and Pine Island sounds (Table 1, Figure 1). Distribution plots of different size classes of gag showed that their distribution did not change as they grew, regardless of size or month, so all gag are included in Figure 1. The salinity (mean $\pm s_{\bar{x}}$) where gag were captured was relatively consistent (31.0 ± 0.4 psu, range = 13–40 psu).

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 SL 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' cohorts (> 288 mm SL) were collected year-round (Figure 2). The mean water temperature ($\pm s_{\bar{x}}$) where gag were captured was 27.7 ± 0.3°C (range = 14.5–33.5°C).

Because 78% of all gag were captured in the haul seine from May to December in Gasparilla and Pine Island sounds (Table 1), we used only these data in the general linear model to examine specific habitat use in areas and times when gag were most abundant. The variables that significantly affected gag abundance were geographic location (Pine Island Sound vs. Gasparilla Sound), year, month, water depth, shoreline vs. shoal, and overall seagrass percent cover (ANCOVA; $r^2 = 0.25$; Table 2). 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 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 May to December in both Gasparilla and Pine Island sounds and did not contribute to the model.

In Gasparilla and Pine Island sounds, juvenile gag were collected principally in habitats that contained ≥ 50% overall seagrass coverage (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 8 of the shoal samples were on oyster bars (19 gag collected); the other 30 samples were on shoals that had ≥ 50% overall seagrass coverage (133 gag collected). The majority of sample sites ($n = 280$) were along mangrove shorelines that had ≥ 50% overall seagrass coverage, and that is where most of the juvenile gag ($n = 226$) were collected. The catch-per-unit-effort increased from 0.3 to 1.4 gag per haul when the bag depth was greater than one meter.

DISCUSSION

Juvenile gag are typically concentrated in polyhaline areas close to passes, and these areas apparently represent the first suitable environments that presettlement

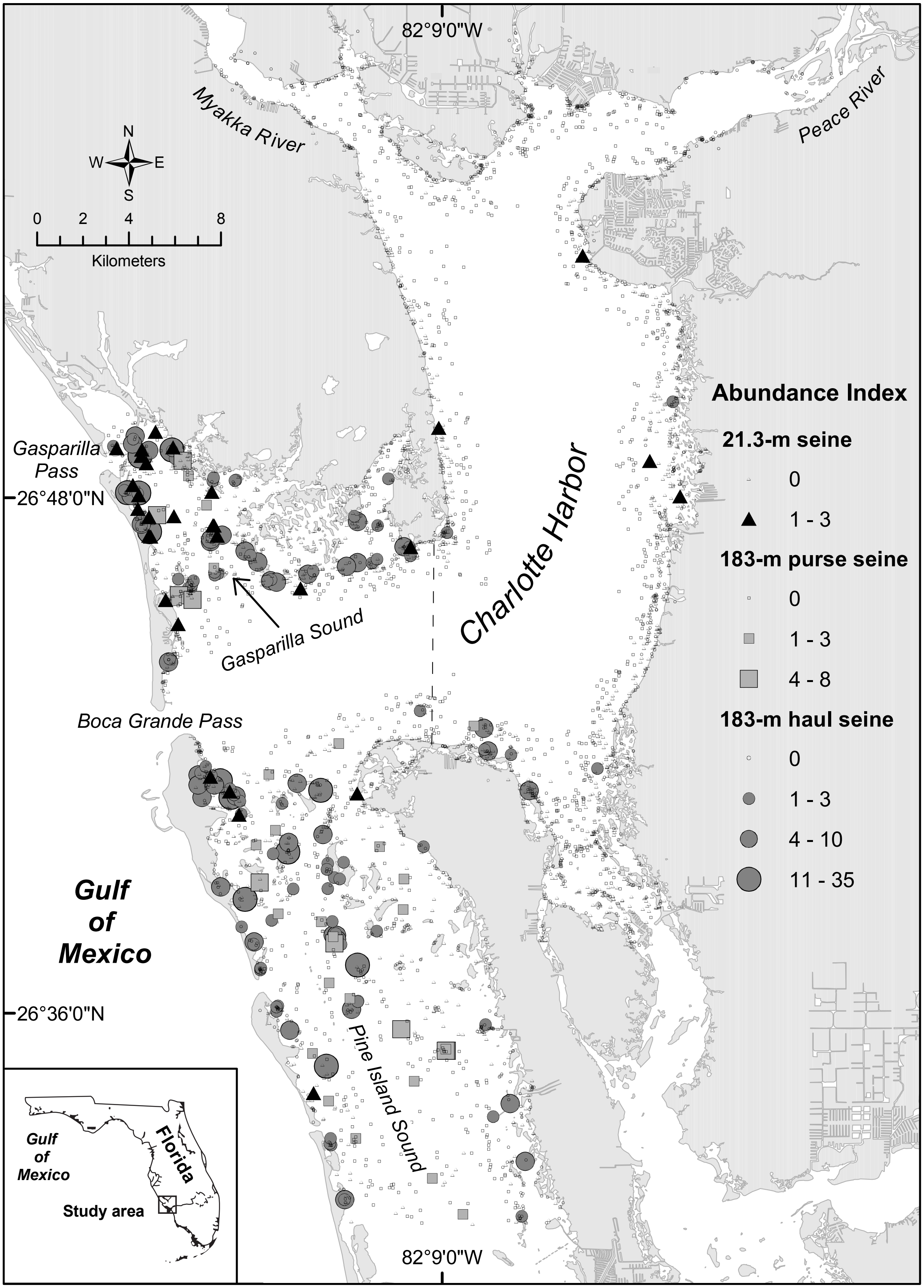

Figure 1. Distribution and relative abundance (abundance index = number of fish haul^{-1}) of juvenile gag in Charlotte Harbor, Florida. Samples (n = 4,480) were collected throughout the estuary, but most (95%) individuals were captured in Gasparilla and Pine Island sounds (areas west of dotted line).

TABLE 1

Summary of samples collected from 1996 to 2002 in Charlotte Harbor, Florida. The 2 sample regions are separated by the dotted line in Figure 1. (f) = number of samples that captured gag.

Gear	Eastern Charlotte Harbor		Gasparilla & Pine Island sounds		Total	
	Total samples	No. of gag (f)	Total samples	No. of gag (f)	Total samples	No. of gag (f)
21.3-m seine	1,192	7 (4)	872	33 (23)	2,064	40 (27)
183-m haul seine	712	33 (8)	644	582 (121)	1,356	615 (129)
183-m purse seine	530	1 (1)	530	82 (34)	1,060	83 (35)
Total	2,434	41 (13)	2,046	697 (178)	4,480	738 (191)

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 GOM (Hood and Schlieder 1992, Collins et al. 1998). Larvae remain in the plankton for about 40 d, and juveniles typically settle in temperate estuarine habitats in April and May (Keener et al. 1988, Ross and Moser 1995, Collins et al. 1998, Fitzhugh et al. 2005). Our data indicate that juvenile gag also moved into subtropical Charlotte Harbor and settled during April and May.

Due to the shape and hydrologic regime of Charlotte Harbor (rivers located far from passes and expansive polyhaline sounds), juvenile gag of various size classes were 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 GOM. In contrast, 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 survival decreases in lower salinities.

Within the polyhaline areas of estuaries, gag have been collected near seagrass beds, oyster-shell habitats, mangroves, seawalls, and jetties (Hastings 1979, Bullock and Smith 1991, Mullaney and Gale 1996, Koenig and Coleman 1998, present study). In Charlotte Harbor, juveniles were most abundant where water depths were >1 m on seagrass-covered shoals and along 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). Therefore, high-salinity habitats that provide structure appear to be preferred by juvenile gag during their estuarine residency throughout their range.

One habitat that has received little attention, but provides considerable structure and large areas of suitable habitat for juvenile gag, is fringing mangroves. A consistent number (low $s_{\bar{x}}$ 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. 4,120 m^2) and multiple habitats (e.g., seagrass beds, fringing mangroves) encompassed by the haul seine, the exact habitat where juvenile gag resided could not be determined using this gear. However, a hook-and-line study that targeted common snook (*Centropomus undecimalis*) 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 red mangrove prop roots, 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

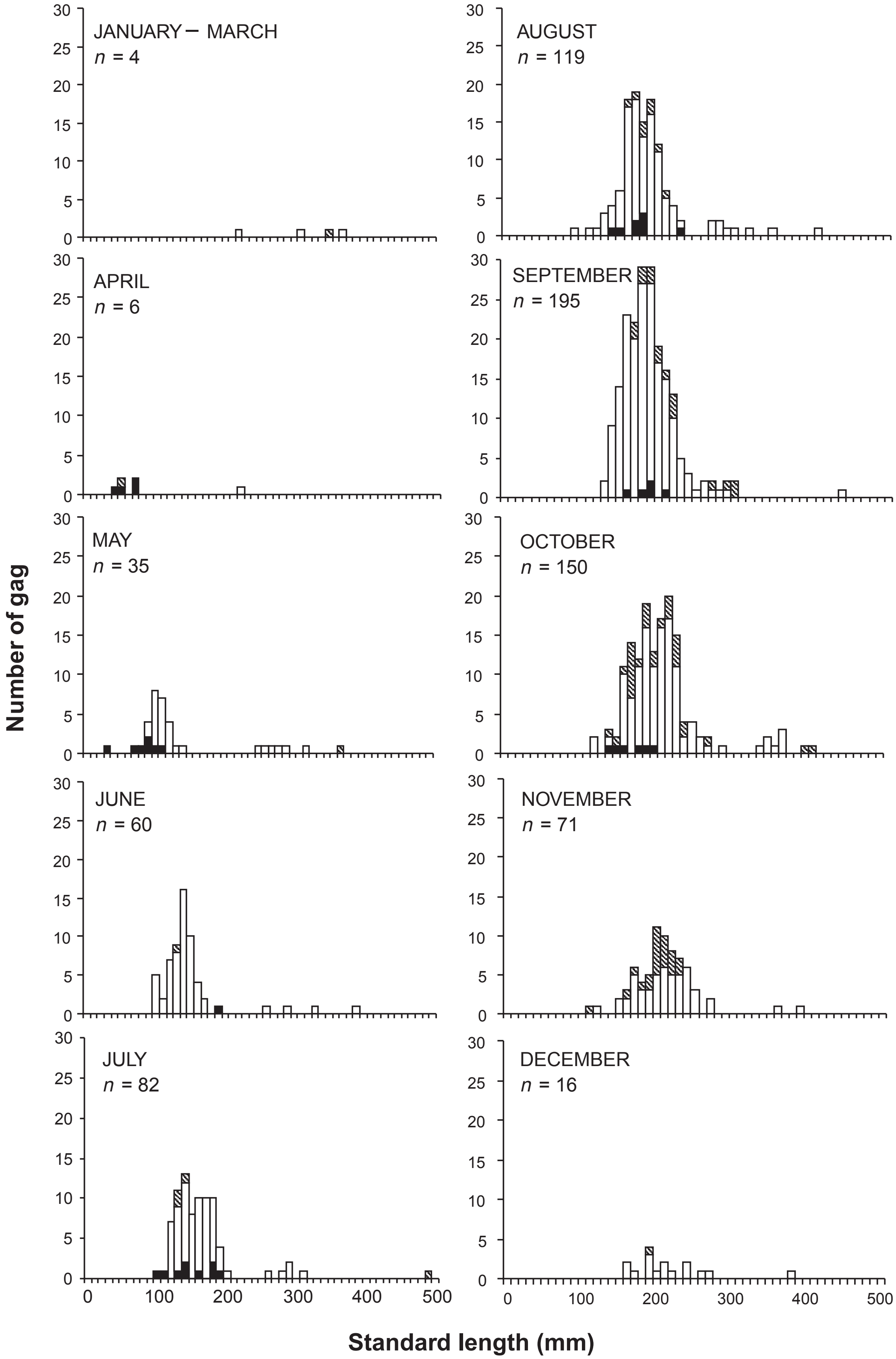

Figure 2. Monthly size distribution of juvenile gag in Charlotte Harbor, Florida (1996–2002). Black = 21.3-m seine, White = 183-m haul seine, Hatched = 183-m purse seine.

TABLE 2

The significant (α < 0.01) 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 from May to December.

Source	df	Sum of squares	*F*	*P*	r^2
Model	17	56.82	8.10	< 0.0001	0.25
Month	7	10.67	3.70	0.0007	
Year	6	17.51	7.07	< 0.0001	
Geographic location	1	3.91	9.48	0.0022	
Shoreline vs. shoal	1	3.79	9.18	0.0026	
Water depth	1	12.62	30.59	< 0.0001	
Seagrass percent cover	1	8.71	21.12	< 0.0001	
Error	407	167.90			
Corrected total	424	224.72			

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 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 GOM 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.

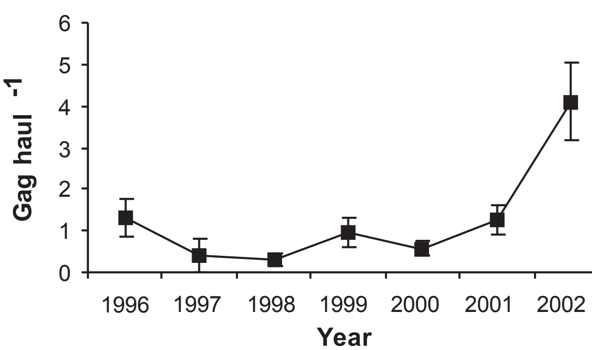

Figure 3. Annual mean relative abundance (abundance index = number of fish haul^{-1}) of juvenile gag captured in the 183-m haul seine from May to December in Gasparilla and Pine Island sounds (mean ±$s_{\bar{x}}$).

Although most juveniles egress to the GOM during their first winter, some individuals remain in estuaries for a second year or possibly return to their respective estuaries after moving into the GOM (Heinisch and Fable 1999, present study). Heinisch and Fable (1999) hypothesized that some fish remained in temperate St. Andrews Bay, Florida, during 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 offshore and then return to their respective estuaries. Future studies would be necessary to understand the extent to which this may occur. One method that could be used to determine the movement between estuaries and offshore habitats is chemical markers within otoliths (Hanson et al. 2004).

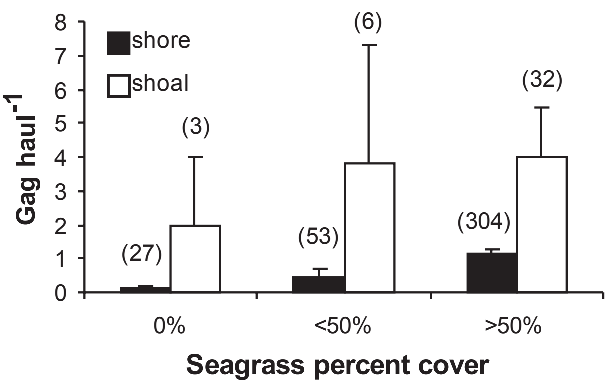

Figure 4. Mean relative abundance (abundance index = number of fish haul^{-1}) of juvenile gag captured with the 183-m haul seine from May to December in Gasparilla and Pine Island sounds by habitat (mean ±$s_{\bar{x}}$). Shore habitats included mangrove and beach shorelines, and shoal habitats included sandbars and oyster bars. Seagrass percent cover included up to three of the seagrass species found in Charlotte Harbor. The number in parentheses indicates the number of samples taken in each habitat.

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 remained in subtropical Charlotte Harbor longer and egressed at a larger size than in estuaries at higher latitudes. Habitat use by juvenile gag within the high-salinity areas of Charlotte Harbor was greatest on shallow seagrass shoals, but red mangrove-lined shorelines represent a suitable habitat not previously reported for this species. Interannual variability in gag abundance was evident in Charlotte Harbor, with 2002 having a stronger year-class than the other years of this study. Variability in young-of-the-year abundances 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 (Keener et al. 1988, Epifanio and Garvine 2001, Paperno 2002, Fitzhugh et al. 2005). 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., hurricanes) or anthropogenic alterations to water quality and habitat.

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