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Inshore Movements, Residency, and Abundance of Adult Winter Flounder, *Pseudopleuronectes americanus*, and Piscivorous Predation on Young-of-the-Year Winter Flounder within Coastal Bays of Long Island and an Investigation on the Effect of Temperature and Photoperiod on Vertebral Band Deposition in Little Skate, *Raja erinacea*

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Skyler Rose Sagarese

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Abstract of the Thesis

Inshore Movements, Residency, and Abundance of Adult Winter Flounder, *Pseudopleuronectes americanus*, and Piscivorous Predation on Young-of-the-Year Winter Flounder within Coastal Bays of Long Island and an Investigation on the Effect of Temperature and Photoperiod on Vertebral Band Deposition in Little Skate, *Raja erinacea*

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I investigated adult winter flounder movement patterns using underwater acoustic telemetry to determine the spatial behavior of winter flounder occupying Shinnecock Bay, New York, and to document if any fish indicated behaviors consistent with the historical notion of resident "bay fish." Most tagged fish remained in Shinnecock Bay with eighty-nine percent of the total detections occurring between May and October. Residency within the bay varied greatly with some fish residing within the bay for many months while others were only detected over a few days. Breakpoint analysis showed a decrease in flounder activity during dawn, day-time, and dusk for most fish. Overall, winter flounder in Shinnecock Bay can be classified into three common movement patterns of fish including the following: (1) fish remaining within the bay, (2) fish heading offshore through Shinnecock Inlet, and (3) fish exiting the bay through alternative paths which include Shinnecock Canal and underneath the Ponquogue Bridge.

These results provide insight into flounder movements in a coastal bay of Long Island which may help identify potential reasons for a general decline in winter flounder; however, much work remains to fully understand the stock structure of this species.

I investigated piscivorous consumption on young-of-the-year (YOY) winter flounder, *Pseudopleuronectes americanus*, and compared the species' current role in Long Island bay food webs to past studies. Gut contents of eight piscivorous fish species were examined from Port Jefferson Harbor, Great South Bay, and Shinnecock Bay. YOY winter flounder contributed less than 0.5% and 1.6% (percent index of relative importance and percent by weight, respectively) to the diets of piscivorous fish. The diets of fish ranged from plant matter and crustaceans to fish and mollusks. Most predator-prey length relationships examined were positive but weak. Currently, important food items in this system include sand shrimp (*Crangon sp.*), rock crabs (*Cancer irroratus*), and Atlantic silversides (*Menidia menidia*). The role of YOY winter flounder in current food webs of Long Island has dramatically declined compared to past studies.

Environmental and biological factors such as temperature, photoperiod, migration, spawning, and uptake of minerals have been linked to variation in vertebral band deposition in elasmobranchs. Given that age estimates for elasmobranchs are based on band pairs present on vertebrae or spines, it is imperative to determine if external factors are influencing band deposition. I investigated whether photoperiod or temperature has an effect on the timing of vertebral band deposition in captive little skate, *Leucoraja erinacea*. The experimental design consisted of a randomized complete block split plot design with two factors: temperature and light. Temperature was nested within

light and therefore four variables were tested: (1) constant light, (2) constant temperature, (3) seasonal light, and (4) seasonal temperature. For 18 months, little skate experienced accelerated seasonal conditions of temperature and light to mimic 3 years of growth. Even though high mortality of specimens hindered the original statistical analysis, this study provides evidence that seasonal photoperiod and temperature have no effect on timing of vertebral band deposition in captive little skate. Vertebral analysis of seven surviving skates showed that all produced two to three bands regardless of treatment over 18 months. Centrum edge analysis of 56 specimens provided evidence that the timing of band deposition was not affected by treatments. The winter band (translucent) appeared in February 2007 and January 2008 while the summer band (opaque) began in July for both 2007 and 2008. My findings suggest that band deposition may be regulated by an endogenous circadian rhythm.

Dedication

I dedicate this work to my family and the many

mentors who have invested time in helping me achieve my goals

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Chapter 1: Winter Flounder and their Fisheries on Long Island

Over the last few decades a decline in winter flounder, once a plentiful and reliable resource to the people of Long Island (LI), has left a gap in both ecosystem structure and the fishing community. Winter flounder, *Pseudopleuronectes americanus*, held an important place in maritime history of Long Island. This finfish helped pioneer the development of recreational and commercial fisheries in New York State. As the largest inshore island on the Atlantic Coast, Long Island inhabitants have always relied heavily on the sea for resources such as oysters, scallops, clams, finfish, and even whales during the 19th century (Neville 1938). Peak landings of winter flounder in both the recreational and commercial fishery occurred during the early 1980's (Socrates and Colvin 2006; Vonderweidt 2009). Record low landings at the beginning of the 21st century has led to a shortened fishing season (April 1st – May 30th) for 2007 and 2008 while an indefinite closure is being considered for both recreational and commercial fisheries in the near future.

In this thesis, I set out to investigate the mechanisms behind declining winter flounder populations in Long Island bays by examining two potential reasons for decline: offshore movements and predation. Adult winter flounder were tracked using acoustic telemetry to analyze the potential for identifying two stocks of winter flounder. I also quantified the impact of piscivorous fish predation on young-of-the-year because predation is thought to be the primary cause of juvenile flatfish mortality (Pihl and Van der Veer 1992; Bailey 1994; Manderson et al. 2000). Lastly, I conducted an experiment

to determine the effect of temperature and photoperiod on band formation during the aging process in fish. Results from this experiment have implications for understanding formation of growth bands in a wide range of taxa including teleosts and elasmobranchs.

Winter flounder are found from Labrador, Canada to as far south as Georgia in the United States, with highest abundances observed from the Gulf of St. Lawrence to Chesapeake Bay, Maryland (Klein-MacPhee 2002). These epibenthic fish prefer muddy sediments sporadically placed between patches of eelgrass (Olla et al. 1969; Klein-MacPhee 2002). Winter flounder can live to 15 years and grow up to 67 cm in total length, although fish larger than 46 cm are unusual inshore (Fields 1988; Klein-MacPhee 2002). This batch spawning species becomes sexually mature at two years for males and three years for females, with females laying an average of 500,000 adhesive demersal eggs annually (Perlmutter 1947; Klein-MacPhee 2002; Able and Grothues 2007). Spawning occurs in shallow waters between sunset and midnight and peaks during February-March for fish in New York (Lobell 1939; Perlmutter 1947; Stoner et al. 1999; Pereira et al. 1999; Klein-MacPhee 2002). Tagging studies support evidence for homing behavior of winter flounder as some return repeatedly to the same spawning grounds (Lobell 1939; Saila 1961; Grove 1982; Klein-MacPhee 2002).

The distribution of inshore winter flounder in Long Island bays has been documented since the 1930's (Lobell 1938). The Long Island population was divided into racial groups consisting of two groups: "bay fish" which remain inside coastal bays year-round and reach a smaller size and an offshore population of larger individuals which travel inshore only during breeding season (Lobell 1939). In 1937, the occurrence of winter flounder tag returns year-round in Great South Bay indicated the presence of a

resident bay population (Lobell 1939). Olla et al. (1969) observed active winter flounder in Great South Bay during warm summer months. Presence of adult winter flounder inshore during warm months has been documented in other regions throughout the northeastern US and Atlantic Canada (Kennedy and Steele 1971; Howe and Coates 1975; Pereira et al. 1999).

Historically, winter flounder have been an important link in the marine food web of Long Island (Schreiber 1973). Their small gape sizes and absence of teeth make them important predators for small organisms such as crustaceans and annelids (Klein-MacPhee 2002). Inshore fish prey upon polychaete worms, amphipods, shrimp, ascidians, holothurians, squid, and mollusks while winter flounder offshore feed primarily on hydrozoans and anthozoans (Langton and Bowman 1981; Bowman et al. 2000; Klein-MacPhee 2002). In terms of winter flounder as a prey item, predators include multiple fish species, elasmobranchs, birds, crustaceans, and marine mammals. Adults are preyed upon by striped sea robin, striped bass, bluefish, Atlantic cod, hake, dogfish, skate, osprey, and seals including harbor, gray, and harp (Klein-MacPhee 2002; Rountree 1999). Juvenile and young-of-the-year winter flounder are eaten by sand lance, toadfish, flounder, bluefish, sea robin, weakfish, hake, striped bass, cormorant, wading birds, crabs, and sand shrimp (Klein-MacPhee 2002; Howe et al. 1976; Pereira et al. 1999; Poole 1964; Richards et al. 1979; Manderson et al. 1999; Manderson et al. 2004; Leopold et al. 1998; Hjorleifsson and Palsson 2001; Witting and Able 1995).

Possibly the most important predator of winter flounder is the fisherman. After spawning, winter flounder resume feeding and as a result become vulnerable to fishermen (Tyler 1971; Phelan 1992). Winter flounder have been a favorite among Long Island

fishermen for many reasons; their thick and meaty fillets are superior to those of other flatfish in the New York region (Klein-MacPhee 2002); they were once one of the most abundant shore fishes in Long Island waters (Lobell 1939); they reside in protected bays when other important species are absent (Poole 1969); and they are easy to catch by boat or by fishing off piers and bridges (Lobell 1939; Klein-MacPhee 2002). Winter flounder tend to be present inshore when water temperatures are below 15°C, hence the "winter" in their common name (McCracken 1963; Klein-MacPhee 2002). They can experience high natural mortality rates when temperatures drop below -1.4°C during winter or when high temperatures combine with low oxygen content during summer (Nichols 1918; Poole 1969; Duman and De Vries 1974; Howe and Coates 1975; Klein-MacPhee 2002).

Early tagging studies performed in the south shore bays of Long Island indicated the importance of the recreational fishery as anglers returned almost as many tagged fish as commercial gear (Lobell 1939). The recreational fishery for winter flounder during the 20th century was dominated by fisherman using hook and line from rented row boats around Long Island (Lobell 1939; Westman 1939; Poole 1969). During this period, winter flounder were one of the most important fish to marine sport fishermen (Poole 1969). In 1938 the Long Island recreational fishery removed 1,039,115 winter flounder from local waters between March and November (Lobell 1939).

During the latter half of the 20th century, the innovation of motorized boats and improvements in fishing gear and technology made locating and catching winter flounder much easier. As fishing effort and efficiency increased, more and more winter flounder were removed from the population until few were left. Recreational landings for the southern New England Mid-Atlantic stock peaked at 12.7 million pounds during 1984

and have since declined to 454,152 pounds in 2004, with landings in recent years ranging from 450,000 to 1.8 million pounds (Vonderweidt 2009; Figure 1.1). In 2006, over 200,000 people and 35 party boats on Long Island relied on the harvest of winter flounder among other species for revenue (Smith 2006). However, the Marine Recreational Fisheries Statistics Survey reports that inshore recreational landings of winter flounder in Long Island waters is only 2% of peak levels observed in the 1980's (Socrates and Colvin 2006).

Commercial harvest of winter flounder became an important source of income for local fishermen after the introduction of trawls pulled by wind-powered sloops or "draggers" and fyke nets to the fishing community in the early 1900s (Lobell 1939). Otter trawls were very efficient at capturing bottom dwelling fish such as flounder and allowed fishermen to locate areas of greatest concentration of winter flounder. Fyke nets allowed the collection of winter flounder from muddy regions which were difficult to trawl, for example, in Great South Bay (Lobell 1939). During 1938, 678,889 pounds of winter flounder, valued at $43,202, were harvested by the commercial fisheries of Long Island (Lobell 1939). As observed in the recreational fishery, technological improvements including fuel powered trawlers and GPS capabilities resulted in high catches of winter flounder. Commercial landings for the southern New England Mid-Atlantic stock peaked at 24.6 million pounds during the early 1980's then declined to 3.2 million pounds in 2004 (Vonderweidt 2009; Figure 1.1). Commercial landings of winter flounder specific to New York State reached 3.2 million pounds in 1966 and declined to 330,690 pounds in 2004 (Socrates and Colvin 2006).

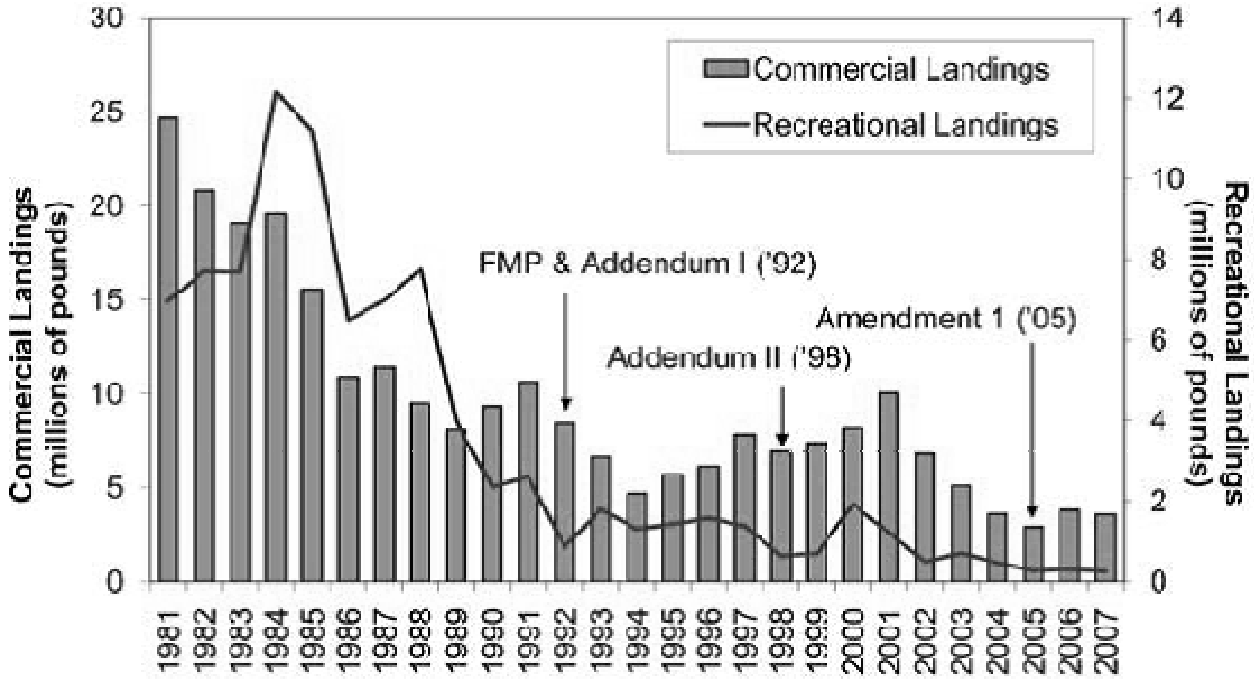

Figure 1.1: Southern New England/Mid-Atlantic Winter Flounder Landings. Source: NEFSC Groundfish Assessment Review Meeting, 2008. Taken from: Winter Flounder Profile, March 2009.

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Chapter 2: Inshore Movements, Residency and Abundance of Adult Winter Flounder, *Pseudopleuronectes americanus*, in Coastal Bays of Long Island, New York, Using Acoustic Telemetry

Introduction

The decline of winter flounder, *Pseudopleuronectes americanus*, in inshore waters of Long Island, New York has lead to drastic changes in both commercial and recreational fisheries including reduced fishing seasons and quotas along with a possible indefinite closure. Winter flounder has supported recreational and commercial fisheries since the inception of flounder fishing in the early 1900's (Hanlon 1983). Today, the Long Island recreational fishery includes more than 200,000 people and 35 party boats which target winter flounder among other finfish species (Smith 2006). Inshore recreational landings indicate that winter flounder catch is currently less than 2% of peak levels observed in the early 1980's (Socrates and Colvin 2006). Winter flounder has become scarce in Long Island bays while offshore the species has also declined, but is comparatively more abundant (ASMFC 2009).

Within the northeastern US, winter flounder are known to form local races that differ in behavior and appearance (Klein-MacPhee 2002). Although the stock structure of winter flounder on Long Island is poorly understood (Poole 1966), two stocks of winter flounder have historically been identified: an inshore stock which resides in the coastal bays for most of the year (termed "bay fish") and an offshore stock where fish attain larger sizes and only travel inshore to spawn (Lobell 1939; Perlmutter 1947). "Bay fish" were believed to remain inshore and migrate into deeper waters when either the

shallows became too warm (Lobell 1939) or food availability became inadequate (Van Guelpen and Davis 1979; Klein-MacPhee 2002). If "bay fish" are currently extant in Long Island Bays they would display unique migratory behavior from the offshore stock. However, inshore winter flounder may simply represent juvenile fish that will eventually migrate offshore as they mature (Poole 1966).

Migrations undertaken by winter flounder have been related to several factors including spawning season, environmental conditions, ice formation, and turbulence (Pereira et al. 1999; Klein-MacPhee 2002). It is widely recognized that winter flounder migrate to inshore spawning grounds in the autumn and leave as waters warm in the spring (Lobell 1939; Perlmutter 1947; Van Guelpen and Davis 1979; Klein-MacPhee 2002). Peak spawning activity occurs between sunset and midnight during February and March for fish in New York waters (Lobell 1939; Perlmutter 1947; Pereira et al. 1999; Klein-MacPhee 2002). On Long Island a second spatial pattern has been recognized. After spawning, fish belonging to the offshore stock exit the bay while the "bay fish" are believed to remain inshore (Lobell 1939; Perlmutter 1947; Saila 1961; Pearcy 1962; McCracken 1963; Lux and Nichy 1971; Howe and Coates 1975; Klein-MacPhee 2002). Evidence for homing behavior of winter flounder exists as many return repeatedly to the same spawning grounds (Lobell 1939; Saila 1961; Klein-MacPhee 2002).

Inshore winter flounder in Canadian waters have exhibited local movement related to environmental conditions (McCracken, 1963). These movements appear to be related to water temperatures as fish tend to leave inshore waters when they are too warm or when temperatures drop below the freezing point. McCracken (1963) observed mature winter flounder leaving the shore zone when summer water temperatures rose above 15ºC

and returning inshore at temperatures below 15ºC in Canadian waters. Howe and Coates (1975) found supporting evidence of McCracken's theory of migration: when water temperatures in Massachusetts fell below 15°C in October, tagged fish returned to inshore waters. In addition to temperature, extreme environmental conditions can induce migratory behavior in winter flounder. In a winter study in Newfoundland, the creation of both turbulence from strong winds and drifting pack ice from near freezing temperatures induced migratory behavior in winter flounder (Van Guelpen and Davis 1979). Although winter flounder possess an antifreeze protein that allows them to remain in freezing temperatures down to -1.4°C, they can still be mechanically damaged from anchor ice and turbulent water flow (He 2003; Hanson and Courtenay 1996; Van Guelpen and Davis 1979; Klein-MacPhee 2002).

In this study we investigated adult winter flounder movement patterns and abundance within a coastal bay of Long Island, NY using underwater acoustic telemetry. Acoustical technology allowed for detailed monitoring of winter flounder movement year-round within the study area. My objective was to determine the spatial behavior of winter flounder occupying Shinnecock Bay and document if any fish indicated behaviors consistent with the historical notion of resident "bay fish."

Materials and Methods

Study Site. Shinnecock Bay is a barrier beach and lagoon estuary located on the south shore of Long Island, approximately 120 km east of New York City (Figure 2.1). This bay is connected to the Atlantic Ocean by a single inlet in the south where tidal velocities average 4.6 km/s (USFWS 1997). In the north, a man-made canal controls water flow from Peconic Bay to Shinnecock Bay and prevents Shinnecock Bay waters

from flowing into Peconic Bay (USFWS 1997). Shinnecock Bay has an average tide of 0.2 m (USFWS 1997), an average salinity of 30 ppt (Green and Chambers 2007) and water temperatures that can reach up to 24°C during summer (Figure 2.2). It encompasses an area of 39 km^2 that includes open water in the eastern and shallow western region (Green and Chambers 2007). Average depth for the eastern portion is about 3 m as compared to the shallower western portion where depths remain less than 2 m (USFWS 1997).

Field methods: *Abundance Surveys for Adult Winter Flounder in 2007& 2008*: A stratified random sampling survey was conducted bimonthly between April and August 2007 and monthly between May and August 2008 to obtain abundance estimates of winter flounder in Shinnecock Bay. Trawl stations were randomly selected by dividing Shinnecock Bay into numbered boxes of the same size and using a random number generator in Microsoft Excel to determine which box would be sampled. For each station from April to July in 2007 a 9 m otter trawl with 0.6 cm mesh at the cod end was pulled by the R/V Pritchard for 8 min at 1.3 m/sec. Trawls from August 2007 and 2008 were conducted aboard the R/V Shinnecock using a different 9 m otter trawl. Trawls were limited to 5 min at 0.8 m/sec aboard the R/V Shinnecock as manual labor was required to land the catch. A vessel & gear change in August 2007 was warranted due to the shallow nature of the bay, the large draft required by the R/V Pritchard, and the capability of the R/V Shinnecock to sample a larger portion of the bay. At each station, starting and ending GPS were recorded and environmental measurements including bottom water temperature, salinity, and dissolved oxygen were collected. All captured winter flounder were measured in total length to the nearest mm.

Collection and Tagging of Adult Winter Flounder: Additional otter trawling days aimed solely at catching adult winter flounder were added in 2008 to increase my sample size for acoustical tracking. Between January and March of 2008, I trawled one day each month for spawning winter flounder. During the summer of 2008, two additional sampling days were added between May and July as winter flounder appeared most abundant during this time.

Immediately upon capture, adult winter flounder were measured in total length to the nearest mm. Flounder over 24 cm were considered adults (Perlmutter 1947; Klein-MacPhee 2002). Those adults that appeared healthy (i.e.: no scars or parasites) were considered tag worthy. A 24 mm long VEMCO coded pinger ultrasonic transmitter (V9-1L-R64K) was surgically implanted within the peritoneal cavity of each flounder. After surgery, fish were treated with ©Betadine to limit infections and their 15 mm incision (tag diameter = 9 mm) was closed up using ©Ethibond Excel polyester sutures. After surgery, fish were held for a short time in a holding tank on the boat for observation and then released at the site of capture.

The VEMCO tags chosen have a power output of 142 to 150 dBs (decibel) and work on a frequency of 69 kHz. Each tag emits a pulse train with a unique ID code used for identification purposes. Battery life ranges from 200 to 400 days depending on power output and pinger delay. My first 31 tags used were programmed to ping every 150 to 300 seconds and had an estimated tag life of 400 days while the remaining 9 tags pinged every 40 to 120 seconds and had a smaller estimated tag life of 200 days.

Active and Passive Tracking of Tagged Winter Flounder: Acoustically tagged fish were tracked passively using 18 stationary receivers (Figure 2.1). Twelve of the

eighteen stations were in open water (Figure 2.3) and contained a VR2W receiver mounted on a concrete block while the remaining stations had VR2Ws directly attached to pilings (Figure 2.3; Stations 4 and 14) or concrete blocks chained to a jetty (Figure 2.3; Stations 1, 2, 3 and 17). VR2Ws are submersible single-channel acoustic receivers capable of identifying VEMCO coded transmitters and measure 308 mm long by 73 mm in diameter. When a tagged fish swims within 400 m of the receiver, the VR2W records the transmitter's serial number, ID code, and date/time of detection. Data from the VR2W is transferred via a Bluetooth connection to a laptop equipped with VUE software.

Active tracking employed a portable receiver, the VR100, with an omni-directional hydrophone to search for tagged fish (Figure 2.3). This receiver records the transmitter ID code, date/time, and GPS location where the signal was received. For this technique, I divided Shinnecock Bay into boxes based on the range I obtained in a field test of the VR100. A station was then assigned to the center of each box and a target GPS was identified. One day of tracking lasted about 10 hours with 5 min spent at each station as this was the maximum time between pings for my tags. Active tracking covered the entire bay and occurred once a month during October and November of 2007; April, May and July of 2008; and twice during June 2008.

Interpretation of telemetry data: For this study, I tested all transmitters in the lab and assumed they worked properly after deployment. If a tag was recorded in the same location using the VR100 or on a single VR2W on consecutive days for at least 2 months, I classified that fish as dead due to natural causes. If a fish was not picked up on any receiver including those gating the bay, there were three possible outcomes for the fish: (1) this fish may have swam to a region out of range from my receivers within the

bay; (2) it may have been eaten by a larger predator; or (3) it may have been harvested during the short fishing season.

To determine if a fish was entering or leaving the bay through Shinnecock Inlet, I created a gate at this site. Four receivers were placed around Shinnecock Inlet: two receivers were set on the bayside (north) while two receivers were set inside the inlet (south) on the eastern and western jetties. This allowed observation on the movements of winter flounder in relation to both the north and south receivers and determine the relative direction of movement (entering or exiting the bay). In addition, other receivers at Shinnecock Canal and Ponquogue Bridge (west) were used to investigate alternative exits from the eastern portion of Shinnecock Bay. Tracking of movements in and out of the bay was essential in identifying resident and offshore winter flounder. Based on the array and knowledge of winter flounder stocks, I believe three migration patterns exist in Shinnecock Bay including inner bay movements, emigration to offshore waters, and connectivity to other inshore areas via alternative routes. Fish exhibiting inner bay movements may be "bay fish" if they remain within the bay year-round. Those fish which leave the bay through the inlet will be identified as "offshore fish." Lastly, fish traveling through Shinnecock Canal or underneath Ponquogue bridge will be considered connecting to other inshore areas and could be "bay fish" or "offshore fish."

Analysis of telemetry data: *Receiver CPUE*: CPUE is defined as the number of receivers with valid fish detections divided by the total number of receivers for each day. A high CPUE indicated that most receivers detected a fish over that day while a low CPUE indicated that few or no receivers detected a fish that day. CPUE was also calculated in terms of the number of detections per day while accounting for differences

in pinger delay. In addition, core monitors for each fish were identified as the receiver with the greatest number of detections for a particular fish and represent regional preferences of an individual fish (Topping et al. 2006).

Residence time: To establish the degree of site fidelity for winter flounder in the study area, a residency index (I_R) was determined by dividing the total number of days a fish was detected (N_{total}) by the total number of days between the date of release and the last date of detection, or the time at liberty (N_L) (Topping et al. 2006; Abecasis and Erzini 2008):

$$I_R = \frac{N_{Total}}{N_L}$$

To determine if the residency index varied with fish size, a linear regression was performed between fish size and the residency index. Residency was also described in terms of total and continuous presence. I differentiated between continuous presence (tally of consecutive days an individual was resident) and the total number of days a fish was detected within the bay (total presence) (Collins et al. 2007). A t-test assuming equal variances ($\alpha = 0.05$) was used to test for a significant difference in both the total number of days and continuous days monitored between smaller (< 30 cm) and larger flounder (≥ 30 cm). Results for both continuous and total presence along with residency index were graphed as a frequency histogram.

Activity – Day versus Night: Winter flounder provide an ideal candidate for studying activity periods as they often bury into the sediment during resting periods making the probability of detection very low. To examine activity, detections were summed in hourly intervals for each individual fish. For fish with more than 1000 detections, a segmented regression with a breakpoint analysis was performed for the

hourly intervals and number of detections to identify times where important changes in flounder activity occurred. The breakpoint(s) are considered the point or points which separate two significantly differing linear regressions as derived from the data (Frisk et al. *in review*). In breakpoint analysis, a series of linear regressions are fitted between breakpoints parsimoniously to maximize the overall fit of the segmented regression while penalizing the number of breakpoints in the series using the Bayesian Information Criterion (BIC) (Frisk et al. *in review*). For graphical representation, I combined the hourly detections into four groups: night (7:00 pm – 5:00 am), dawn (5:00 – 7:00 am), day (7:00 am – 5:00 pm), and dusk (5:00 – 7:00 pm). For each interval, I determined if there was a positive or negative relationship with number of detections or if the interval represented a transition period where both types of relationships were present. A positive relationship indicated an increase in fish activity while a negative relationship represented a decrease in fish activity. Results were displayed in a bar graph showing the frequency of each relationship for each time interval.

Results

Abundance from Trawling Data. Since I changed vessels during August 2007, I was only able to provide relative abundances of winter flounder for each year which cannot be compared between years. A total of 125 winter flounder were collected from Shinnecock Bay in 2007 and 2008 (Table 2.2). Approximately 20% were classified as adults (> 24 cm) while the remaining 80% consisted of small juveniles (5-14.9 cm, 41%), large juveniles (15-24.9 cm, 31%), and newly hatched YOY (< 5 cm, 8%). Winter flounder of varying sizes were collected in all survey months except April 2007 (Table

2.2). The month with the largest absolute catch and CPUE of winter flounder occurred during August of 2007, where 40 individuals were caught (Figure 2.4a, 2.5), 12 of which were greater than 24 cm (Table 2.2). However, this result must be taken with caution as this was the same month where a new vessel and gear was implemented to better survey the bay. After this change in July, the CPUE for all winter flounder increased in August (Figure 2.5). During 2008, CPUE peaked for all winter flounder during May, decreased until July, than increased during August (Figure 2.5).

Adult winter flounder were caught in May and August of 2007 and all of 2008 (Table 2.2). They were also present within Shinnecock Bay during warm summer months of 2007 when bottom water temperature ranged from 21-24°C (Figure 2.2). CPUE of adult winter flounder during 2008 remained below 0.5 fish per trawl with its highest value found during June of 0.4 fish per trawl (Figure 2.5).

Winter Flounder Tagging and Tracking. A total of 40 adult winter flounder were acoustically tagged starting in August 2007 (Table 2.3). Lengths of tagged fish ranged from 24 cm to 42.3 cm and averaged 32.0 ± 0.09 cm (standard error). Thirteen fish were tagged in 2007 with the remaining twenty seven tagged in 2008 (Figure 2.4b, c). In 2007, 62% of the adult winter flounder that were tagged came from August sampling. In 2008, 41% were captured during July, the last month tagging occurred (Figure 2.4b, c). A total of 94,250 valid detections were collected throughout my 18 receiver array. Active tracking was abandoned after 7 sampling days due to unreliable results when compared to preliminary stationary receiver data. Based on downloaded VR2W data, tagged fish were present in the area but were not picked up by the VR100. As winter

flounder may bury themselves in the sediment during inactive periods, the VR100 may have had difficulty detecting flounder.

Receiver CPUE: Receiver CPUE peaked at the end of May 2008 with 36% of receivers detecting a tagged fish. CPUE varied between 0.125 and 0.275 throughout the summer (Figure 2.6a). CPUE fluctuated between 0 and 0.1 during late 2008 and early 2009 due to a lack of detections anywhere within the bay. The number of detections per day peaked during mid-July (Figure 2.6b). Overall, 98.5% of the total detections were made between stations 6, 7, 8 and 9, a region we nicknamed the "hotspot." This area is relatively deep and consists mainly of eel grass beds and sandy patches. Station 9 was the most common core monitor as ten fish were most often detected within its range. As expected, the remaining receivers (stations 6, 7, and 8) within the "hotspot" were also core monitors for 34% of tagged fish.

Residency and Site Fidelity. Time series data of daily flounder presence collected over the entire study area shows variation in fish residency over 19 months (Figure 2.7). Out of the 13 fish tagged in 2007, 5 were detected throughout the study area in 2008 while one fish (#12) was picked up near the inlet in late 2007, but failed to exit the bay. Four of the five fish occurred in the "hotspot" with varying residency; fish #13 for 1 week in March, fish #18 from April to May, fish #40 between April and July, and fish #19 from May to September after visiting the Canal from March to April. The remaining fish (#14) left the bay via Shinnecock Canal in February.

In 2008, 23 out of the 27 tagged flounder were detected throughout the study area with some reoccurring in 2009. Three fish (24, 27 & 36) exhibited a short residency in the "hotspot" (< 2 weeks) before disappearing. Seven fish (3, 5, 25, 28, 30, 33 & 37)

exhibited longer residency (ranging from 1 to 5 months) within the "hotspot." One fish (#32) took a unique path and traveled back and forth between the southeastern corner of Shinnecock Bay and the "hotspot." Three fish (26, 31 & 35) exited the bay through the inlet within 1 week of being tagged while two fish (6 & 10) left after 2 weeks. Fish #1 remained in the hotspot for a month then traveled to the inlet but did not exit. Three fish (7, 8 & 23) were picked up near the inlet but did not exit the bay. Fish #4 also exited the bay in May but returned to the bay at the end of March, 2009. Out of the seven fish during this study which exited Shinnecock Bay, only one fish was not picked up on the northern receivers at the inlet. Two additional fish exited the bay but through different routes: fish #34 left through Shinnecock Canal in October while fish #39 traveled underneath Ponquogue Bridge and entered the western portion of Shinnecock Bay in November.

Total days a fish was detected averaged 22 ± 5.66 (S.E.) days and ranged between 1 and 132 days (Figure 2.8a). There was no significant difference in the total number of monitored days between small (< 30 cm) and large (≥ 30 cm) flounder (t-test, df = 27, P < 0.46). Continuous monitoring periods averaged 10 ± 2.96 (S.E.) days and ranged between 1 and 81 days (Figure 2.8b). There was no significant difference in the number of days a fish was continuously monitored between small (< 30 cm) and large (≥ 30 cm) flounder (t-test, df = 27, P < 0.35). The most common interval for both total and continuous monitoring time was 1-5 days. Residency indices for flounder detected throughout the study averaged 0.385 ± 0.06 (S.E.) and ranged from 0.008 to 1.0 (Figure 2.8c). To test whether residence time varied with fish size, residency index for each fish

was regressed against size. There was a significant relationship between fish size and residency index ($n = 29$, $a = -0.03$, $b = 1.43$, $r^2 = 0.3027$, $P < 0.002$).

Classification of Movements. Three types of migrations were apparent within this study: fish remaining within the bay for many months, an offshore movement through the inlet, and fish exiting via alternate routes such as Shinnecock Canal or underneath Ponquogue bridge (Figure 2.9; Appendix 2.1 A,B,C). Out of the 29 tracked fish, 52% remained within the hotspot for at least a week or repeatedly returned to the region. Eight fish were picked up on more than 1 "hotspot" receiver while most of the remaining fish revisited the same receiver. Five fish remained within the hotspot region for at least 3 months. Twenty-one percent of tagged fish traveled through the inlet while 17% were present near the inlet but failed to exit the bay. The remaining 10% of fish exited the bay through additional routes including Shinnecock Canal and underneath Ponquogue Bridge.

Day vs. Night Activity. Eight winter flounder were used in breakpoint analysis. The number of breakpoints present ranged from 5 to 1 (Figure 2.10). Five hours (2 & 9 am; 1, 5, & 7 pm) represented breakpoints for more than 1 fish. In addition, 9 am was the mode as this breakpoint showed up for 3 fish. Between the intervals of 12:00 – 5:00 am and 8:00 pm - 12 am, 5 fish and 4 fish, respectively, became more active. The remaining intervals (5:00 – 10:00 am; 10:00 am – 3:00 pm; 3:00 – 8:00 pm) represented periods where a majority of the fish (75%; 87.5%; 62.5%, respectively) experienced a decline in activity. Activity peaked around 5:00 am for 5 of the 8 fish. Figure 2.11 combines the results of all 8 winter flounder breakpoint analyses and explores the different relationships during time intervals. During night-time, transitions existed in 62.5% of fish as both increases and decreases in activity were observed. A negative relationship

between time interval and number of detections dominated most fish during dawn (62.5%), day (75%), and dusk (75%) resulting in a decrease in flounder activity. Although less common, an increase in flounder activity occurred in a few individuals during dawn and one individual at dusk.

Discussion

I have documented adult winter flounder occupying Shinnecock Bay during all seasons with a peak in abundance of tagged fish occurring during the summer. The majority of winter flounder acoustically tagged did not adhere to the commonly observed pattern of an autumn inshore migration followed by an offshore migration in spring. Most tagged fish remained in Shinnecock Bay with eighty-nine percent of the total detections occurring between May and October. The movement patterns of at least 5 fish are consistent with the historical notion of a separate stock of fish representing resident "bay fish" as these fish were detected in the bay during summer. Further, presence of winter flounder is confined to a small portion of Shinnecock Bay with many individuals observed migrating 1 km or less. Overall, winter flounder in Shinnecock Bay can be classified into three common movement patterns of fish including the following: (1) fish remaining within the bay, (2) fish heading offshore through Shinnecock Inlet, and (3) fish exiting the bay through alternative paths including Shinnecock Canal and underneath Ponquogue Bridge.

Adult winter flounder movement and inshore residency were investigated in this study using long-term passive tracking and seasonal trawl surveys, particularly during summer months. Most of my tagged fish were collected inshore between May and

August when bottom water temperatures reached 24°C. This finding contradicts previous studies regarding adult winter flounder movements south of Cape Cod. Winter flounder are thought to vacate warm shore zone waters when temperatures rise above 15°C (McCracken 1963; Howe and Coates 1975; Guelpen and Davis 1979; Phelan 1992, Hanson and Courtenay 1996). Many tagging studies have failed to catch adult winter flounder inshore during summer months while being inundated with adults during spawning in winter months (Saila 1961, Howe and Coates 1975; Phelan 1992). My study presented an opposing trend; I caught and tagged most adults inshore during summer months and only caught 1 adult during winter. Fish tagged during summer may have been "bay fish" while the remaining fish caught during fall/winter/spring were a combination of "offshore fish" visiting the bay to spawn and resident fish.

Flounder tracked during this study appeared to favor one particular region of the bay termed the "hotspot." Almost all fish were tagged within this region and spent varying amounts of time in range of receivers. Some fish even made multiple trips to the "hotspot" after visiting other regions of the bay such as the canal or inlet. Although these flounder were not tracked continuously during the year, I can assume they remained within the bay as they were not picked up on any receivers located at exits or they were captured. In 1937, Lobell suggested the existence of a resident population of winter flounder in Great South Bay and other south shore bays based on year-round tag returns. In the summer of 1968, Olla et al. (1969) found winter flounder (15 to 36 cm) in Great South Bay where bottom temperatures ranged from 17.2-24°C. My results indicate winter flounder in Shinnecock Bay, which repeatedly return to the hotspot, may be remnants of a historical inshore population. Those tagged flounder which tended to move

toward the inlet shortly after tagging may be members of the offshore stock. Those fish which left the bay through alternative paths may represent members of adjacent stocks. Fish heading through the canal may be members of a Peconic Bay stock while those traveling underneath Ponquogue bridge into Western Shinnecock Bay may continue west towards Quantuck Bay and Moriches Bay.

Adult winter flounder are certainly capable of withstanding temperatures warmer than 15°C by adapting to warm conditions, as supported by this and previous studies. Proposed adaptations include burial in sediment, reduced swim speeds, and inactivity (Olla et al. 1969; He 2003). Winter flounder can escape warm bottom waters by burying 6 cm into the sediment where temperatures remain roughly 4°C cooler (Olla et al. 1969). In addition to burying, winter flounder can reduce swim speed or become inactive to conserve energy (He 2003; Olla et al. 1969). Although winter flounder in Shinnecock Bay appear to tolerate warm waters, extreme temperatures combined with low oxygen levels can cause mass mortality events as observed in Moriches Bay, Long Island, in 1917 (Nichols 1918; Klein-MacPhee 2002). Historical data suggest that "bay fish" are vulnerable to high water temperatures commonly observed during summer months. Lethal temperatures for adult winter flounder range from 26.5°C to 28°C (McCracken 1963; Hoff and Westman 1966).

Data collected during this study was used to investigate winter flounder activity based on the number of detections divided into hourly intervals. Many fish decreased in activity from dawn till dusk in receiver locations. These fish may have relocated to feed or escape predation. Activity observed during daylight may be related to winter flounder feeding, as they are diurnal sight feeders (Pearcy 1962). Intermediate-sized flounder

have been shown to prefer lower light intensities than larger flounder (McCracken 1963). Six of the eight flounder examined were of an intermediate size and may have relocated to deeper water during daytime.

An interesting observation made throughout this study was the lack of tagged winter flounder in the "hotspot" from November to April with the exception of one fish. Many factors may be responsible for this sudden absence of flounder such as emigration to an unmonitored region of the bay, predatory events, or mortality. One possible explanation may include the presence of arctic seals in the bay. Harbor, grey, and harp seals enter the southern bays of Long Island during November and remain inshore until they depart in May (USFWS 1997). Throughout winter, seals were abundant and highly active in the "hotspot" region (pers. obs.). Investigation of the spatial interaction of seals and winter flounder may be an interesting topic for further research.

The appearance of these seasonal predators may be placing additional pressure on winter flounder numbers through predation. Unfortunately, there is an absence of literature describing seal diets in coastal waters within the northeastern US due to the difficulty in obtaining diet information. The only information regarding seal diets comes from the Atlantic coast of Canada and Europe. On Sable Island, grey seals primarily fed upon sand lance (*Ammodytes sp*.) and Atlantic Cod (*Gadus morhua*) with flatfishes (including winter flounder) accounting for 10% by weight (Bowen and Harrison 1994). In European waters, harbor seals have been observed feeding on moderate amounts of flatfish (Harkonen 1987; Hall et al. 1998; Berg et al. 2002). In these studies, various gadids accounted for the majority of the seal diets, but as the abundance of these finfish are low in Shinnecock Bay, winter flounder may make up a larger proportion of seal

diets. Historically, in Shinnecock Bay, flounder were abundant and provided a substantial food source for visiting seals.

Both active and passive tracking failed to capture a "dead fish" which stayed in the same location for multiple months without moving, although 11 tagged fish were never recorded. In a pilot study conducted in Port Jefferson Harbor on the north shore of Long Island for three months, the VR100 repeatedly detected a tagged fish at the same GPS location which I concluded was dead. In Shinnecock Bay, many fish which visited the "hotspot" were detected by more than 1 receiver. Those fish which were present only on one receiver tended to revisit that receiver multiple times throughout the year and were not consistently detected as would be expected if the fish died or the tag fell out. A study which implemented external tags on summer flounder, *Paralichthys dentatus*, concluded that 25% of their tags were lost based on no movement (Sackett et al. 2008).

My results provide supporting evidence that some winter flounder are year-round residents of Shinnecock Bay. However, residency within the bay was highly variable with some fish remaining in the hotspot for multiple months while others made multiple trips to the hotspot area. Additional research is needed to determine if winter flounder display partial migrations with resident and migratory fish in a single population or if "bay fish" and "offshore fish" represent separate populations. It is critical to determine the stock structure and migratory behavior of winter flounder on Long Island to determine the impacts of local harvest on the sustainability of the species. For example, if "bay fish" represent a separate genetic population, the seasonally more abundant "offshore" population may mask a long term decline of "bay fish" that once supported fisheries within the bays of Long Island (Lobell 1938). On the other hand, if "bay fish"

are a phenotype and winter flounder have partial migrations, the relative impact of harvest on “bay fish” and “offshore fish” can be complex (Gross 1991). These results provide insight into flounder movements in a coastal bay of Long Island which may help identify potential reasons for a general decline in winter flounder; however, much work remains to fully understand the stock structure of this species.

Table 2.1: Summary of station logistics including the number of fish detected per station, the number of detections, the periods that flounder were monitored using VR2Ws, and description of location.

Station Number	Number of Fish Detected	Number of Detections	Monitoring Period	Location
17	11	234	Aug 20 2007 - Dec 14 2008	Backside of Inlet
3	5	40	Aug 20 2007 - April 26 2009	Backside of Inlet
4	1	98	Dec 28 2007 - May 8 2009	Bridge
2	7	62	Dec 28 2007 – May 24 2009	Inside Inlet
1	3	15	June 1 2008 – May 24 2009	Inside Inlet
14	3	355	Jul 26 2007 - Apr , 2009	Marina
5	-	-	Mar 20 2008*	Open Water
6	4	55525	Mar 20 2008 - Apr 6 2009	Open Water
7	9	2665	Mar 20 2007 - Aug 28 2008*	Open Water
8	15	20498	Mar 20 2008 - Apr 6 2009	Open Water
9	17	14108	Mar 20 2008 - Apr 6 2009	Open Water
10	0	0	Jun 12 - Dec 14 2008	Open Water
11	1	36	Jun 12 - Dec 14 2008	Open Water
12	1	19	Jun 12 - Dec 14 2008	Open Water
13	1	10	Jun 12 - Dec 14 2008	Open Water
15	0	0	Jun 26 - Dec 14 2008	Open Water
16	0	0	Jun 26 - Dec 14 2008	Open Water
18	1	585	Jul 10 2008 - Aug 28 2008*	Open Water
Total		94250		

Note: * indicates the last date its receiver was located

Table 2.2: Descriptive statistics of winter flounder collected during stratified random surveys conducted in Shinnecock Bay during 2007 and 2008 by month. Note: The results below represent relative abundances and cannot be compared before and after the vessel and gear change in August 2007.

Year	Month	n_{total}	n_{adults}	L_{min} (cm)	L_{max} (cm)	L_{avg} (cm)	Temp (°C)
2007	April	0	0	0.0	0.0	0.0	-
	May	5	4	23.3	36.1	31.00 ± 2.30	10.44 ± 1.60
	June	6	0	3.7	22.7	13.22 ± 3.20	18.72 ± 0.49
	July	14	0	3.7	10.5	7.90 ± 0.53	21.79 ± 0.08
	August	40	12	7.3	40.5	20.20 ± 1.99	22.65 ± 0.18
2008	May	23	1	4	24.5	13.88 ± 1.11	N/A
	June	16	4	2.7	40.5	16.85 ± 2.90	N/A
	July	6	1	5.9	27.1	13.56 ± 4.16	N/A
	August	15	3	8.2	27.8	19.28 ± 1.48	N/A
		125	26				

n_{total} = total number of winter flounder caught; n_{adult} = number of adult winter flounder caught (fish larger than 24 cm were considered adults); L_{min} = minimum length; L_{max} = maximum length; L_{avg} = mean length; ± indicates standard error.

Table 2.3: Summary of tag information, total length, release date, date of last record, total number of detections, and presence at VR2W stations for each tagged winter flounder.

Fish No.	Tag ID	Length (cm)	Date Tagged	Last Detection	No. of detections	VR2W Stations
1	5453	37.5	5/29/2008	6/22/2008	62	1,6,7,8
2	5454	32.5	5/29/2008	-	0	
3	5455	38.0	5/29/2008	10/2/2008	1175	6,7,8
4	5456	32.0	5/14/2008	4/1/2009	128	2,17,8,9
5	5457	24.0	5/14/2008	6/12/2008	30	8,9
6	5458	25.0	5/14/2008	5/28/2008	2004	2,17,8,9
7	5459	33.0	5/14/2008	5/16/2008	26	17
8	5460	39.5	1/10/2008	5/7/2008	11	3,17
9	5461	28.0	4/11/2008	-	0	
10	5462	31.0	4/11/2008	4/26/2008	15	2,17,9
11	5464	30.0	11/1/2007	-	0	
12	5465	38.0	9/28/2007	11/1/2007	34	17
13	5466	34.6	9/28/2007	4/3/2008	8	7
14	5467	34.8	9/28/2007	2/12/2008	57	14
15	5468	40.0	9/28/2007	-	0	
16	5469	42.3	9/25/2007	-	0	
17	5470	40.4	9/8/2007	-	0	
18	5471	35.1	9/8/2007	5/30/2008	11	2,3,7,8,9
19	5472	35.1	9/8/2007	9/6/2008	2104	7,8,14
20	5475	38.4	9/25/2007	-	0	
21	5476	37.8	9/8/2007	-	0	
22	5326	35.7	9/8/2007	-	0	
23	50615	31.4	7/9/2008	7/15/2008	46	17,9
24	50616	26.5	7/9/2008	7/16/2008	102	9
25	50617	25.4	7/9/2008	11/30/2008	836	9
26	50621	27.0	6/27/2008	6/30/2008	36	1,2,3,17
27	50622	25.4	7/9/2008	7/10/2008	41	9
28	50623	27.1	7/9/2008	4/27/2009	1322	9
29	50624	28.5	7/28/2008	-	0	
30	50627	28.0	6/27/2008	8/13/2008	906	8
31	50629	26.0	6/27/2008	7/1/2008	1	1,17
32	50630	25.5	7/9/2008	7/16/2008	600	7,8,9,18
33	50631	27.1	7/28/2008	12/9/2008	4633	8,9
34	50634	40.5	6/27/2008	10/10/2008	8496	7,8,9,12,13,14
35	50635	29.0	6/27/2008	6/29/2008	99	2,3,8
36	50636	26.6	7/9/2008	7/29/2008	5069	8,9
37	50637	28.0	7/9/2008	8/16/2008	467	9
38	50639	26.2	7/9/2008	-	0	
39	50640	28.5	6/27/2008	11/15/2008	65,191	17,4,6,7,8,9,11
40	5477	38.8	9/25/2007	8/27/2008	734	17,6,7,8,9
	Mean*:	32.0±0.09	S.E	Total:	94250	

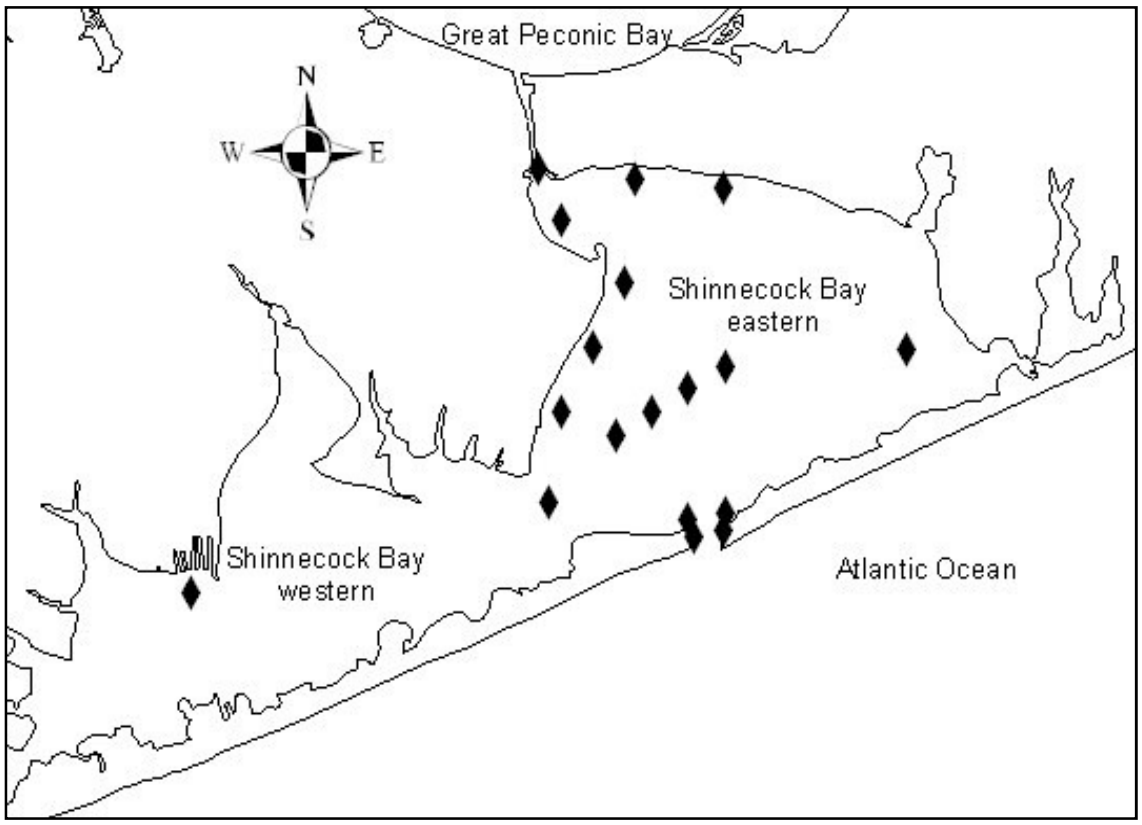


Figure 2.1: Map of the study area, Shinnecock Bay, New York. Black diamonds represent positions where acoustic receivers were submerged. Note: tracking was conducted in the eastern portion.

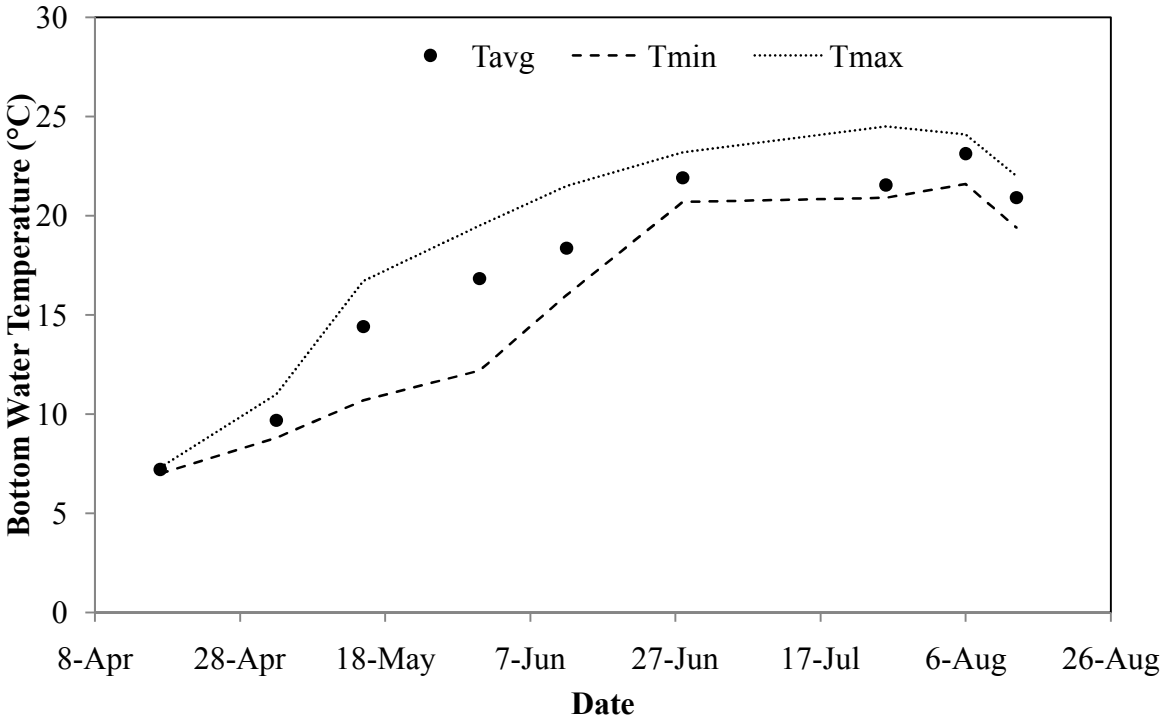


Figure 2.2: Bottom water temperature from Shinnecock Bay between April and August of 2007 where T_{avg} = mean temperature, T_{min} = minimum temperature, T_{max} = maximum temperature. Measurement of bottom water temperature was achieved by placing a weight on the YSI unit.

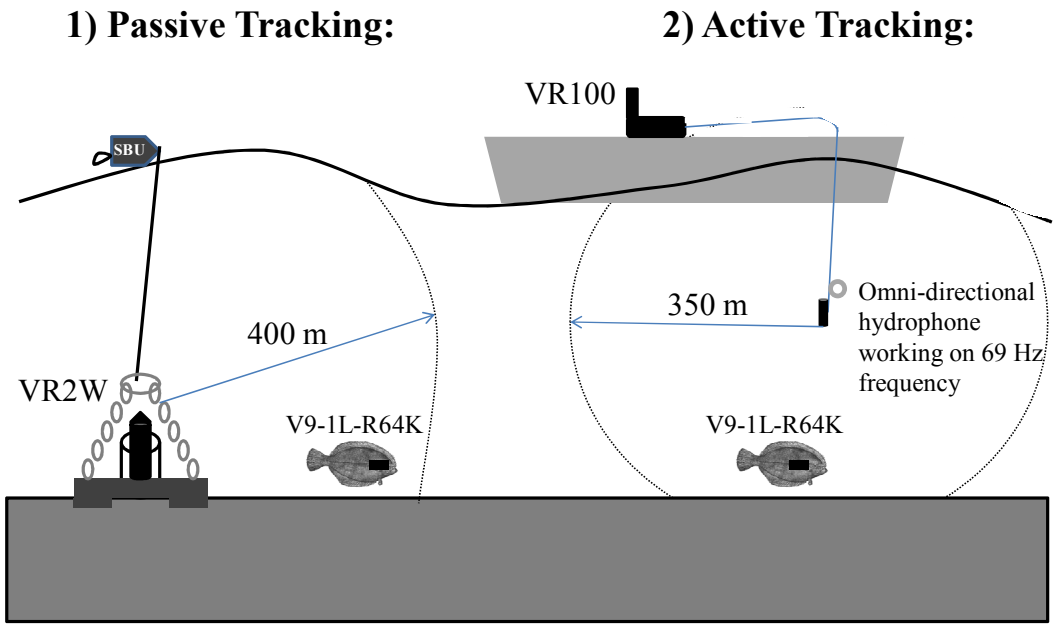


Figure 2.3: Schematic drawing of the two tracking systems (adapted from Yokota et al. 2006). The range for the VR2W was calculated for a 142 dB V9 coded pinger tag assuming calm wind speeds and is subject to change depending on conditions. The range of the VR100 unit was determined by a field test and is also subject to change depending on conditions. Black rectangle on fish represents acoustic tag.

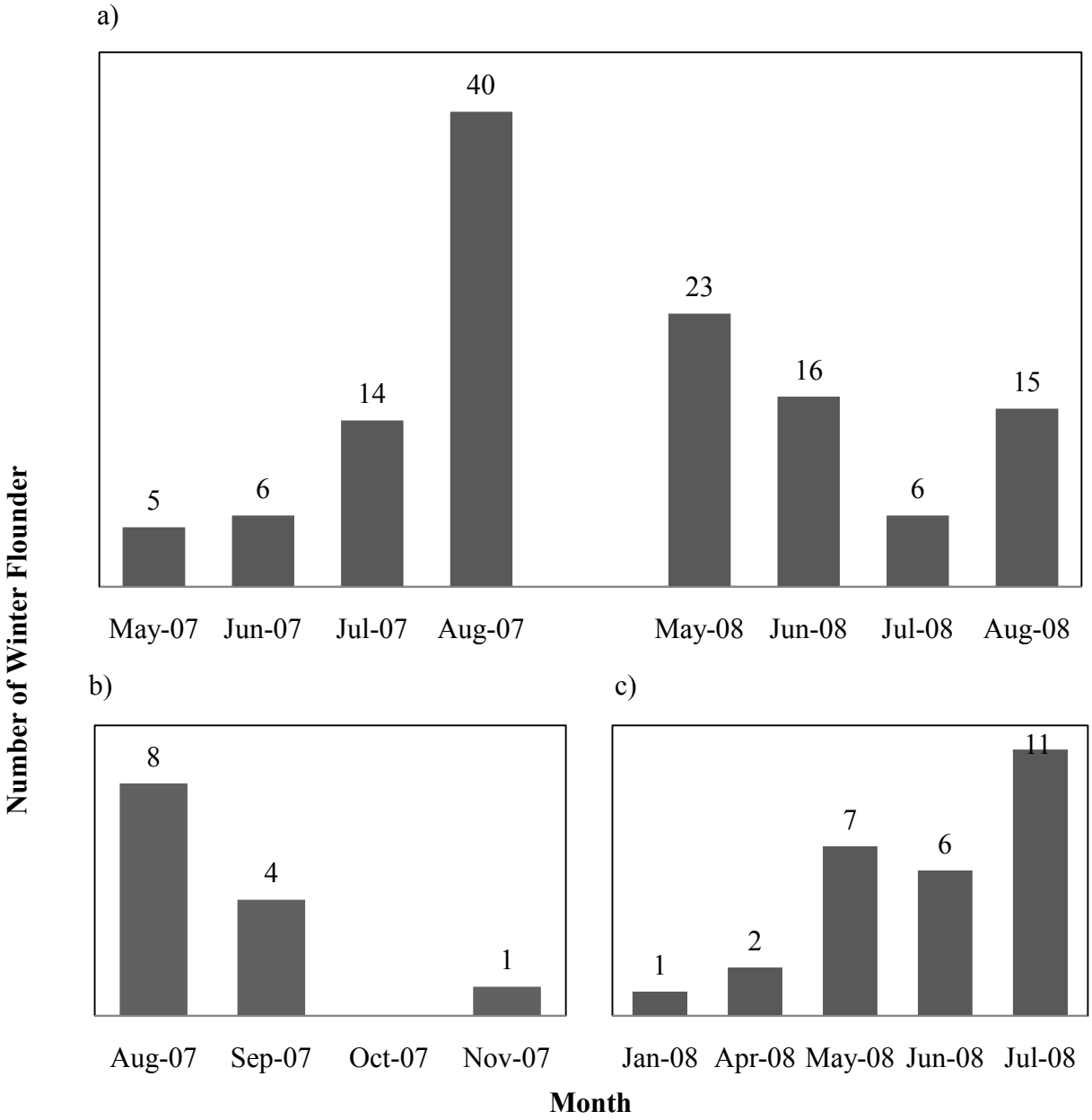


Figure 2.4: (a), *Total* number of winter flounder captured during stratified random surveys in 2007 and 2008 for all sizes; (b), number of *adult* winter flounder collected during survey and additional trawls for acoustic tagging during 2007; (c), number of *adult* winter flounder collected during survey and additional trawls for acoustic tagging during 2008.

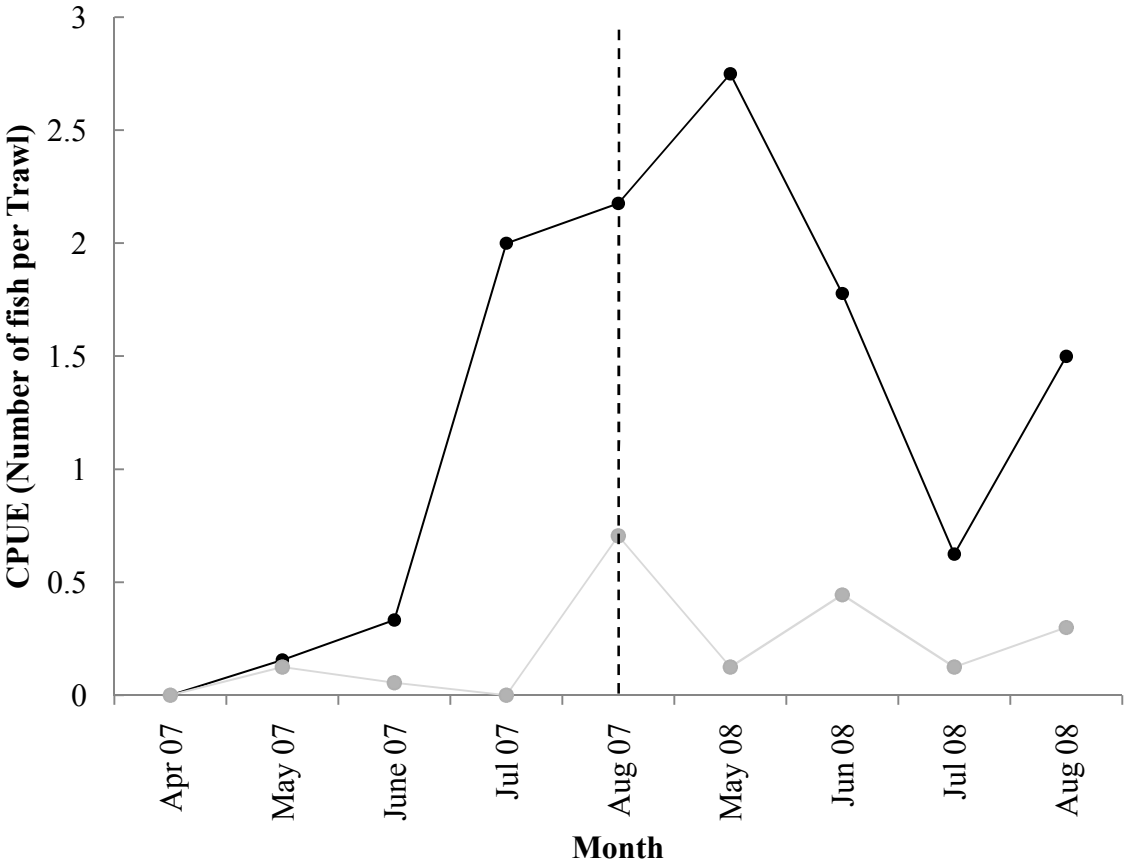


Figure 2.5: Catch per unit effort for winter flounder from stratified random survey in Shinnecock Bay, New York. Dark gray = all winter flounder; Pale gray = adult winter flounder. Vertical dotted line represents when vessel and gear change occurred.

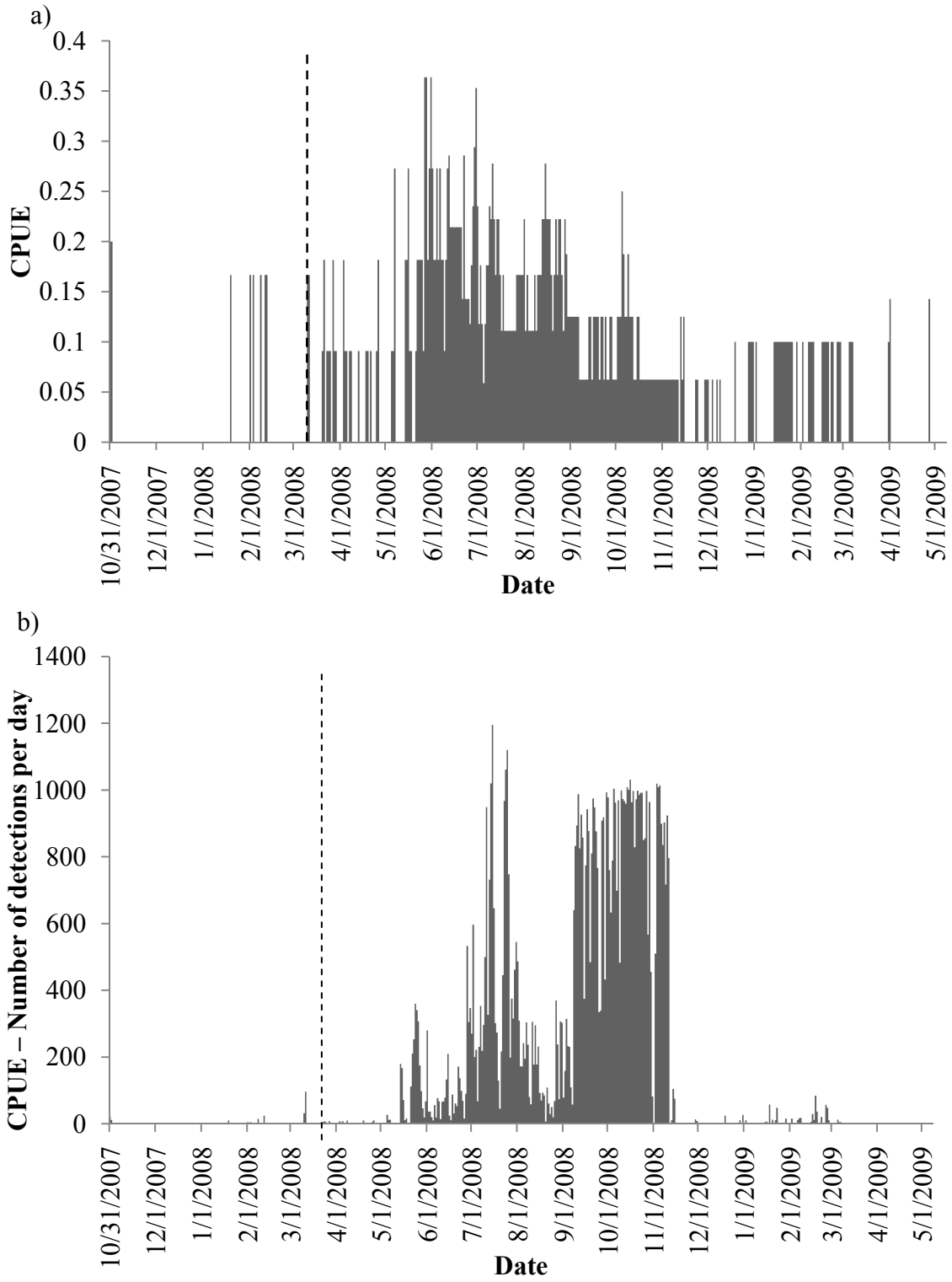


Figure 2.6: Catch per unit effort (CPUE) in terms of detections from VR2W receivers where CPUE is determined on a daily basis by dividing the number of receivers containing detections into the total number of active receivers on that date (a); and number of detections per day after accounting for differences between tag types and pinger delay (b). The dotted line represents the placement of VR2W receivers within the "hotspot" area.

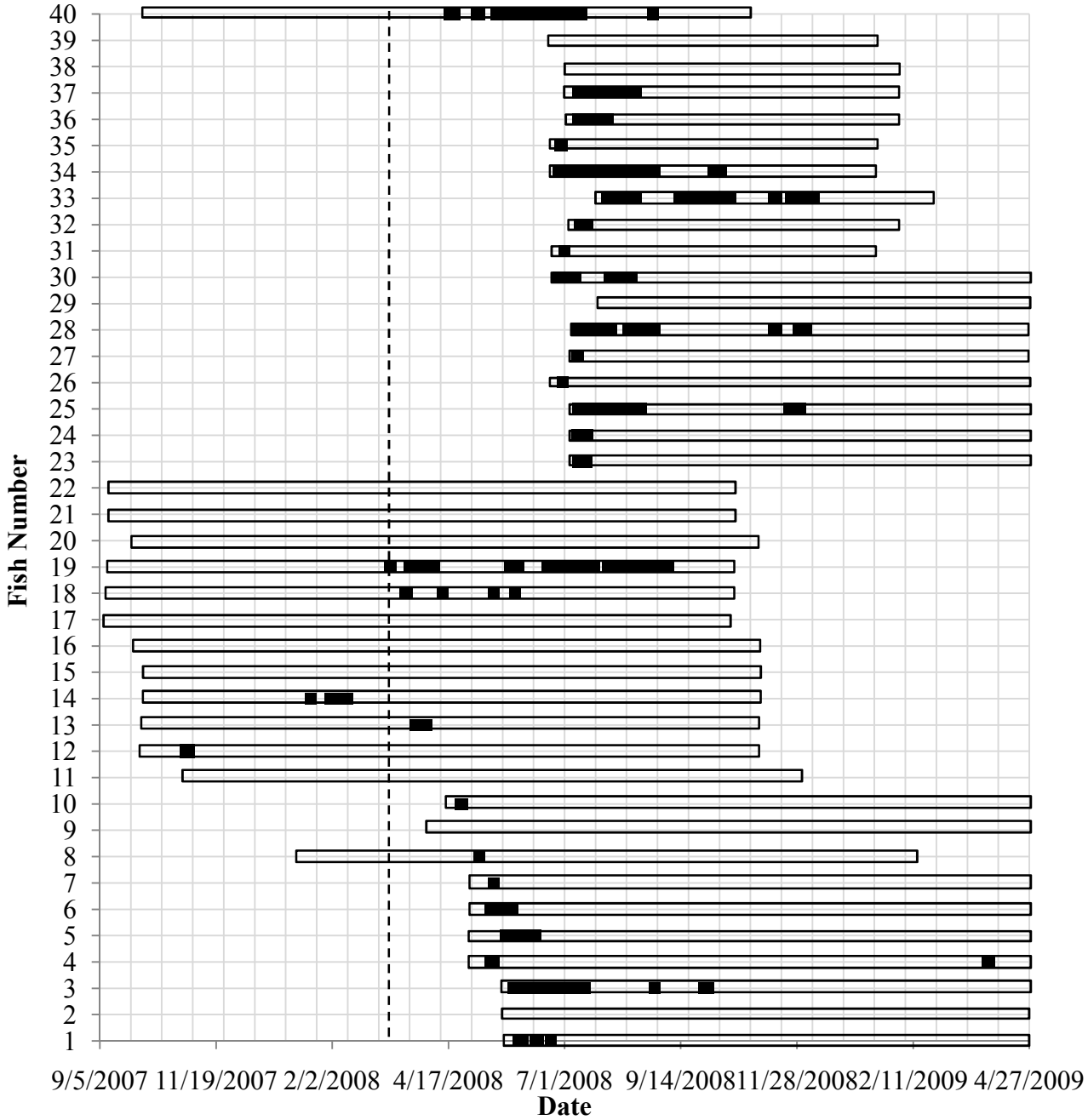


Figure 2.7: Time series of fish presence for all receivers in the study area. Rectangles indicate the interval a tag was active based on expected battery life. Black squares represent the days winter flounder were tracked. Dotted line represents the date where acoustic array was complete.

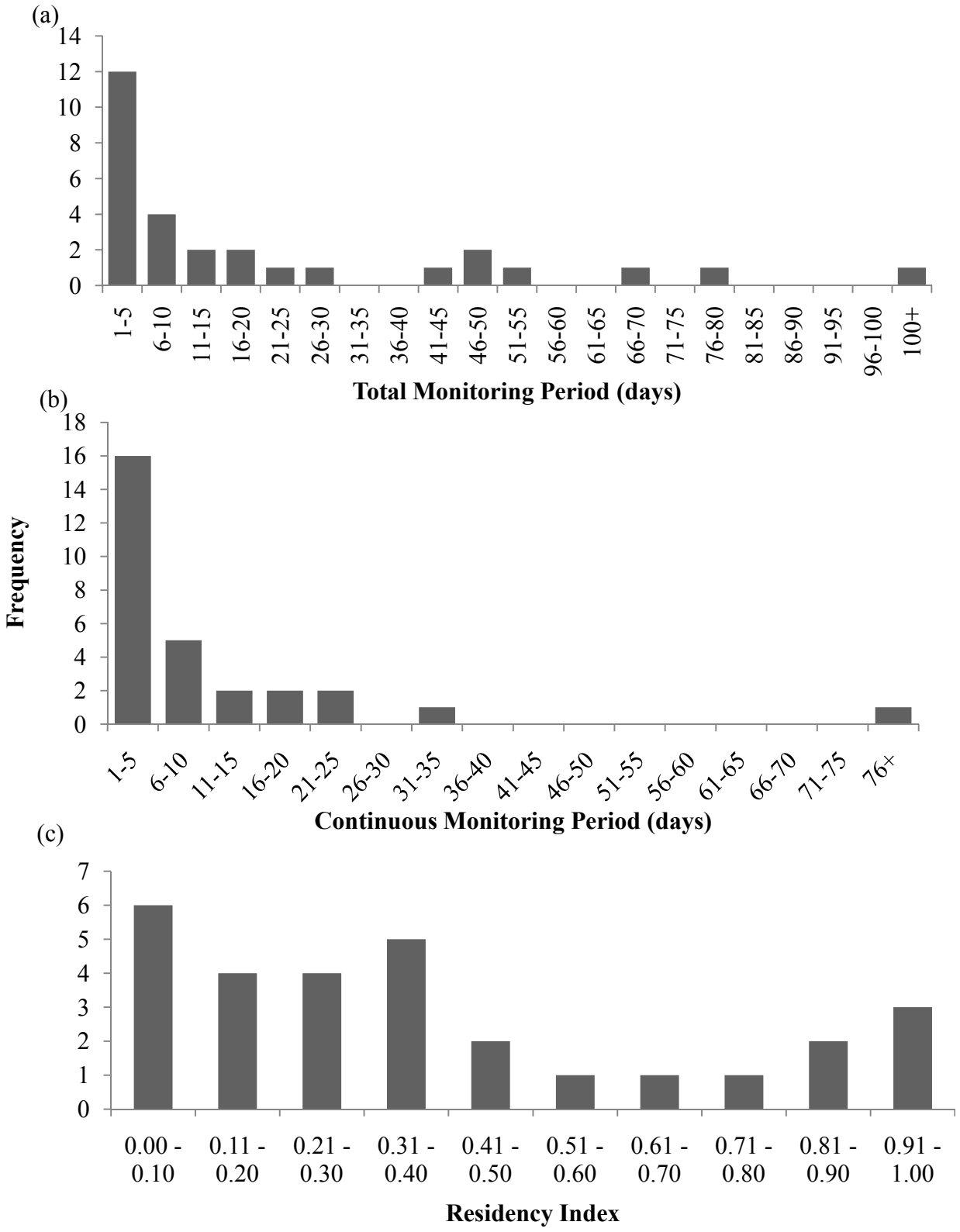
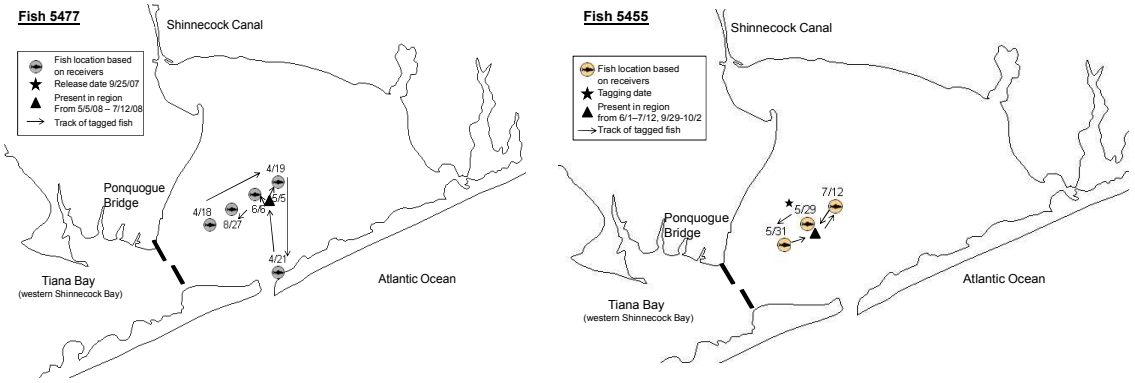
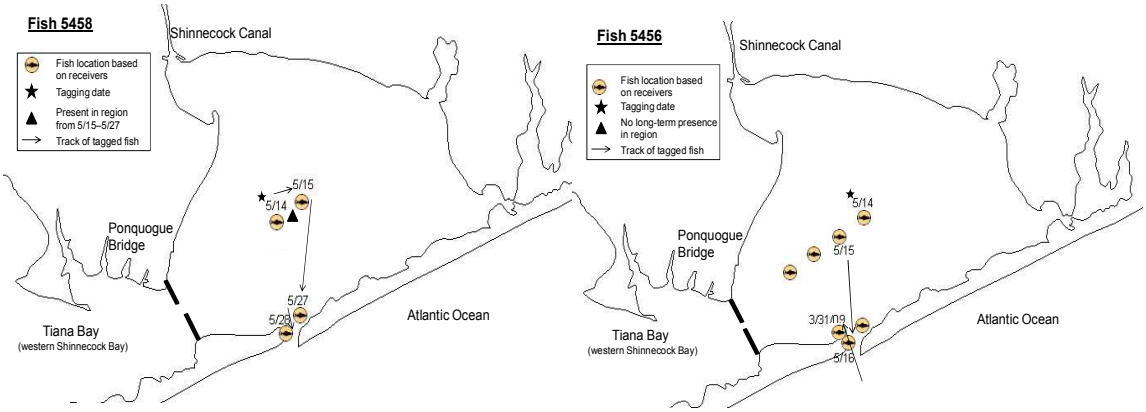


Figure 2.8: Frequency histogram of residency times for *Pseudopleuronectes americanus* monitored in Shinnecock Bay: (a) total monitoring period, (b) continuous monitoring period, (c) residency index.

a) Inner Bay Movements



b) Emigration to Offshore Water



c) Connectivity to Other Inshore Areas

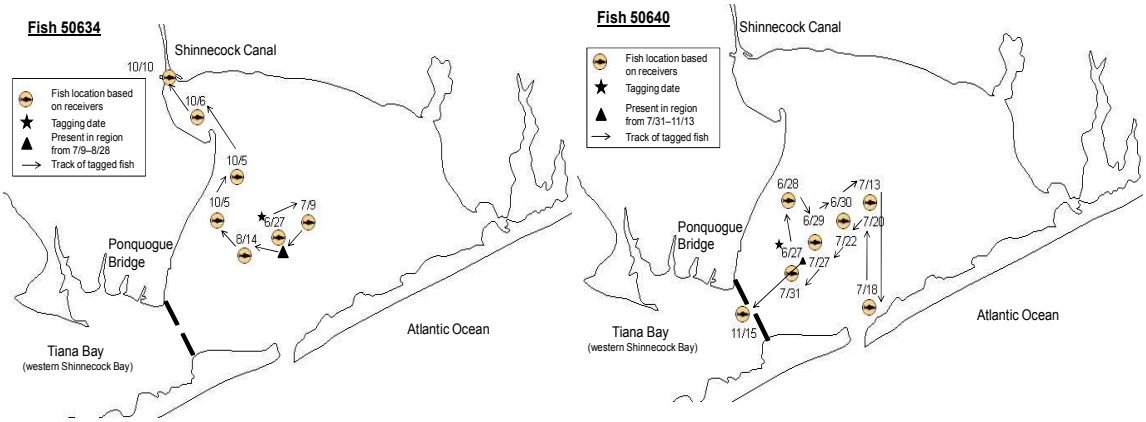


Figure 2.9: Tracks of 6 representative tagged fish during acoustic tracking in 2008 demonstrating (a) long-term inner bay movements, (b) Emigration to offshore waters and (c) connectivity to other inshore areas. Map courtesy of NOAA shoreline data.

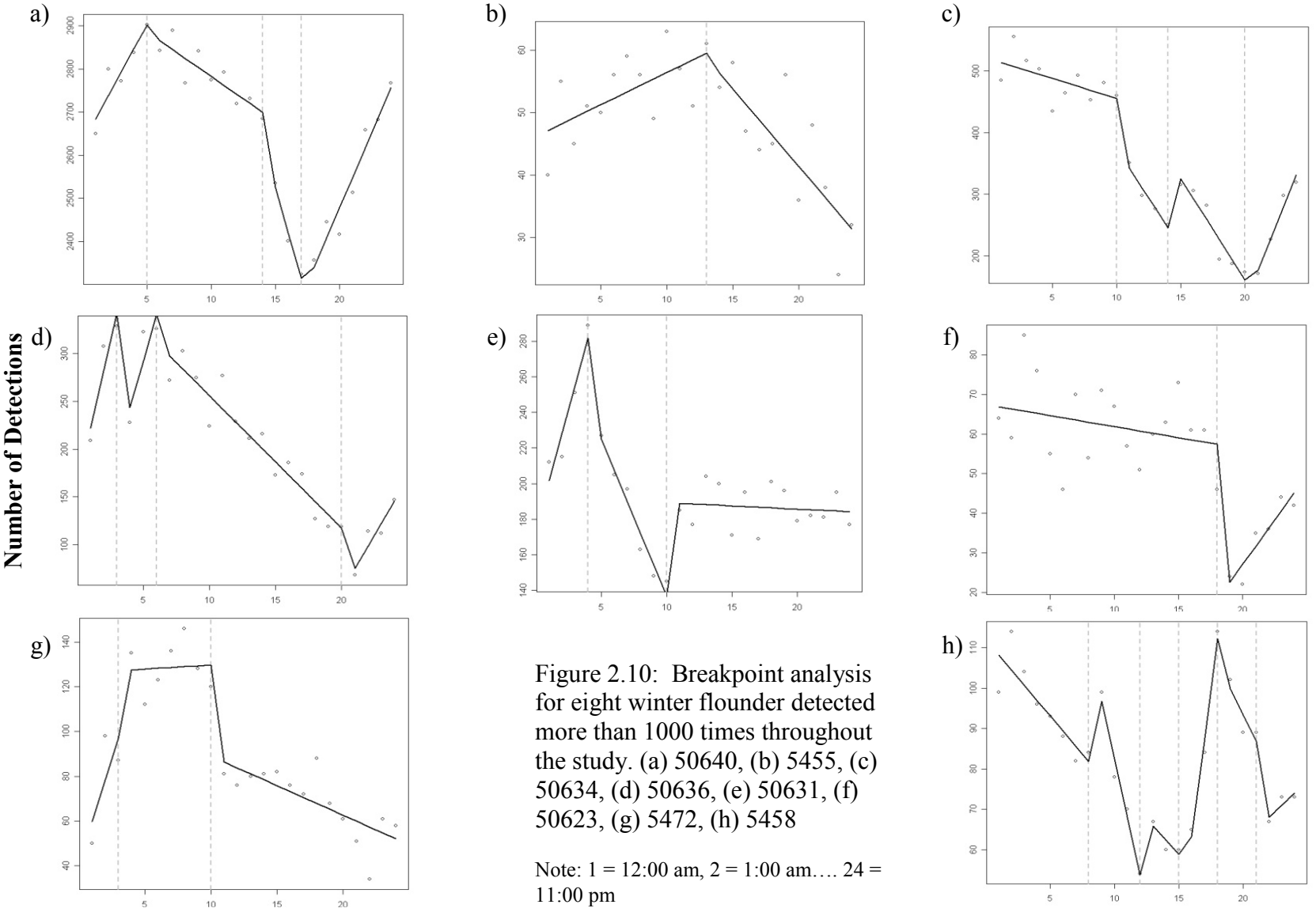


Figure 2.10: Breakpoint analysis for eight winter flounder detected more than 1000 times throughout the study. (a) 50640, (b) 5455, (c) 50634, (d) 50636, (e) 50631, (f) 50623, (g) 5472, (h) 5458

Note: 1 = 12:00 am, 2 = 1:00 am…. 24 = 11:00 pm

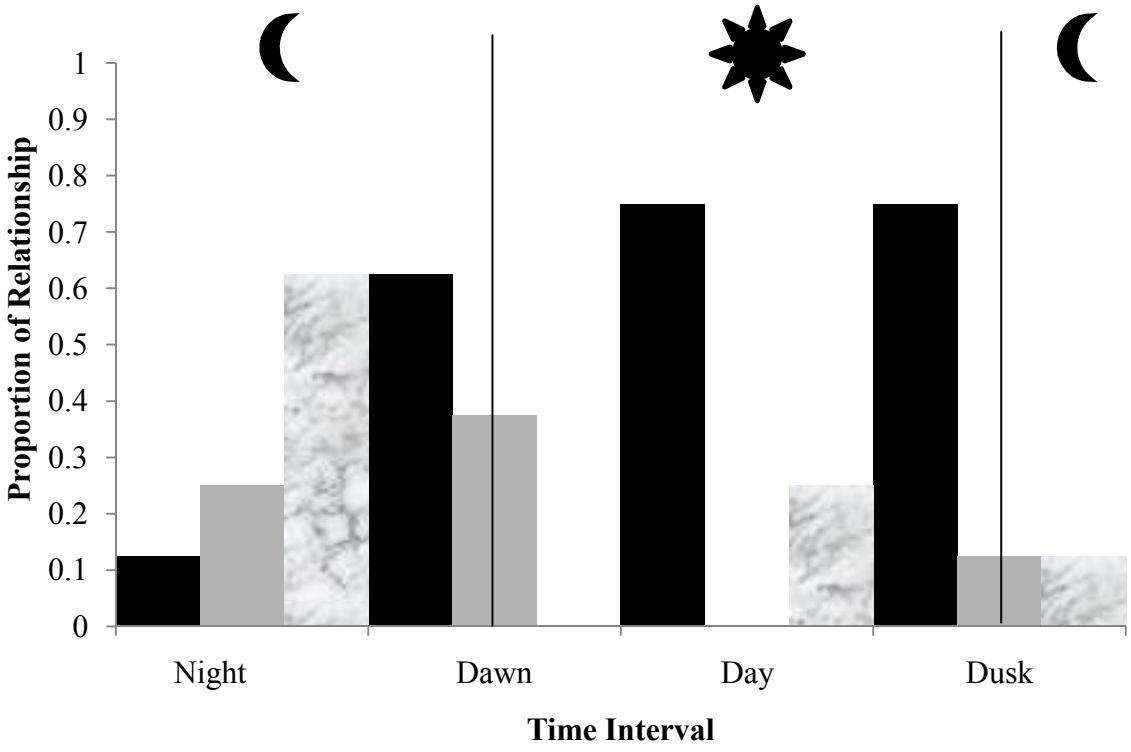


Figure 2.11: Proportion of Significant Relationships (Negative or Positive) and Relationships in Transition during Specified Time Intervals for Winter Flounder (> 1000 detections) based on Breakpoint Analyses. Black = negative relationship, Gray = positive relationship, White Marble = transitional relationships. Moon image indicates night-time while the sun image represents day-light between the 2 black lines.

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Chapter 3: The disappearance of young-of-the-year winter flounder, *Pseudopleuronectes americanus*, from the food web in Long Island Waters

Introduction

Winter flounder has been an important commercial species on Long Island, New York since the early 1900's (Hanlon 1983). The species was previously abundant along Long Island's 450 km of coastline (Engers and Buckner 2000) and supported substantial commercial and recreational fisheries. Winter flounder are targeted as a food source because they provide the thickest and meatiest fillets of flatfish found in the New York region (Klein-MacPhee 2002). In recent years, inshore winter flounder have become scarce in Long Island bays raising concern that they are becoming extirpated from local waters. Inshore recreational landings indicate that winter flounder catch peaked in the early 1980's and is currently less than 2% of peak levels (Socrates and Colvin 2006). Management has responded with a reduction in the fishing season to 2 months (Apr 1st – May 30th) and an indefinite closure is being considered for both recreational and commercial fisheries (ASMFC 2009). The mechanism(s) behind the decline of winter flounder in coastal bays of Long Island have not been elucidated; however, many factors are possible including overfishing, climate change, habitat degradation and predation.

Quantitative understanding of piscivorous predation on fish is critical for development of multi-species models and understanding ecosystem dynamics (Steimle et al. 2000). Development of food web models for use in ecosystem-based management depends on correctly identifying trophic dynamics of species and ecological guilds (Pauly

et al. 2000). Predation on juvenile flatfish has been documented in many studies (Pearcy 1962; Poole 1964; Witting and Able 1995; Manderson et al. 2000, 2004) and is believed to be the primary cause of juvenile flatfish mortality (Manderson et al. 2000). Winter flounder spawn and lay demersal eggs during winter and early spring (Klein-MacPhee 2002). As a result, their eggs may be preyed upon by benthic predators, such as crangonid shrimp and brachyuran crabs, which can occur in high densities and pose a significant threat to the survival of small, settling flatfish (Van Der Veer and Bergman 1987; Witting and Able 1995; Taylor 2005; Taylor and Danila 2005). After hatching, larvae become pelagic for approximately 60 days where they are exposed to a new array of predators such as the hydromedusa *Sarsia tubulosa* and pelagic fish predators (Pearcy 1962; Taylor 2005). Upon settling during late spring and early summer, YOY winter flounder become susceptible to decapod crustaceans, demersal fish, and avian piscivores (Manderson et al. 1999, 2000; Fairchild and Howell 2000; Taylor 2005). Most studies of early juvenile flatfish mortality have focused on crustacean predation (Fairchild and Howell 2000; Van der Veer et al. 2000; Breves and Specker 2002; Manderson et al. 2004; Taylor 2005; Taylor and Danila 2005). As flounder outgrow crustacean predators, they become more vulnerable to piscivorous fish (Manderson et al. 2004).

The interactions of piscivorous fish with YOY winter flounder have been examined extensively in the Sandy Hook Bay/Navesink River, New Jersey estuarine system (Manderson et al. 1999, 2000, 2004; Bowman et al. 2000). In this estuarine nursery, summer flounder (*Paralichthys dentatus*) are a main source of winter flounder mortality, particularly between April and June when their ranges overlap (Pearcy 1962; Able and Fahay 1998; Manderson et al. 2000; Taylor 2005). Lab studies have shown that

summer flounder prefer demersal winter flounder to pelagic fish and benthic invertebrates (Manderson et al. 2000). Sea robins are also capable of catching YOY winter flounder by using their finrays to search for and flush benthic prey from substrata (Manderson et al. 1999, 2006). A diet analysis by Manderson et al. (1999) found winter flounder in 69% of striped sea robin stomachs (*Prionotus evolans*) collected in the month of June from the Sandy Hook Bay/Navesink River estuary. In addition to summer flounder and striped sea robin, predation on YOY winter flounder has been documented for YOY bluefish (*Pomatomus saltatrix*), windowpane flounder (*Scophthalmus aquosus*), oyster toadfish (*Opsanus tau*) and striped bass (*Morone saxatilis*) throughout the northwest Atlantic (Poole 1964; Howe et al. 1976; Pereira et al. 1999; Manderson et al. 1999, 2000, 2006; Klein-MacPhee 2002).

My goal in this study was to investigate the predatory impacts of piscivorous fish on newly spawned YOY winter flounder and to assess the current contribution of YOY winter flounder to the food webs of coastal Long Island. We used otter trawls and beach seines to collect predatory fish for dietary analysis. Species chosen for analyses included summer flounder, YOY bluefish, striped sea robin, windowpane flounder, oyster toadfish, clearnose skate (*Raja eglanteria*), striped bass, and scup (*Stenotomus chrysops*). Specifically, for each predatory fish examined, prey items present in stomach contents were reported in terms of percent by number (%N), percent by weight (%W), percent frequency of occurrence (%O), index of relative importance (IRI), and percent index of relative importance (%IRI).

Materials and Methods

Study sites and field sampling. Fish were collected from three bodies of water around Long Island, New York: Port Jefferson Harbor, Great South Bay, and Shinnecock Bay (Figure 3.1). All three sites are important feeding and nursery grounds for winter flounder (Poole 1966; USFWS 1997a, 1997b, 1997c). Port Jefferson Harbor, located on the rocky north shore, contains many deep, cool channels and connects to Long Island Sound through a narrow inlet. It covers an area of approximately 4 km^2, has an average depth of 4.4 m, and experienced an average salinity of 26 ppt during the 2007 survey (Gross et al. 1972; USFWS 1997c). In contrast, Great South Bay and Shinnecock Bay, both situated on the sandy south shore, are barrier beach and lagoon estuaries with abundant salt marshes and tidal flats. Great South Bay is the largest saltwater bay in New York State, covering an area of 235 km^2 with an average depth of 1.3 m and has a single direct connection to the Atlantic Ocean through Fire Island Inlet (Wilson et al. 1991; Hinga 2005). The Bay is influenced by heavy riverine and groundwater flow and is characterized by salinity ranging from 25 – 30 ppt (Hinga 2005). Shinnecock Bay covers an area of 39 km^2, averages less than 2 m in depth, and has an average salinity of 30 (Green and Chambers 2007; Buonaiuto and Bokuniewicz 2008). It is connected to the Atlantic Ocean by an inlet which was carved during the hurricane of 1938. These three bays were divided into two categories for analyses: (1) north shore (Port Jefferson Harbor) and (2) south shore (Shinnecock and Great South Bays).

Sampling was conducted from April 2007 to October 2008. Fish were collected over a total of 53 days: 21 in Port Jefferson Harbor, 10 in Great South Bay, and 22 in Shinnecock Bay. Otter trawls and beach seines were employed to obtain fish from

different regions of each bay. These sampling gears were chosen as they provide more accurate estimates of food consumption by sampling both low-activity fish or "nonforaging" fish and actively feeding fish (Cortés 1997). A 9 m otter trawl (0.6 cm cod-end) was towed at 2.5 knots for 8 minutes (12 minutes in Great South Bay) and collected fish from the deeper areas and navigation channels of each bay. Trawl stations were randomly selected by dividing each body of water into numbered boxes of the same size and using a random number generator to determine which box would be sampled. A 61 m beach seine with 0.6 cm mesh allowed for collection of fish in the shallows of Port Jefferson Harbor and Shinnecock Bay. Beach seine stations were randomly selected from 500 m intervals along the perimeter of each site. Catch-per-unit-effort (CPUE) was calculated for each predatory fish to obtain an idea of abundance within the ecosystem. Due to the failure of the listed gears to obtain ample striped bass, hook and line fishing was employed in year two of the study. While five striped bass were collected in beach seines from Port Jefferson Harbor, additional samples were obtained from Moriches Bay (14 fish) and Montauk Point (4 fish).

Diet analyses. We compared diets of fish from north shore waters to those from south shore waters. Upon capture, the fish were immediately put on ice and placed in the laboratory freezer as soon as possible. In the laboratory, fish were thawed and measured for total length (mm) and weight (g). Stomachs were extracted and weighed (g) both before and after emptying the contents. The stomach fullness index (SFI) was calculated for each predatory fish by dividing the stomach content weight (SW) by the fish weight (FW) and multiplying it by 10 (Hureau 1969):

$$SFI = \frac{SW(g)}{FW(g)} \bullet 10$$

Each prey item was reported as a percent by number (%N), percent by weight (%W), and a percent frequency of occurrence (%O):

$$\%N_i = \frac{N_i}{N_{total}} \bullet 100$$

where N_i = number of i prey items;

$$\%W_i = \frac{W_i}{W_{total}} \bullet 100$$

where W_i = combined weight of i prey items;

$$\%O = \frac{S_p}{S_{total}} \bullet 100$$

where S_p = number of stomachs a specified prey item is found in and S_{total} = total number of

stomachs examined. An index of relative importance (IRI) was calculated for each prey item i by multiplying $\%O_i$ by the sum of $\%N_i$ and $\%W_i$ (Pinkas et al. 1971):

$$IRI_i = \%O_i(\%N_i + \%W_i)$$

In addition, IRI_i was converted into a percentage (%IRI) as suggested by Cortés (1997) to allow for comparisons to other studies:

$$\%IRI_i = \frac{IRI_i \bullet 100}{\sum IRI_i}$$

where IRI_i = IRI for i prey item.

All prey items examined were identified, weighed, counted, and measured when feasible. In the case of scup, only %W was reported due to their process of crushing prey and making enumeration difficult. The prey category 'Marine Plant Matter' (MPM) consisted of algae and seaweed while 'Terrestrial Plant Matter' (TPM) included tree branches and other fragments of terrestrial plants. The 'Nonliving Matter' included plastic debris and rocks, while the 'Unknown' grouping consisted of unrecognizable pieces. %IRI of prey items was graphed for each predator for visual recognition of dominating prey types.

YOY winter flounder specific predation. The impact of predation on YOY winter flounder by those fish selected for this study was quantified by calculating %IRI for winter flounder and comparing this value for each predatory fish examined.

Regional comparisons. The weights (g) of each prey item were used to perform a multivariate analysis of variance (MANOVA) to compare prey items among sites for each species and among species across all sites. A canonical discriminant analysis (CDA) was run using SAS treating the weight of each food category as the dependent variable and the sites/species as the treatments. For overall significance, we used the pillai's trace value because it tends to be the most robust test statistic to violations of multivariate normality.

Identification of prey and size. All prey items were identified to the lowest possible taxa and measured to the nearest millimeter when possible. Highly digested prey items required locating and identifying otoliths found in the gut using a photographic atlas of sagittal otoliths of the Northwest Atlantic Ocean (Campana 2004). For other prey items where only partial remains were present such as bay anchovies or

Atlantic silversides, the eye diameter or caudal peduncle length was used to estimate total length (Scharf et al. 1997). The relationship between the sizes of predators and their prey was examined using a least squares regression analysis (Scharf et al. 1998).

Results

Survey Results. Between April 2007 and October 2008, a total of 445 otter trawls and 260 beach seines were conducted (Table 3.1). Since 98% of predatory fish were captured in otter trawls excluding YOY bluefish (84% from beach seine) and striped bass (78% from hook and line), we present abundance estimates based on otter trawls. Figure 3.2 shows the abundance of predatory fish collected by otter trawl along with their respective average lengths. Scup, summer flounder, windowpane flounder, clearnose skate, oyster toadfish, and striped sea robin were chosen for dietary analyses based on abundance in otter trawls and a length distribution favoring large individuals. CPUE based on the trawling data is given for each species in Figure 3.3. Scup were the most abundant fish present in the trawl and experienced its highest CPUE in the north shore waters (Figure 3.3c). CPUE for summer flounder reached a maximum at 1.6 during July 2008 in south shore waters and 1.1 during May 2007 in the north shore waters (Figure 3.3e). Windowpane flounder, striped sea robin, oyster toadfish and clearnose skate were all less abundant and experienced low CPUE values ranging from 0 to 0.7 throughout the sampling period (Figure 3.3f,d,b,a).

Diet Analyses. Gut contents of 533 fish were examined to determine general diet patterns for each of the eight species. Descriptive statistics for each fish in my analysis are given in Table 3.2. Oyster toadfish and striped bass had the highest proportion of

empty stomachs at 36% and 35% respectively, while clearnose skate and striped sea robin had the lowest proportion of empty stomachs at 10% and 11% respectively. Of the eight species examined, scup had the highest average SFI while summer flounder had the lowest average SFI. Fifty-eight different types of prey were identified in this dietary analysis as shown in Appendix 3.1. All species were found to prey on distinct fish in varying amounts. Overall, twenty-four different species of fish were identified in the analyzed stomachs. Bluefish and striped bass fed primarily on fish while oyster toadfish, windowpane flounder, and clearnose skate rarely consumed fish (Figure 3.4). Figure 3.5 shows the total abundance of fish in trawls according to the 2007-2008 otter trawl survey and their abundance in stomach contents. The five most abundant fish in otter trawls were bay anchovy (*Anchoa mitchilli*), scup, Atlantic menhaden (*Brevoortia tyrannus*), Atlantic silverside (*Menidia menidia*), and butterfish (*Peprilus triacanthus*). Each was identified in one or more of the stomach contents of examined predatory fish as shown in Appendix 3.1. Bay anchovies were fed upon by summer flounder, YOY bluefish, and windowpane flounder; scup by summer flounder and striped sea robin; butterfish by summer flounder; Atlantic menhaden by YOY bluefish and summer flounder; and Atlantic silversides by all but oyster toadfish, scup, and windowpane flounder. Sand shrimp (*Crangon sp.*) contributed a large portion to the diets of all fish examined except bluefish and oyster toadfish (Figure 3.4). Crustaceans dominated the diets of summer flounder, windowpane flounder, striped sea robin, and clearnose skate. Summer flounder (Figure 3.6g) and striped sea robin (Figure 3.6f) preyed heavily on sand shrimp while mysid shrimp (*Neomysis sp.*) dominated windowpane flounder diets (Figure 3.6h) and rock crabs (*Cancer irroratus*) dominated clearnose skate diets (Figure 3.6b). Oyster

toadfish (Figure 3.6c) fed primarily on marine plant matter. The diet of scup was dominated by clams, most from the genus Gemma (Figure 3.6d). YOY bluefish fed mainly upon Atlantic silversides and Atlantic menhaden (Figure 3.6a) while striped bass fed on age 1+ summer flounder (Figure 3.6e).

YOY winter flounder specific predation. Predation on YOY winter flounder was documented in four of the eight species examined including summer flounder, striped bass, striped sea robin, and YOY bluefish (Table 3.3). During 2007, two winter flounder were consumed in June (one from the north shore by a striped sea robin and one from the south shore by a summer flounder), two in July (both from the south shore, one by a YOY bluefish and one by a summer flounder), and three in August (all three were consumed by summer flounder from the south shore). For 2007-8, low %IRI values (ranging from 0 to 0.410) indicate that YOY winter flounder contributed little to the overall diet of the species studied. During 2007, YOY winter flounder contributed more to predator diets than in 2008 (Table 3.4). Only 1 event of predation on YOY winter flounder was found during 2008. This predator was a striped bass from Moriches Bay.

Regional comparisons. A MANOVA was used to test for differences in the weights of prey items between sites. The test was limited to three of the eight species examined due to inadequate sample sizes for both regions sampled. Bluefish, summer flounder, and windowpane flounder were examined for differences in prey items between sites (Table 3.5). No significant difference between diet compositions between sites was detected in summer flounder ($P < 0.3132$) or windowpane flounder ($P < 0.1377$) while a significant difference was detected for bluefish ($P < 0.0001$). The resulting univariate test statistics indicate that a significant difference occurred in bluefish diet composition

for bay anchovy ($P < 0.0025$), sand shrimp ($P < 0.0222$), and Atlantic silverside ($P < 0.0001$). A separate MANOVA was performed to test for differences in the weights of prey items between all eight species pooled over all regions. The test revealed a significant difference between the diet compositions of all predators ($P < 0.0001$). The univariate test statistics indicated that a significant difference occurred in 25 of the 58 prey items (Table 3.6).

Identification of Prey & Size. Summer flounder length was regressed with the length of the following prey items: Atlantic silverside, blue mussel, rock crab, sand lance, sand shrimp, winter flounder and bay anchovy. A significant regression occurred between the lengths of summer flounder and rock crab ($n = 51$, $a = 0.093$, $b = -2.359$ $P < 0.000$, $r^2 = 0.414$) (Figure 3.7a), summer flounder and sand shrimp ($n = 116$, $a = 0.036$, $b = 1.663$, $P < 0.000$, $r^2 = 0.113$), and summer flounder and bay anchovy ($n = 23$, $a = -0.101$, $b = 7.706$, $P < 0.005$, $r^2 = 0.325$). No significant trends were estimated for YOY bluefish length and the lengths of bay anchovy and Atlantic menhaden. A weak positive relationship was estimated between Atlantic silverside length and YOY bluefish length ($n = 104$, $a = 0.206$, $b = 0.560$, $P < 0.005$, $r^2 = 0.075$). Similarly, linear regression of clearnose skate length was significantly related to rock crab length but explained little of the variance ($n = 70$, $a = 0.070$, $b = -2.312$, $P < 0.012$, $r^2 = 0.089$). No significant trends were observed for lengths of clearnose skate compared to sand shrimp length. The relationship between striped sea robin and sand shrimp length was significant, but weak ($n = 208$, $a = 0.084$, $b = 0.296$, $P < 0.000$, $r^2 = 0.149$) (Figure 3.7b). There was no significant regression between windowpane flounder and either sand shrimp or mysid shrimp.

Discussion

Dietary habits of common piscivorous fish in Long Island bays indicate that winter flounder are currently not an important food source. Winter flounder, once an abundant prey item in stomachs of piscivorous Long Island fish (Poole 1964; Schreiber 1973), contributed less than 0.5% to the %IRI and 1.6% to the %W for the diets of summer flounder, striped sea robin, striped bass, and YOY bluefish and were absent from the diets of oyster toadfish, clearnose skate, scup, and windowpane flounder. Although minimal, consumption of YOY winter flounder was documented between June and August. The diets of fish differed, with YOY bluefish and striped bass preferring fish, oyster toadfish preferring marine plant matter, scup preferring bivalves, and the remaining four fish feeding heavily on crustaceans. In Long Island bays sand shrimp (*Crangon sp.)*, Atlantic silversides (*Menidia menidia*), and rock crabs (*Cancer irroratus*) dominated the diets of piscivorous fish.

Historically, YOY winter flounder has been an important prey item in the coastal waters of Long Island (Poole 1964). However, in my study only 1.5% of the total number of predator stomachs examined contained a YOY winter flounder, making them a rare prey item. During the late 1950's, Poole (1964) examined the feeding habits of 1210 summer flounder and found winter flounder to be the second most important prey item in Great South Bay based on %W (27.8%) and the fourth most important prey item based on %O (7.4%). Examination of 97 summer flounder stomachs in my study from the south shore indicates a drastic decrease in %W of YOY winter flounder to 2.4% and a slight decrease in %O to 5.2%. In the late 1980's, YOY winter flounder occurred in 2.1% of

YOY bluefish stomachs (n = 424) examined from Great South Bay and accounted for 11% of the total weight of prey items (Juanes and Conover 1995). YOY bluefish from the south shore during my study appeared to feed less frequently (1.1%) on YOY winter flounder and accounted for only 1.5% of the total weight of prey items.

Current estimates of the contribution of YOY winter flounder to the diets of piscivorous fish in the Long Island region are lower than nearby river systems and estuaries. In the Hudson-Raritan estuary, New York, Steimle et al. (2000) found winter flounder relatively common in the diets of skates (clearnose, little, and winter) and in striped bass stomach contents. Predation on YOY winter flounder is fairly common in the nearby estuarine habitat of Sandy Hook Bay/Navesink River, New Jersey (Manderson et al. 1999, 2000, 2006; Scharf et al. 2004). Manderson et al. (2006) examined diet contents of piscivorous fish from 1998 – 2002 and found a %O of juvenile winter flounder ranging from 6.9% to 33.3% for striped sea robin, 11% to 41.2% for summer flounder, 0% to 3.8% for striped bass and 0% to 1% for bluefish. In the present study, YOY winter flounder occurred less frequently in striped sea robin diets (2.78%) and summer flounder diets (3.55%) and obtained similar %O values for striped bass at 4.3% and bluefish at 0.5%. Manderson et al. (1999) found an average of 3 ± 0.6 winter flounder per striped sea robin stomach and a maximum of 11 winter flounder found in a single stomach whereas we found a single YOY winter flounder in 1 of the 36 sea robin stomachs examined. In 1999, Manderson et al. (2000) found YOY winter flounder in 27% of summer flounder stomachs, with as many as 11 YOY present in a single stomach. In contrast, we found YOY winter flounder in 3.5% of summer flounder stomachs and

found a maximum of 1 YOY winter flounder per stomach, a result which may reflect regional differences in abundance of YOY winter flounder between regions.

Contribution of YOY winter flounder to the diets of piscivorous fish appear related to abundance. During the 1950's, winter flounder were abundant in the south shore bays of Long Island and consequently in stomach contents of piscivorous fish (Poole 1964). In recent years, a decrease in winter flounder in the Long Island ecosystem appears to have diminished their importance as a prey item. Survey abundance of YOY winter flounder from both Shinnecock Bay and Port Jefferson Harbor shows that 2008 was a period of lower abundance compared to 2007 (Yencho and Frisk *in prep*). YOY winter flounder CPUE based on the beach seining survey declined from 1.69 in 2007 to 1.34 in 2008 for Shinnecock Bay and from 7.59 in 2007 to 1.00 for Port Jefferson Harbor (Yencho and Frisk *in prep*). Presence of YOY winter flounder in predator stomach contents probably mimics this abundance trend, with more YOY predation occurring in 2007 and a single predation event in 2008 (Table 3.5). As YOY winter flounder become less abundant in the environment, the probability of a predatory event is reduced. Therefore, absence of YOY winter flounder from 4 of 8 species examined and decreased contribution to the diets of primary predators reflects a decline in the winter flounder from Long Island bays.

Summer flounder exhibited the most diverse diet, consuming 37 different types of prey, 15 of which were fish species. No significant difference in the weight of prey items was detected between summer flounder in the north and south bays (Table 3.5). In both regions, diets were dominated by sand shrimp and other crustaceans. A similar dominance of sand shrimp is observed in estuaries throughout the mid-Atlantic. In the

Hudson Raritan estuary, Steimle et al. (2000) examined 229 summer flounder stomachs and found sand shrimp exhibited a %O of 49.5%. In New Jersey, Manderson et al. (2000) examined 55 stomachs and found sand shrimp contributed 30% by volume. In Great South Bay, Poole (1964) examined 1210 summer flounder stomachs and found that sand shrimp dominated in terms of %W (30%). In contrast to other summer flounder diet studies, we found mantis shrimp to be the third most important prey item, possibly reflecting a relative high abundance in Long Island bays.

Striped sea robin proved to have one of the most consistent diets by feeding almost entirely on sand shrimp. Since sand shrimp tend to partially bury in sandy/silty bottoms, they are vulnerable to the modified pectoral fins of striped sea robins which are used to search and flush out prey items from the sediment (Manderson et al. 1999). A comparable result was found in the Hudson-Raritan estuary where sand shrimp occurrence ranged from 50% to 96.2% between July 1996 and November 1997 in striped sea robin diets (Steimle et al. 2000). In the Sandy Hook Bay/Navesink River estuary, sand shrimp are common in sea robin diets during June whereas mysid shrimp become more important in July and August (Manderson et al. 1999). A different result was observed in Long Island Sound by Richards et al. (1979) who concluded that crabs were more abundant in striped sea robin stomachs than sand shrimp (38.97%N and 25.38%N, respectively).

The diet of windowpane flounder also consisted mainly of crustaceans, but in contrast to the importance of sand shrimp seen in summer flounder and striped sea robin, mysid shrimp were the most important prey item. As observed with summer flounder, no significant difference in the weight of prey items was detected between windowpane

flounder in the north and south bays (Table 3.5).Mysid shrimp cluster near the sea floor during daylight due to their negatively phototaxic nature and, as a result, are vulnerable to demersal predators (Steimle et al. 2000). Windowpane flounder have a small gape size, or distance between the maxillary bones in the mouth interior, which favors the consumption of mysid shrimp as they only reach about 2 cm in length. When the In the Hudson-Raritan estuary, windowpane flounder feed heavily on mysid shrimp (65.9%O) but also consume modest amounts of sand shrimp (31.7%O) (Steimle et al. 2000).

The examination of YOY bluefish proved very different from all other fish for two reasons: first, a significant difference between the weights of prey items from each location was found (Table 3.5), and second, bluefish preferred fish such as Atlantic silversides and Atlantic menhaden to crustaceans (Figure 3.5). Prey items including bay anchovy, sand shrimp and Atlantic silversides had greater weights in the bays of the south shore compared to the north shore. Out of 19 types of prey identified, fish, particularly Atlantic silversides, were the most common prey type in bluefish stomachs with 9 additional fish species observed less frequently. Bluefish and Atlantic silversides are both present inshore during early spring and remain abundant during summer months, making silversides vulnerable to piscivorous YOY bluefish (Juanes and Conover 1995). My study also identified Atlantic menhaden as an important prey item, but not to the same extent as observed in the Sandy Hook-Navesink River estuary (Scharf et al. 2004). In contrast to previous studies, we seldom found sand shrimp in bluefish stomach contents. Juanes and Conover (1995) examined diet composition of spring-spawned bluefish in 1988 and 1989 from Great South Bay and concluded both sand/grass shrimp

(ranged from 21.73 %W in ’89 to 49.5%W in ’89) and Atlantic silversides (ranged from 22.3%W in ’89 to 38.4%W in ‘88) were important prey items.

This study is the first documentation of the diet of adult scup in inshore waters. Instead of teeth, scup have hard plates designed for crushing prey. Therefore, the difficulties in enumerating individual prey items limited my results to %W. Mollusks, mainly clams, were the most abundant prey item consumed by adult scup with fewer specimens consuming polychaetes. Previous studies conducted in offshore waters in both southern New England and the Middle Atlantic Bight reported adult scup feeding mainly on polychaetes and amphipods between 1981 and 1990 (Steimle et al. 2000). Diets of juvenile scup from inshore waters have been investigated in the Hudson-Raritan estuary. Steimle et al. (2000) examined 254 scup ranging from 8 cm to 24 cm FL and determined the three most common prey items to be unidentified organic matter (35.8%O), mysid shrimp (32.3%O), and bivalve mollusk remains (14.3%O). For scup, although we had an adequate sample size (n = 69), almost all were collected from the north shore (61 out of 69) and did not warrant a comparison between regions.

The energetic demands of upper trophic finfish occurring in Long Island Bays are dominated by crustaceans and to a lesser extent fish. Based on %IRI, crustaceans appear to be the most important prey category as they dominate the diets of windowpane flounder (99.9%), striped sea robin (99.6%), clearnose skate (99.0%), and summer flounder (76.1%). Specifically, sand shrimp are a key prey item within this system as they are preyed upon by seven of the eight species and are the main prey for striped sea robin and summer flounder and the second most important prey item for clearnose skate and windowpane flounder. Fish were also preyed upon by all species but were less

important than crustaceans. YOY bluefish (96.8%IRI) and striped bass (48.8%IRI) fed primarily on fish, with Atlantic silversides contributing most to the bluefish diet and juvenile (ages 1+) summer flounder most important for striped bass. Atlantic silversides were rarely preyed upon by summer flounder, clearnose skate, striped bass, and striped sea robin.

Overall, 6 of the 14 linear regressions between the length of a predator and individual prey were found to be significant, although many represented a weak relationship. Five of these significant regressions were found to be positive relationships, meaning as predator length increases, they consume larger prey. As striped sea robins increase in length their gape size also increases which, in conjunction with their stronger pectoral fins, allows them to capture and ingest larger prey. As clearnose skate size increased, they appeared to consume larger rock crabs. Clearnose skate are also limited by their gape size, so smaller individuals may be prevented from consuming large rock crabs. In addition, large skates may focus their energy on capturing larger prey due to increased payoff in the size of their food. Summer flounder length was regressed against a number of prey items but only the relationship to rock crab, sand shrimp and bay anchovy lengths were significant. In my study, summer flounder appears to feed heavily on small crustaceans and juvenile bay anchovies. To compensate for feeding on smaller prey items, they consumed many at a time. There are energetic tradeoffs amongst species feeding on either more abundant smaller prey items or less abundant, larger prey items (Magnhagen 1985; Scharf et al. 2000). Combinations of predator and prey size, number, morphology and behavior influence the most energetically efficient foraging tactics. We are uncertain of the causes for certain species favoring abundant smaller prey and others

favoring less abundant larger prey, but this is an issue that deserves further study. In contrast to the previous fish that appeared to increase in size with their invertebrate prey, YOY bluefish were found to increase in size with Atlantic silversides. YOY bluefish eat large concentrations of fish within their first year and grow rather quickly, reaching about 22 cm by the end of their first year (Klein-MacPhee 2002).

This study presented evidence of a decline in YOY winter flounder consumption by piscivorous fish throughout Long Island bays, likely as a result of the decline in abundance of YOY winter flounder. In recent years, an increase in YOY winter flounder recruitment to settlement has been documented (Socrates and Colvin 2006). However, the high abundance of newly settled winter flounder has translated into a low abundance of YOY (Yencho and Frisk *in prep.*), which suggests an increase in mortality of newly settled winter flounder. The mechanism(s) behind the change in abundance warrant further investigation. In Long Island bays, a decrease in abundance of newly settled winter flounder may be attributed to additional predators not thoroughly examined in this study such as striped bass, weakfish, and crustaceans. Since the food webs of Long Island bays are highly populated by crustaceans that feed upon YOY winter flounder in other estuaries along the northeastern Atlantic coast, dietary analyses should be undertaken to determine the impact of crustacean predation on YOY winter flounder.

My results suggest that the loss of important prey species such as winter flounder impacts the diet of other important ecological and economic species. An overall decline in winter flounder abundance throughout the past few decades has forced piscivores to shift their diets to other prey items such as crustaceans and small foraging fish. In addition, fewer winter flounder in the environment allows other species, particularly

those who feed upon polychaetes, amphipods, and mollusks (Steimle et al. 2000) such as scup and crustaceans, to expand their role in the food webs of Long Island Bays.

Table 3.1: Summary of effort and gear used to collect piscivorous fish for dietary analysis from Long Island Waters in 2007 and 2008.

Year	Gear	Sites Sampled	Number of nets set	Months Sampled	Depth Range (m)
2007	Otter Trawl	PJH, GSB, SH	282	Apr – Oct	1.6 - 20.7
2008	Otter Trawl	PJH, SH	163	May - Sept	1.2 – 23.0
2007	Beach Seine	PJH, SH	170	Mar - Nov	Intertidal
2008	Beach Seine	PJH, SH	90	May - Oct	Intertidal

Note: PJH = Port Jefferson Harbor, GSB = Great South Bay, SH = Shinnecock Bay.

Table 3.2: Descriptive statistics of predatory fish examined for dietary analysis.

Species	n	L_{min}	L_{max}	L_{avg}	W_{avg}	S_{avg}	SFI_{avg}	No. of empty stom. (%)
Bluefish	191	12.0	23.0	17.64 ± 0.16	0.06 ± 0.00	1.56 ± 0.15	0.23 ± 0.02	23 (12%)
Summer Flounder	141	26.0	64.9	38.22 ± 0.61	0.68 ± 0.03	5.55 ± 1.04	0.06 ± 0.01	29 (21%)
Scup	69	17.5	37.0	25.54 ± 0.54	0.32 ± 0.02	1.42 ± 0.22	0.47 ± 0.06	11 (16%)
Windowpane Flounder	42	21.0	31.6	26.60 ± 0.43	0.26 ± 0.01	1.77 ± 0.30	0.07 ± 0.01	6 (14%)
Striped Sea Robin	36	20.7	42.6	31.44 ± 0.84	0.45 ± 0.03	5.08 ± 1.16	0.10 ± 0.02	4 (11%)
Striped Bass	23	39.6	95.9	68.56 ± 4.67	3.52 ± 0.58	24.79 ± 10.65	0.09 ± 0.03	8 (35%)
Clearnose Skate	20	49.5	71.0	63.34 ± 1.10	1.58 ± 0.07	20.74 ± 2.40	0.13 ± 0.01	2 (10%)
Oyster Toadfish	11	13.6	30.0	22.9 ± 1.70	0.40 ± 0.09	3.39 ± 1.20	0.08 ± 0.02	4 (36%)

Note: n, sample size; L_{min}, minimum length in cm; L_{max}, maximum length in cm; L_{avg}, average length in cm; W_{avg}, average weight of fish in kg; S_{avg}, average stomach content weight in g; SFI_{avg}, average stomach fullness index. ± indicates the standard error.

Table 3.3: Relative importance of young-of-the-year winter flounder in the diets of piscivorous fish chosen for examination[a].

Species	N	%N	%W	%O	IRI	%IRI
Summer Flounder	141	0.523	1.603	3.546	7.54	0.410
Striped Bass	23	0.645	0.299	4.348	4.103	0.185
Striped Sea Robin	36	0.167	0.411	2.778	1.605	0.015
Bluefish	190	0.266	0.735	0.526	0.527	0.012

Note: n, sample size; %N, percent by number; %W, percent by weight; %O, percent frequency of occurrence; IRI, index of relative importance; %IRI, percent index of relative importance.

[a]Stomach contents of scup, windowpane flounder, clearnose skate, and oyster toadfish did not contain winter flounder.

Table 3.4: Importance of YOY winter flounder in the diets of species examined by year.

	N		%N		%W	
Species	2007	2008	2007	2008	2007	2008
Summer Flounder	68	73	1.075	0.000	5.638	0.000
Bluefish	107	83	0.513	0.000	1.220	0.000
Striped Sea Robin	31	5	0.183	0.000	0.434	0.000
Striped Bass	0	23	-	0.645	-	0.299

	%O		IRI		%IRI	
Species	2007	2008	2007	2008	2007	2008
Summer Flounder	7.353	0.000	49.360	0.000	1.221	0.000
Bluefish	0.935	0.000	1.622	0.000	0.022	0.000
Striped Sea Robin	3.226	0.000	1.991	0.000	0.017	0.000
Striped Bass	-	4.348	-	4.103	-	0.185

Note: Excluded from this table are scup, windowpane flounder, clearnose skate, and oyster toadfish since their stomach contents did not include winter flounder.

Table 3.5: Result of Multivariate Analysis of Variance ran to test for significant difference in diet composition among sites.

	Sample Size by Site		Multivariate Statistics			
Species	North	South	Pillai's Trace Value	F Value	Pr > F	Significance
Bluefish	98	93	0.268	3.29	< 0.000	Significant
Summer Flounder	44	97	0.288	1.13	0.313	NS
Windowpane Flounder	19	23	0.430	1.62	0.138	NS

Note: Striped sea robin, scup, clearnose skate, striped bass, and oyster toadfish are excluded from this table due to inadequate sample sizes for each region.

Table 3.6: Prey items and their respective weights responsible for the significant difference in diet composition among species in the Multivariate Analysis of Variance.

Prey item	P* <	Predator: Summer Flounder	Striped Sea Robin	YOY Bluefish	Windowpane Flounder	Clearnose Skate	Striped Bass	Scup	Oyster Toadfish
Atlantic Silverside	0.001	18.78	0.81	70.35	0.00	0.89	0.08	0.00	0.00
Blue Crab	0.000	0.00	0.00	0.00	0.00	0.78	0.00	0.00	0.00
Mysid Shrimp	0.000	5.18	0.69	0.00	34.16	0.00	0.00	1.41	0.00
Clam	0.000	0.04	0.07	0.00	0.01	0.00	2.70	33.20	0.00
Copepod	0.002	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00
Lady Crab	0.000	3.61	16.30	0.00	0.00	24.40	2.12	0.00	0.00
Menhaden	0.000	1.35	3.84	67.20	0.00	0.00	0.00	0.51	0.00
Moon Snail	0.002	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00
MPM	0.000	0.42	0.03	0.37	0.02	0.14	0.00	0.02	3.68
Mud Crab	0.000	0.39	0.00	0.00	0.00	0.21	3.65	3.10	8.57
Naked Goby	0.028	0.40	0.00	0.00	0.00	0.00	0.63	0.00	0.00
Nonliving Matter	0.000	1.12	0.43	0.03	0.68	0.00	17.50	0.00	0.00
Northern Puffer	0.000	0.00	0.00	0.00	0.00	0.00	73.70	0.00	0.00
Oyster	0.002	0.00	0.00	0.00	0.00	0.00	1.60	0.00	0.00
Rock Crab	0.000	66.40	1.68	0.00	0.00	177.00	0.00	0.07	0.33
Sand Shrimp	0.000	59.95	88.95	5.70	20.85	26.95	15.44	1.31	0.00
Sculpin	0.001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spider Crab	0.000	0.00	0.00	0.00	0.00	40.20	0.00	0.00	0.00
Summer Flounder	0.000	0.00	0.00	0.00	0.00	0.00	206.50	0.00	0.00
Striped Sea Robin	0.002	0.00	0.00	0.00	0.00	0.00	67.62	0.00	0.00
Unid. Animal Remains	0.000	0.00	0.00	0.00	0.00	0.00	0.00	2.93	0.00
Unid. Annelid	0.000	0.00	0.00	0.00	0.00	0.00	0.00	5.51	0.00
Unid. Crustacean	0.001	0.00	0.00	0.43	0.00	0.00	41.50	0.77	0.00
Unid. Fish	0.000	58.90	1.30	18.40	0.00	0.63	14.10	1.11	2.53
Unknown	0.001	1.45	0.00	0.60	0.03	0.00	0.00	2.96	0.00

Note*: P, probability; all other values are weights of the prey items used in analysis.

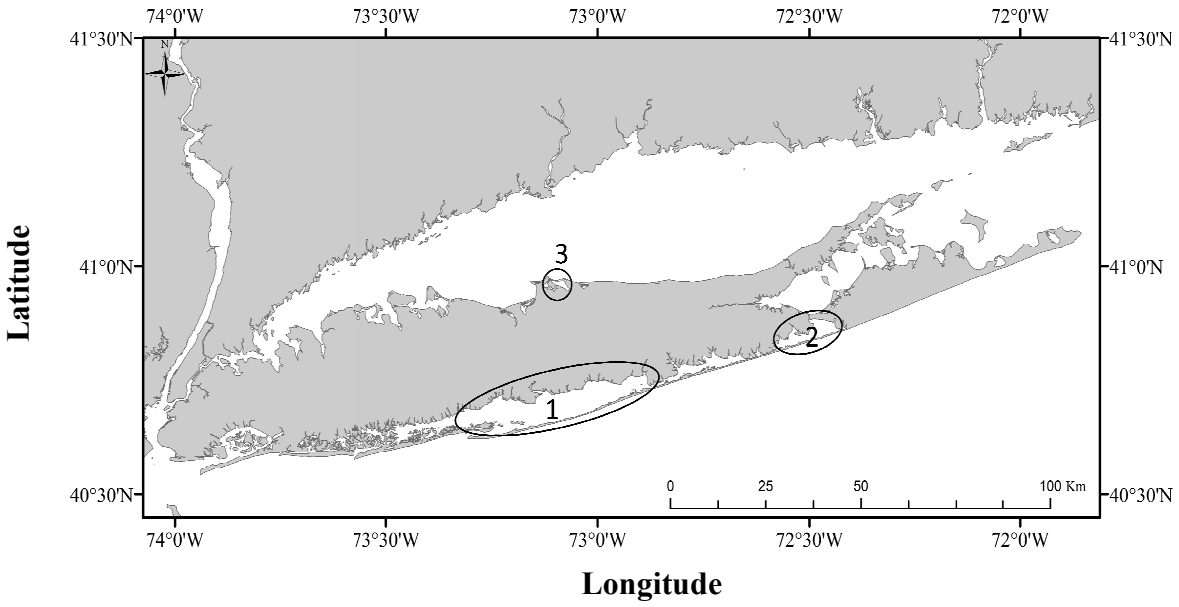

Figure 3.1: Study sites where predatory fish were collected for dietary analysis from Long Island waters in 2007 and 2008: (1) Great South Bay, (2) Shinnecock Bay, (3) Port Jefferson Harbor.

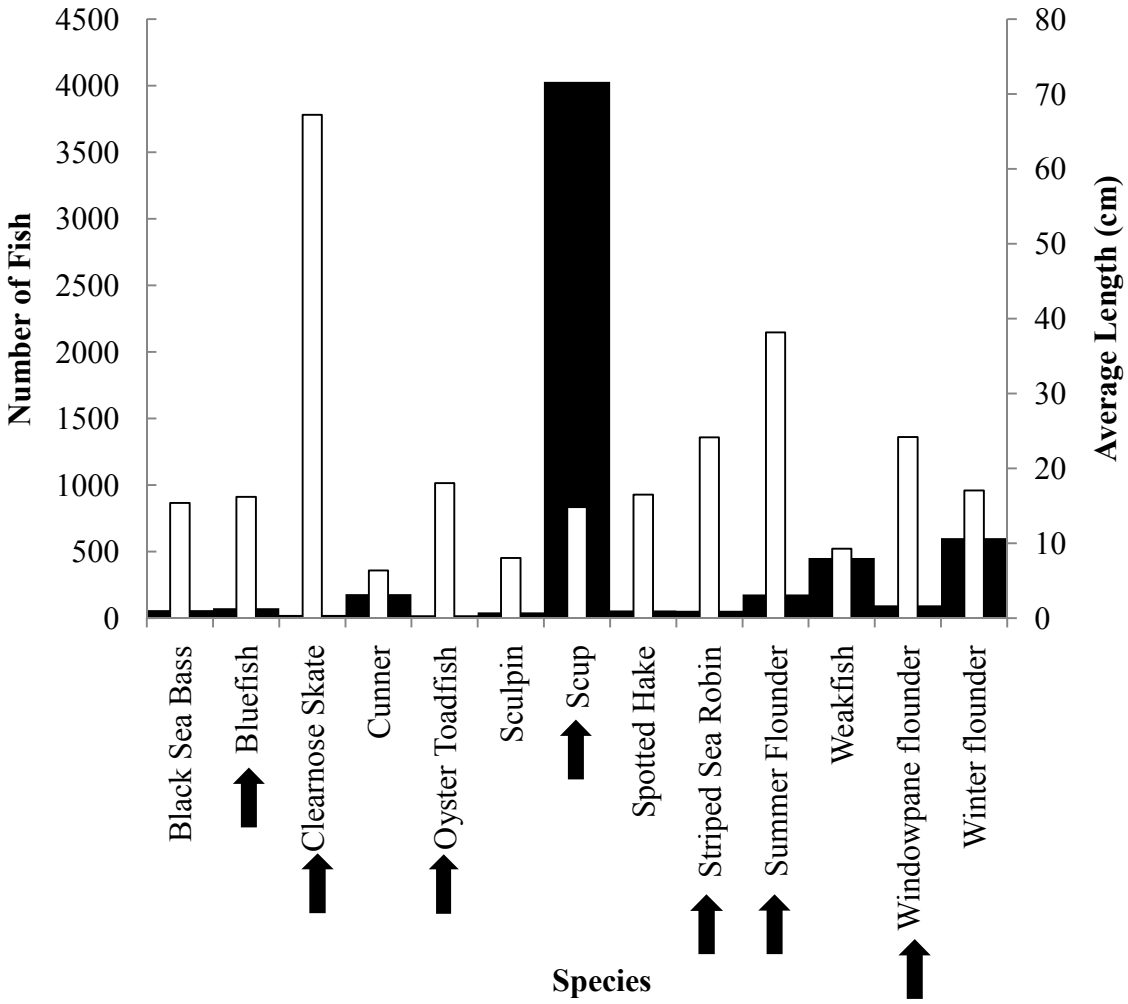

Figure 3.2: Abundance (black) and average length (white) of predatory fish caught during 2007-2008 otter trawling seasons from April to October. Note: arrows indicate fish chosen for dietary analysis.

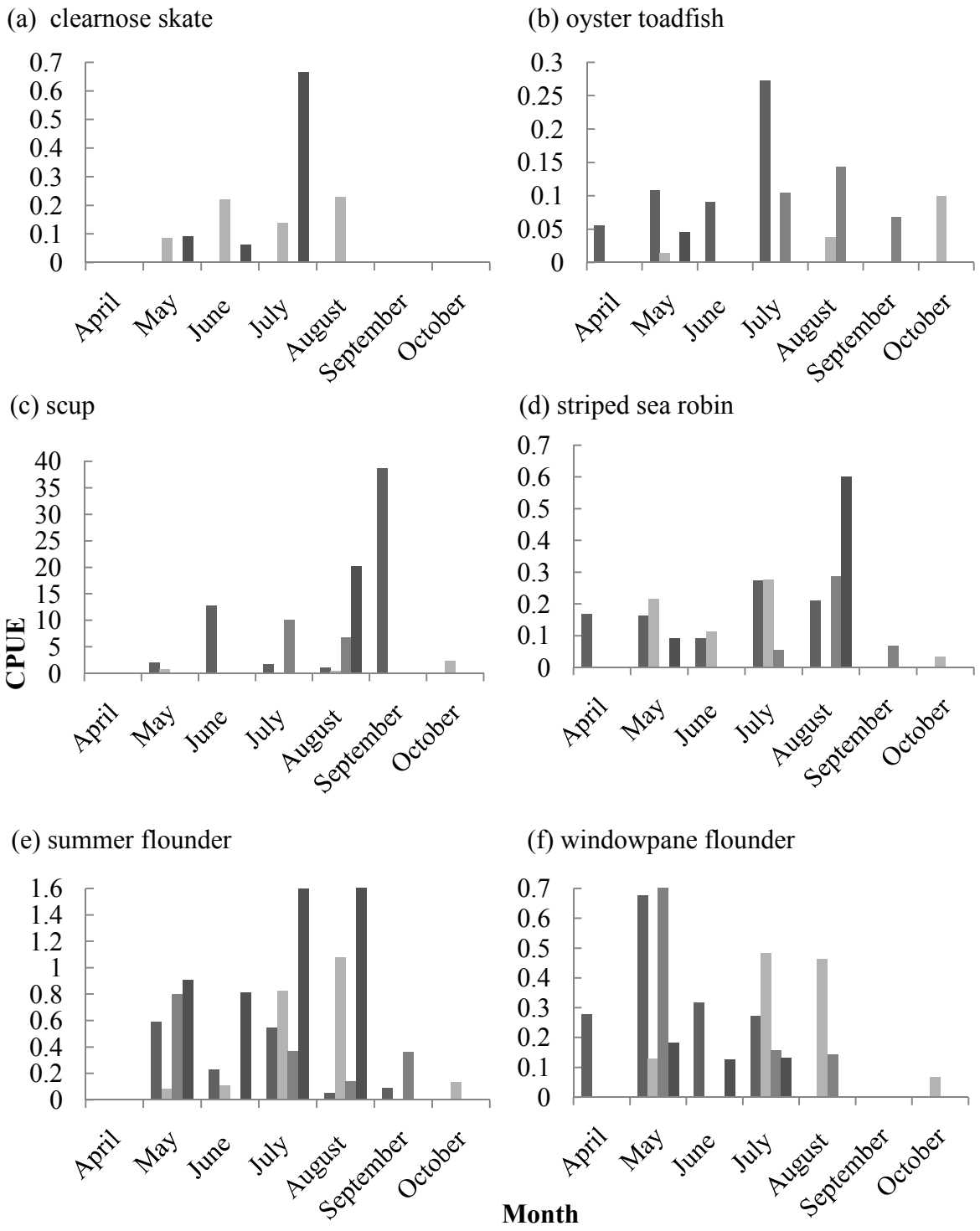

Figure 3.3: Catch per unit effort (CPUE) for fish chosen for dietary analyses from otter trawls in Long Island Waters from 2007 and 2008. Bars from left to right represent North 2007, South 2007, North 2008, South 2008. *Note*: excludes striped bass and YOY bluefish which came from hook and line and beach seines respectively.

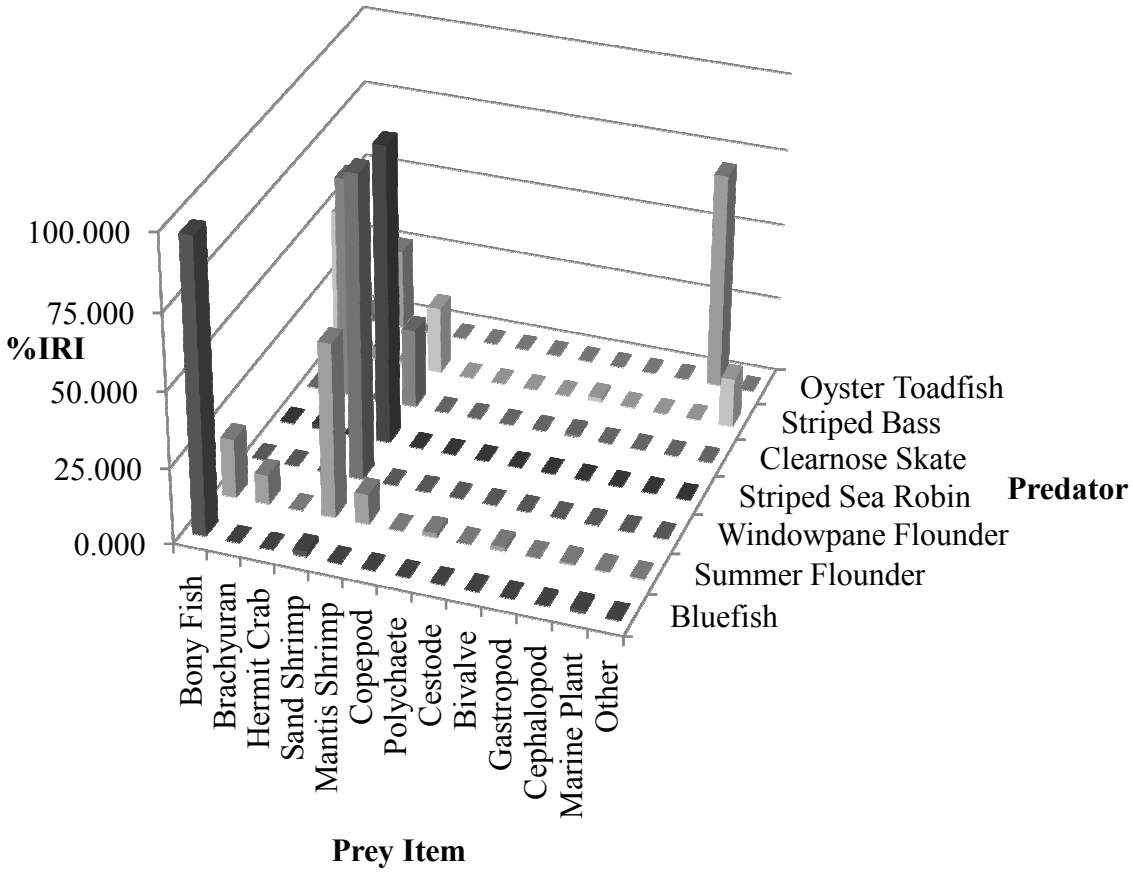

Figure 3.4: Comparison of major prey types given in Percent Index of Relative Importance (%IRI) by species. Note: Scup is excluded from this analysis.

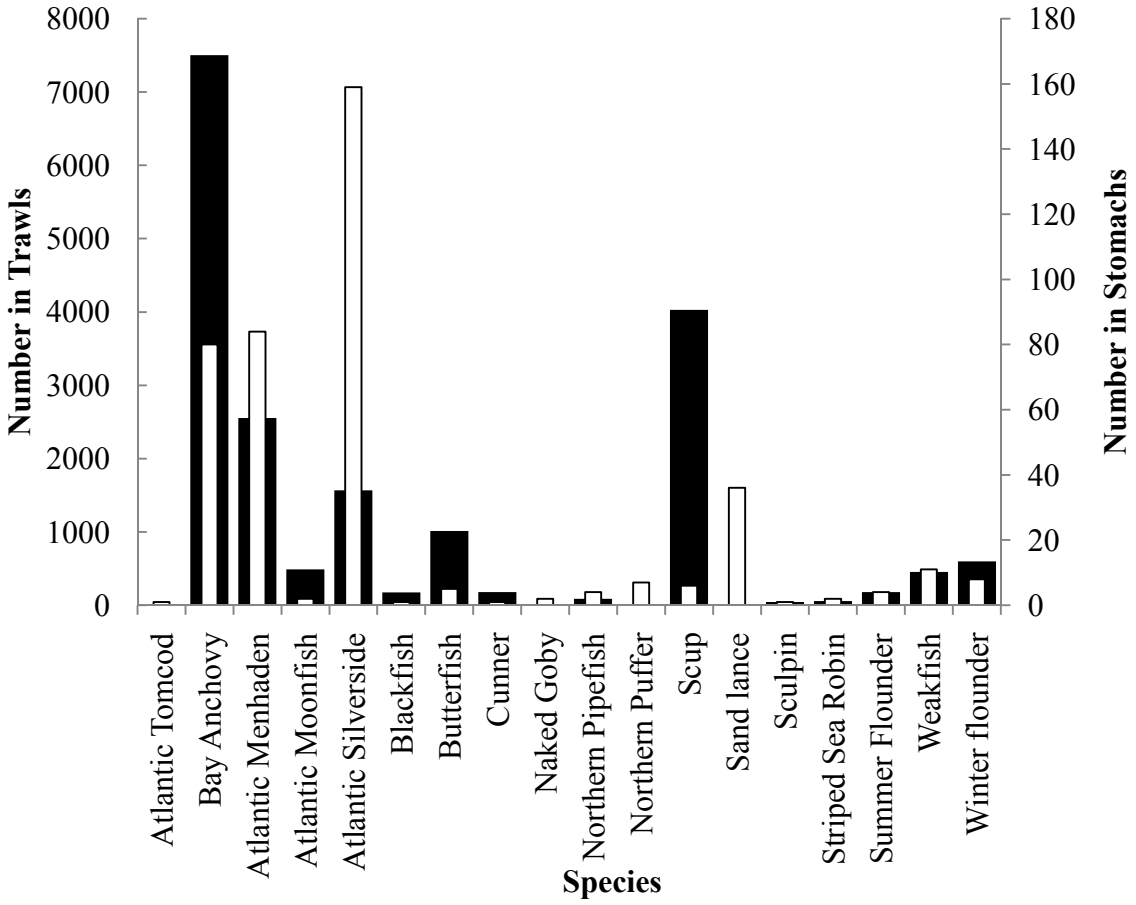

Figure 3.5: Number of fish present in Otter Trawls for 2007 and 2008 combined (black) compared with the number of fish found in stomach contents (white) from Long Island waters.

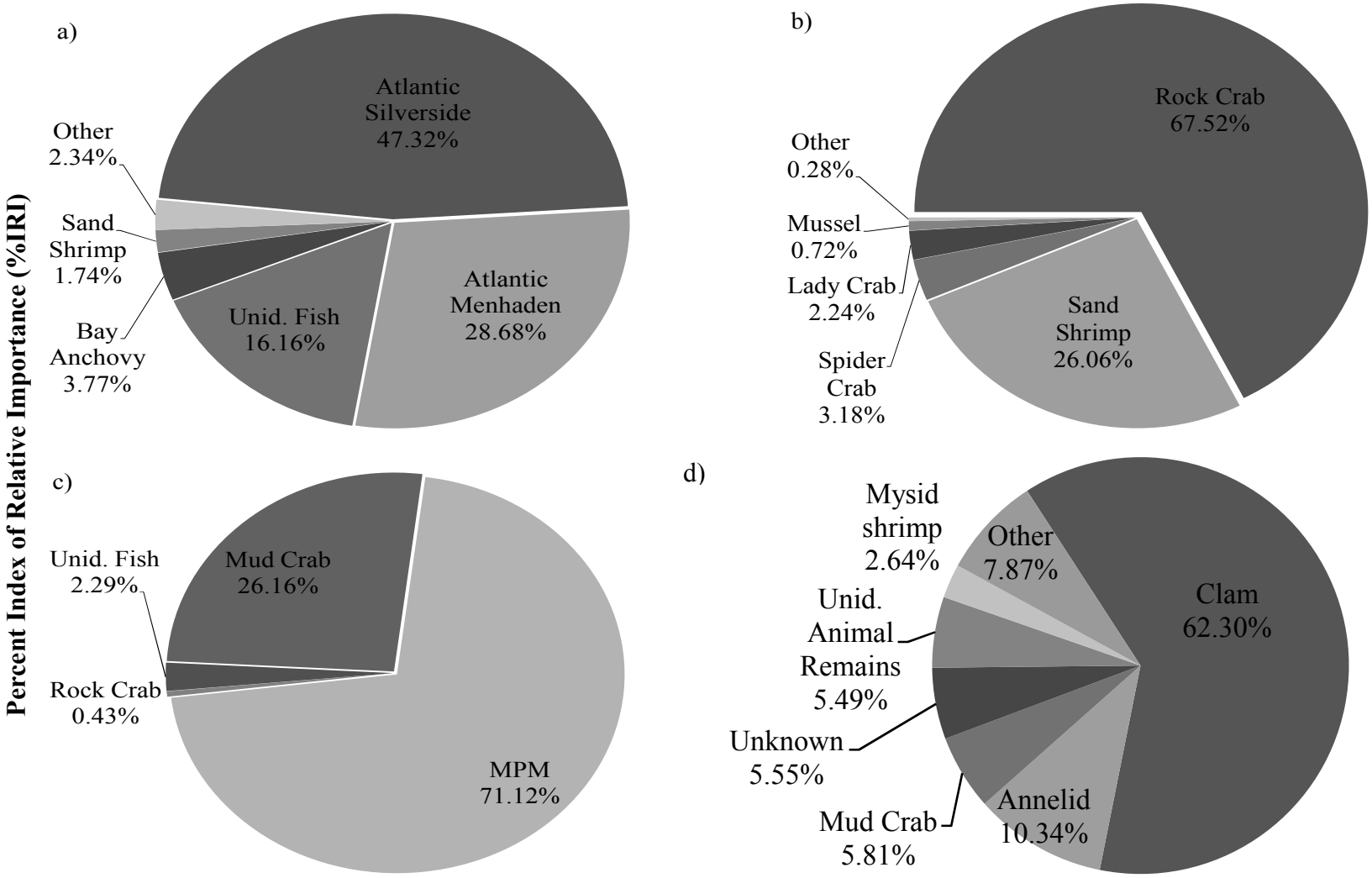

Figure 3.6: Stomach Contents given as Percent Index of Relative Importance of Prey Items (%IRI) for all species examined. Note: Contents of scup reported as Percent by Weight (%W). (a) bluefish, (b) clearnose skate, (c) oyster toadfish, (d) scup,

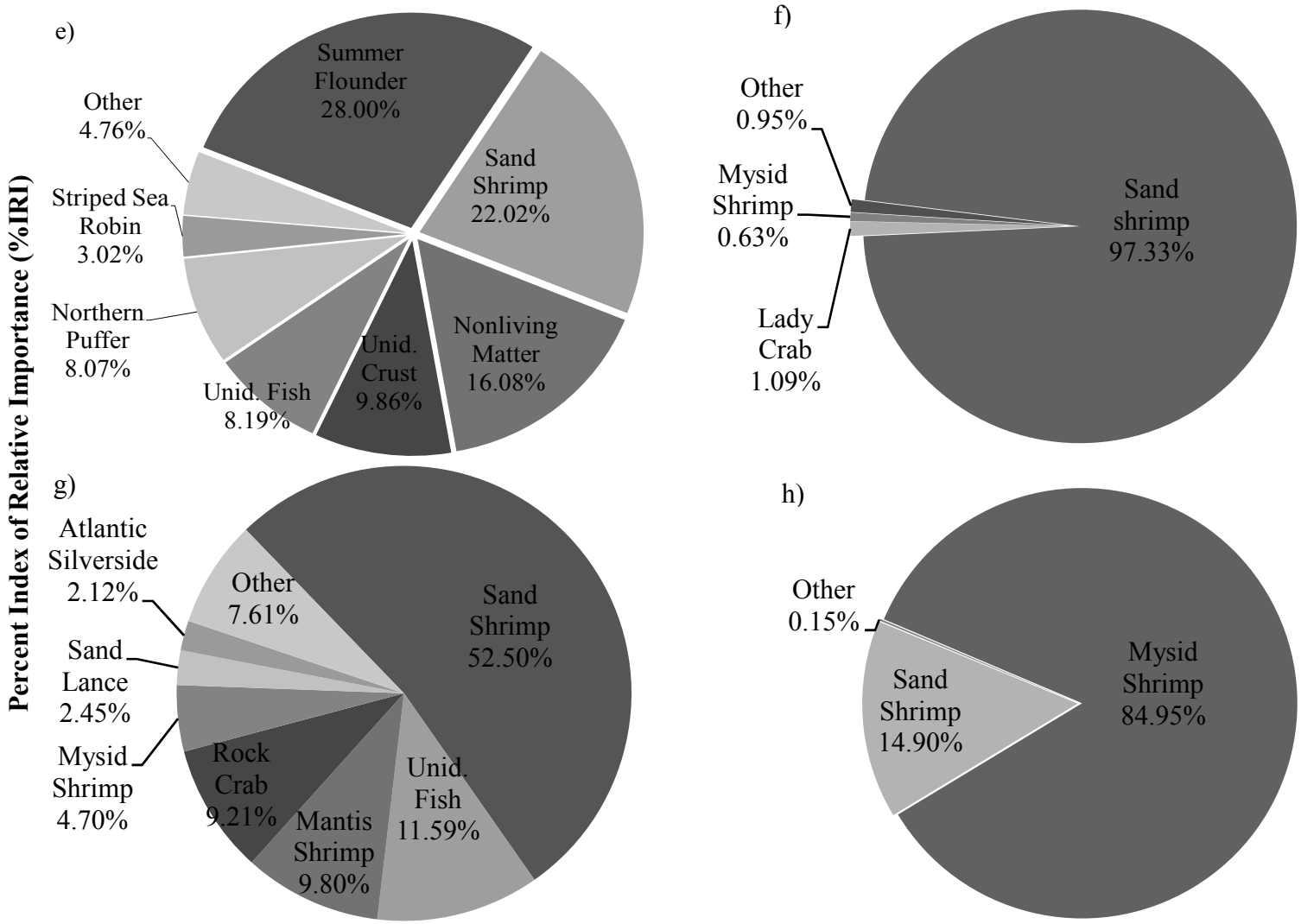

Figure 3.6(cont'd): Stomach Contents given as Percent Index of Relative Importance of Prey Items (%IRI) for all species examined: (e) striped bass, (f) striped sea robin, (g) summer flounder, and (h) windowpane flounder.

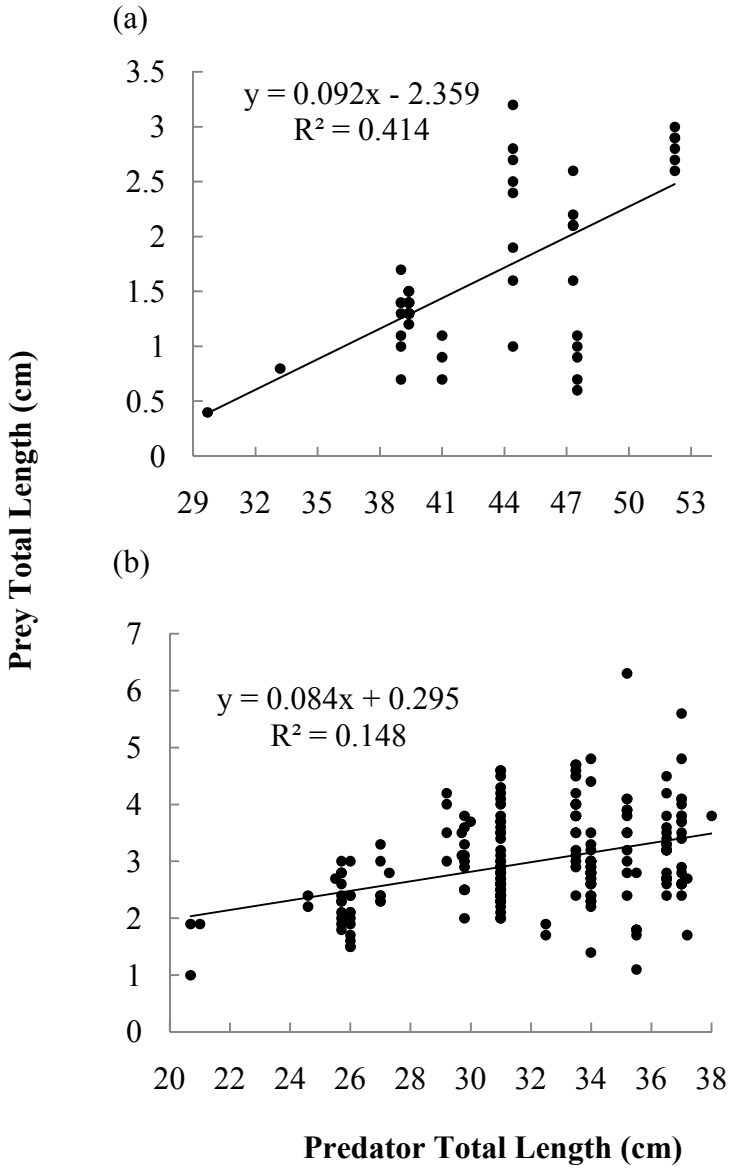

Figure 3.7: Predator size-prey size relationships generated from least squares linear regression where panel (a) is summer flounder and rock crab and panel (b) is striped sea robin and sand shrimp.

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Chapter 4: An Investigation on the Effect of Photoperiod and Temperature on Vertebral Band Deposition in Little Skate, *Leucoraja erinacea*

Introduction

Environmental and biological factors have been linked to variation in vertebral band deposition in elasmobranchs. Differential uptake of minerals by a changing environment, food intake, migration, photoperiod, temperature, and spawning have all been suggested to cause variation in banding patterns (Jones and Geen 1977; Pratt and Casey 1983; Natanson 1993; Goldman 2005; Goldman et al. 2006; Chen et al. 2007). Photoperiod, or the amount of time an organism is exposed to light each day, and temperature are thought to be major factors affecting banding patterns in elasmobranchs (Natanson 1993; Goldman 2005). Few studies have examined the effects of these factors on growth band formation in elasmobranchs. A single laboratory study investigating these factors focused solely on temperature's effect on vertebral band deposition in little skate, *Leucoraja erinacea,* and found no correlation between vertebral band deposition and temperature (Natanson 1993). In the sandbar shark, *Carcharhinus plumbeus*, Torres et al. (2005) noted the formation of band pairs under constant conditions of temperature and photoperiod in aquaria.

Given the importance of aging elasmobranchs through counts of band pairs, it is important to determine if external factors can influence band deposition and therefore distort aging results. Age estimates are essential for fisheries management as they are used in calculations of growth and mortality rates, age at maturity, age at recruitment, and

estimates of longevity (Natanson et al. 2002). The goal of this study was to enhance knowledge of band pair formation by determining whether photoperiod or temperature have an effect on the timing of vertebral band deposition in an elasmobranch species. Little skate was chosen as a test subject for three reasons: (1) they can be kept in captivity; (2) their annual band periodicity has been confirmed by many techniques including marginal increment analysis and radiocarbon dating (Johnson 1979; Waring 1984; Natanson 1993; McPhie and Campana 2009); and (3) they are of commercial importance in the United States and Atlantic Canada (Rago et al. 1998; McMillan and Morse 1999). Further, this relatively fast growing elasmobranch can live up to 12 years, reach a size of 57 cm (total length, TL), and tolerate water temperatures ranging from 2° to 21°C (McEachran 2002; Frisk and Miller 2006; Frisk and Miller 2009).

Although previous studies have included conflicting information regarding the timing of band deposition in little skate, their combined findings provide a suggested timeline of band formation (Johnson 1979; Waring 1984; Natanson 1993). Johnson (1979) suggested presence of narrow, highly calcified bands called hyaline bands during fall/winter based on samples collected in September and January. In agreement, Natanson (1993) recognized the formation of opaque bands during December when oxytetracycline (OTC) was injected into specimens and during August/October when two skates died prematurely. In contrast, Waring (1984) concluded opaque bands formed during summer while marginal translucent bands formed over winter after observing thin translucent bands in autumn samples (Sept-Nov) and broad translucent bands in spring samples (Mar-Apr). We exposed little skate to accelerated seasonal conditions of temperature and light to mimic 3 years worth of growth into 1 ½ years. We hypothesized

that seasonal fluctuations in temperature and photoperiod would not have an effect on band deposition in little skate.

Methods and Materials

Collection and preparation of skates for experiment. Young-of-the-year (YOY) little skate and egg cases were collected off the south shore of Long Island, New York. Those skates collected during trawls were transported to the laboratory in large coolers filled with ambient sea water and aerated by air stones. In the laboratory, they were placed in a rectangular holding tank (0.6 m x 1.2 m x 0.3 m). Seawater was obtained from Shinnecock Bay through a filtration system within the laboratory and was maintained at a temperature of 16°C for several months. Environmental parameters including temperature, salinity, nitrate (NO_3^-), nitrite (NO_2^-), alkalinity, and pH were monitored closely. Skates were fed thawed mysid shrimp two to three times a week.

Before introduction into the experimental setup, newly hatched skates were bathed in an oxytetracycline hydrochloride bath (5 ml/L of water) for 6 hours to avoid mortality from injections. Larger skates were injected intramuscularly at a dose of 25 mg/kg body weight (Natanson 1993; Cailliet and Goldman 2004). Tetracycline (OTC) was used as a temporal mark to both validate the presence of annual bands and to test the effect of temperature and photoperiod on band deposition (Natanson 1993).

Experiment: design, setup, and implementation. A holding box (1.2 m x 1.8 m x 2.1 m) housed 16 plastic trays during the 18 month experiment (Figure 4.1), each of which had a holding capacity of 43.5 gallons. Two closed water systems were utilized for water flow throughout the system; the first circulated constant temperature seawater

while the second cycled water of varied temperature based on seasonal fluctuations. Seawater from Shinnecock Bay was filtered using a 0.5 micron filter and UV filter. Desired temperatures for each system were maintained by water chillers. Each water system emptied into a large sump capable of holding roughly 360 l of seawater. Pondmaster pumps (1.9 l/s) were used to pump water from each sump through its respective chiller. Aqua pumps (Powerhead Riot 1700) propelled water through the plumbing and into each tray. All water pipes were insulated to reduce condensation leakage. Water was returned to the appropriate sump through an interlocking drainage system. Each sump contained Bio Balls and a Pennplex Cascade 1000 Canister for filtration. Timers were installed to control the internal light fixtures. For seasonal light, three fixtures were turned on at different times to mimic the natural changes of the diurnal and seasonal light cycle. For constant light, a single fixture was programmed to provide 12 hours of light and dark. All light external to the experiment was blocked using seam filler and tarps. The purpose of this setup was to compress 3 years of environmental conditions into 1 ½ years.

Trays were randomly placed within light groups with 3-4 skates per tray for a total of 57 skates introduced into the setup on January 1, 2007. Due to the loss of many skates within the first five months of this experiment, a second grouping of 27 little skate were collected by otter trawl, injected with or bathed in tetracycline and placed throughout the setup on May 28, 2007. Upon death, total length was recorded to the nearest mm and each skate was frozen whole.

Preparation of vertebral sections. In the laboratory, skates were thawed, their vertebral column removed and cleaned. For the cleaning process, we soaked vertebral

sections in warm water to aid in the removal of tissue and then allowed them to air dry (Frisk and Miller 2006). Multiple vertebrae samples were taken from the 5 – 20 centra sections for each skate. Two individual centra were mounted for transverse examination while two sections of vertebrae (2-4 centra) were placed on slides for sagittal sectioning. Vertebrae were mounted on glass microscope slides using cyanoacrylate adhesive, given 24 hours to dry, and then sanded down using 400 grit sand paper.

Vertebral analysis for Surviving Skates. Specimens that survived the 18 months were examined to determine the number of bands deposited during the experiment. Vertebral sections were examined through a Nikon Eclipse 80i microscope (4X, 10X, 20X, 40X) with an X-cite Series 120 illumination unit providing ultraviolet light. Images were obtained using a Nikon digital camera (DXM1200C) attached to the microscope. The growth of the vertebrae beyond the OTC mark was examined to determine how many band pairs were deposited within 18 months. A band pair consists of a thin translucent band deposited in the spring which represents winter growth and a wide opaque band formed in the summer (Sminkey and Musick 1995; Cailliet and Goldman 2004).

Centrum edge analysis. I examined the opacity and translucency of the centrum edge over time in individual skate to discern seasonal changes in growth (Cailliet and Goldman 2004). The outermost band of the centrum was examined in both sagittal and transverse sections for 58 little skate to provide a detailed timeline of band type throughout this experiment. When the type of band observed in each sectioning technique did not agree that skate was removed from the analysis. Results were

organized according to the date of death, or ending date, for each skate and graphed in terms of type of band deposition by month.

Statistical analysis. The experimental design consisted of a randomized complete block split plot design with two factors: temperature and light. Temperature was nested within light and therefore four variables were tested: (1) constant light, (2) constant temperature, (3) seasonal light, and (4) seasonal temperature. The original statistical design involved running a two-way ANOVA treating the number of bands formed during the experiment as the measurement variable. However, due to the high mortality of specimens, this procedure was abandoned. Instead, the number of bands deposited (dependent variable) was regressed with time (independent variable) survived in the experimental set-up.

Additionally, I tested if band formation in the experiment followed annual patterns observed in the wild. Specifically, my hypothesis assumes that the winter months of January and February mark the formation of translucent bands as suggested by Waring (1984), with translucent bands observed from March to June (Waring 1984); July and August mark the formation of opaque bands (Waring 1984; Natanson 1993) and opaque bands are observed from September to December (Johnson 1979; Waring 1984; Natanson 1993). The hypothesis was analyzed by testing each period using a chi-square goodness of fit test with a significance level of $\alpha = 0.05$. For the expected frequency, I assumed an equal distribution (1:1 ratio) of opaque bands and translucent bands.

Results

The temperature for the constant sea water system remained fairly constant throughout the experiment (Figure 4.2), only varying a few degrees from 14.2° to 16.1°C (mean of 15.23°C ± 0.03 S.E.). The constant system salinity ranged from 28 to 37 ppt (mean of 32.99 ppt ± 0.17 S.E.). The temperature for the seasonal sea water system mimicked seasonal trends and varied greatly (Figure 4.2), ranging from 2 to 22 °C (mean of 12.69°C ± 0.48 S.E.). For this system, salinity ranged from 24 to 42 ppt (mean of 31.18 ppt ± 0.26 S.E.).

Vertebral Analysis. Tetracycline marks were visible in 11 of the 58 skates examined for band deposition. All were introduced into the experiment on January 1, 2007 and exhibited an OTC mark within the opaque band (Table 4.1). Survival ranged from 1.5 to 18 months. Out of the 57 skates introduced at the beginning of the experiment, 11 survived from 12 – 18 months but only six contained an identifiable OTC mark, lasted 18 months, and were consequently used in vertebral analysis. During the 18 month experiment, four skates deposited 3 bands outward of the tetracycline mark: two skates from the seasonal water-seasonal light treatment, measuring 18.3 cm and 21.6 cm TL (Figure 4.3a) and two skates from the seasonal water-constant light, one at 24.5 cm (Figure 4.3b) and another at 22.9 cm TL. Two skates deposited two bands outward of the tetracycline mark: a 20.6 cm TL from the seasonal water-constant light treatment and a 22.5 cm TL (Figure 4.3c) skate exposed to the constant water-constant light treatment. Overall, in 18 months, a maximum of 3 bands or 1 ½ band pairs was deposited.

No skates survived the entire experiment in the constant water-seasonal light treatment, however, three skates did have a discrete OTC mark enabling examination of band deposition: two bands were exhibited by a 19.7 cm TL skate who survived the first

three months and a 21.2 cm TL skate who survived 6 months; a single band was exhibited by a 17.7 cm TL skate who survived 11.5 months (Table 4.1).

Centrum Edge Analysis. Centrum edge analysis included 56 instead of 58 skates due to a discrepancy in the type of band between the sagittal and transverse views for two individuals. The winter band (translucent) appeared in February 2007 and January 2008 while the summer band (opaque) began in July for both 2007 and 2008 (Figure 4.4). January/February and July appears to be a transition period between depositions of the two bands.

Statistical Analysis. My original statistical analysis was abandoned due to too few specimens left at the end of the experiment. Based on the 11 skates who exhibited a discrete OTC mark, a linear regression was performed for the number of bands deposited during the experiment against the time present in the experiment ($n = 11$, bands = $0.003 \bullet \text{time} + 1.123$, $r^2 = 0.554$, $p < 0.005$) (Figure 4.5). The chi-square goodness of fit, which tested for a difference between expected and observed bands, resulted in a significant difference in the number of opaque and translucent bands deposited during the following intervals: March to June and September to December (Figure 4.6). No significant difference was detected for the periods of January to February and July to August.

Discussion

Many factors have been suggested to affect centrum banding patterns including photoperiod, temperature, food availability and uptake of minerals (Jones and Geen 1977; Branstetter 1987; Natanson 1993; Torres et al. 2005). However, few studies have investigated the causation of band formation in elasmobranchs due to their large size and

the time needed for growth/aging experiments. I choose a small and abundant skate species to expose to three annual patterns of seasonal light and temperature to determine the effects of temperature and light on band formation. Even though high mortality of specimens hindered my original statistical analysis I was able to show that seasonal photoperiod and temperature had no effect on timing of vertebral band deposition in little skate.

All skates present during the entire 18 month experiment produced two to three bands regardless of water temperature and photoperiod treatment. Further, centrum edge analysis provided evidence that the timing of band deposition was not affected by treatments. Wide summer bands were first observed in July for both years and extended until January/February. Narrow winter bands started in January/February and extended until July. A chi-square goodness of fit test provided additional evidence that my observed results for the periods of March to June and September to December were significantly different from the expected ratio of 1:1 opaque and translucent bands. January and July appear to be transition periods between band types as these months contained skates with both opaque and translucent centrum edges. In addition, my chi-square goodness of fit test found no significant difference between expected and observed frequencies of opaque and translucent bands for these months. These findings further those of Natanson (1993) who found no evidence of an effect of seasonal temperature on band formation.

There is a paucity of experiments defining causation of annuli formation of growth increments for fish in general (Campana and Neilson 1985). Experimental results of this work have implications for understanding formation of annuli in a wide range of

taxa including teleosts and elasmobranchs. Similar theories of environmental factors exist and have been tested in aging teleost fishes in relation to daily otolith growth increments (Campana and Neilson 1985). Johnson and Belk (2004) documented otolith growth rings in the Utah chub, *Gila atraria*, when raised in a constant-temperature environment. Temporal regulation of daily bands has been linked to photoperiod in goldfish where rates of calcium deposition on otoliths slowed during sunrise (Mugiya et al. 1981). In plaice, *Pleuronectes platessa*, Alhossaini and Pitcher (1988) found feeding levels and photoperiods influenced the number of rings with more rings deposited at higher feeding and longer photoperiod regimes.

One particular hypothesis which has gained momentum through experimentation on daily growth rings in fish is that an endogenous circadian rhythm may be regulating band deposition (Campana and Neilson 1985). Daily increment formation in growth rings of fish and squid has been linked to an endogenous circadian rhythm. Tanaka et al. (1981) described photoperiod to be a zietgeber, or external cue, for an endogenous circadian rhythm in goldfish otoliths. Similarly, Bettencourt and Guerra (2001) concluded that daily deposition in *Sepia officinalis* resulted from an endogenous circadian rhythm coupled with photoperiod. Unfortunately, this hypothesis may never be testable due to the existence of uncontrolled variables in an experimental design (Campana and Neilson 1985; Bettencourt and Guerra 2001).

Although not experimentally manipulated, my findings suggest that band deposition may be regulated by an endogenous circadian rhythm. I found neither temperature nor photoperiod to affect the number of bands deposited during 18 months in little skate. Sandbar sharks, *Carcharhinus plumbeus*, held in captivity formed growth

bands under constant conditions of temperature and photoperiod suggesting the existence of endogenous cues (Torres et al. 2005). Brown and Gruber (1988) found evidence of band formation in lemon sharks, *Negaprion brevirostris*, a tropical species which lives in waters that lack seasonality and experience a relatively constant photoperiod.

Many elasmobranch species deposit winter bands, or narrow translucent bands, during spring months (Sminkey and Musick 1995). Translucent bands, also called hyaline rings, represent slower growth during the colder winter months in temperate waters and are more calcified than opaque bands (Johnson 1979; Goldman 2004). In contrast, wide opaque bands form during periods of faster fish growth when water temperatures are the warmest and food is plentiful. A small number of studies suggest the timing of band deposition for juvenile skates based on marginal increment analysis (Sulikowski 2003; Sulikowski et al. 2005). Sulikowski (2003) documented opaque band formation during June/July for winter skate and August/September for thorny skate (Sulikowski et al. 2005).

My centrum edge analysis provided evidence on timing of band deposition in little skate. Since many little skate throughout the experiment died prematurely, I was able to categorize the centrum edge for 16 of the 18 months of this experiment, resulting in a sufficient timeline of deposition. Opaque bands were mostly observed during the first two months of the experiment (Jan-Feb ‘07), between July ’07 and January ’08, and at the end (July ’08). Only 3.6% (two specimens) formed bands out of sync with the majority of skates and may have resulted from reading error, individual variation, or lack of growth due to starvation. Translucent bands were present between February ’07 and July ’07 and January ’08 and July ’08.

One of the most challenging aspects of this experiment was keeping YOY little skate healthy and alive in order to carry out my planned statistical analysis. Ultimately, the task of keeping approximately fifty little skate alive for 18 months proved more challenging than originally thought. The first five months of the experiment proved most difficult as I lost 74% of the specimens introduced into the setup, leaving 15 skates. However, little is known about hatching success and survival of little skate offspring (Leonard et al. 1999). Since most of my starting specimens were YOY hatched in the laboratory, some of these deaths may have occurred naturally. Due to the many mortality events, I was unable to carry out my original statistical design consisting of randomized blocks with temperature nested within light. Although I experienced problems throughout the study, I was still able to attain evidence that temperature and photoperiod do not effect band deposition in little skate.

Table 4.1: Data on band sequence deposited during experiment for little skate marked with OTC during experiment.

Skate TL (cm)	Treat-ment	Starting Date	Ending Date	Band Containing OTC Mark	Terminal Band	Band Types Deposited during experiment
19.7	CS	1/1/2007	4/1/2007	O	T	O-T
21.2	CS	1/1/2007	6/12/2007	O	O	O-T
17.7	CS	1/1/2007	11/24/2007	O	O	O
23.0	CC	1/1/2007	2/15/2007	O	O	O
22.5	CC	1/1/2007	7/1/2008	O	T	O - T
21.6	SC	1/1/2007	2/9/2007	O	O	O
24.5	SC	1/1/2007	7/1/2008	O	O	O-T-O
22.9	SC	1/1/2007	7/1/2008	O	O	O-T-O
20.6	SC	1/1/2007	7/1/2008	O	T	O-T
21.6	SS	1/1/2007	7/1/2008	O	O	O-T-O
18.3	SS	1/1/2007	7/1/2008	O	O	O-T-O

[a] note: CS = constant water-seasonal light; CC = constant water-constant light; SC = seasonal water-constant light; SS = seasonal water-seasonal light

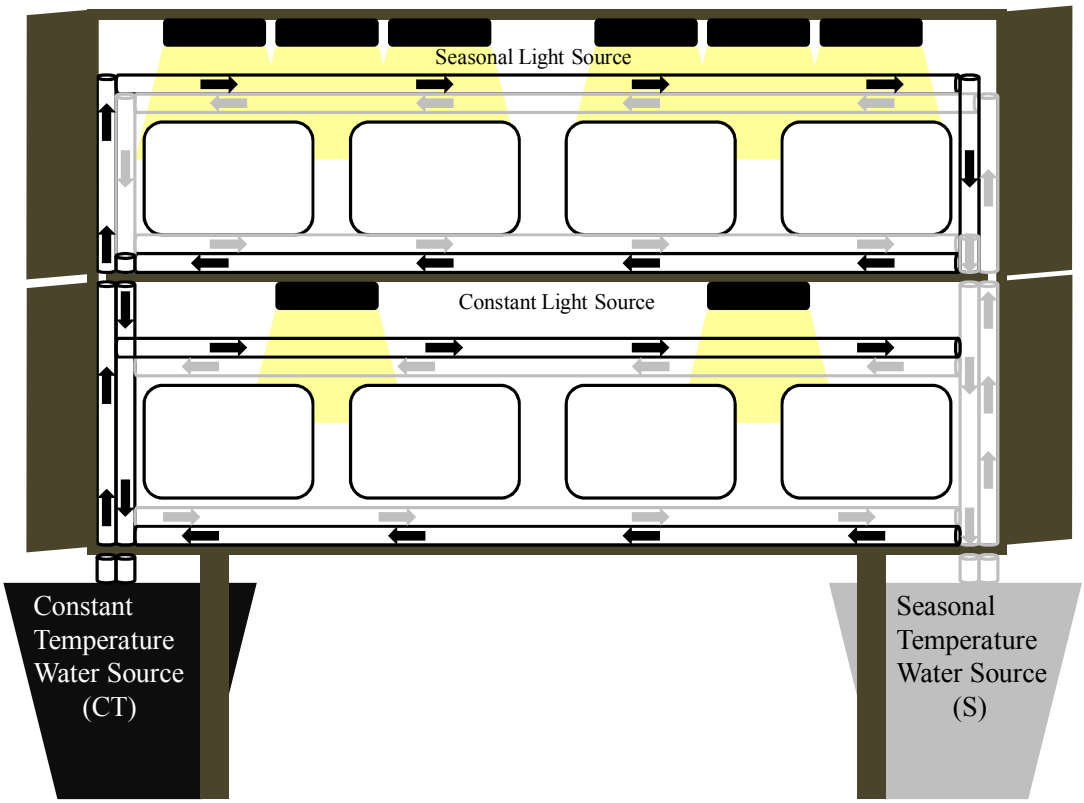

Figure 4.1: Diagram of experimental setup showing the constant and seasonal sea water systems, position of plastic trays containing skates (white boxes), and appropriate light sources. The top level represents the seasonal light scheme while the bottom represents the constant light level.

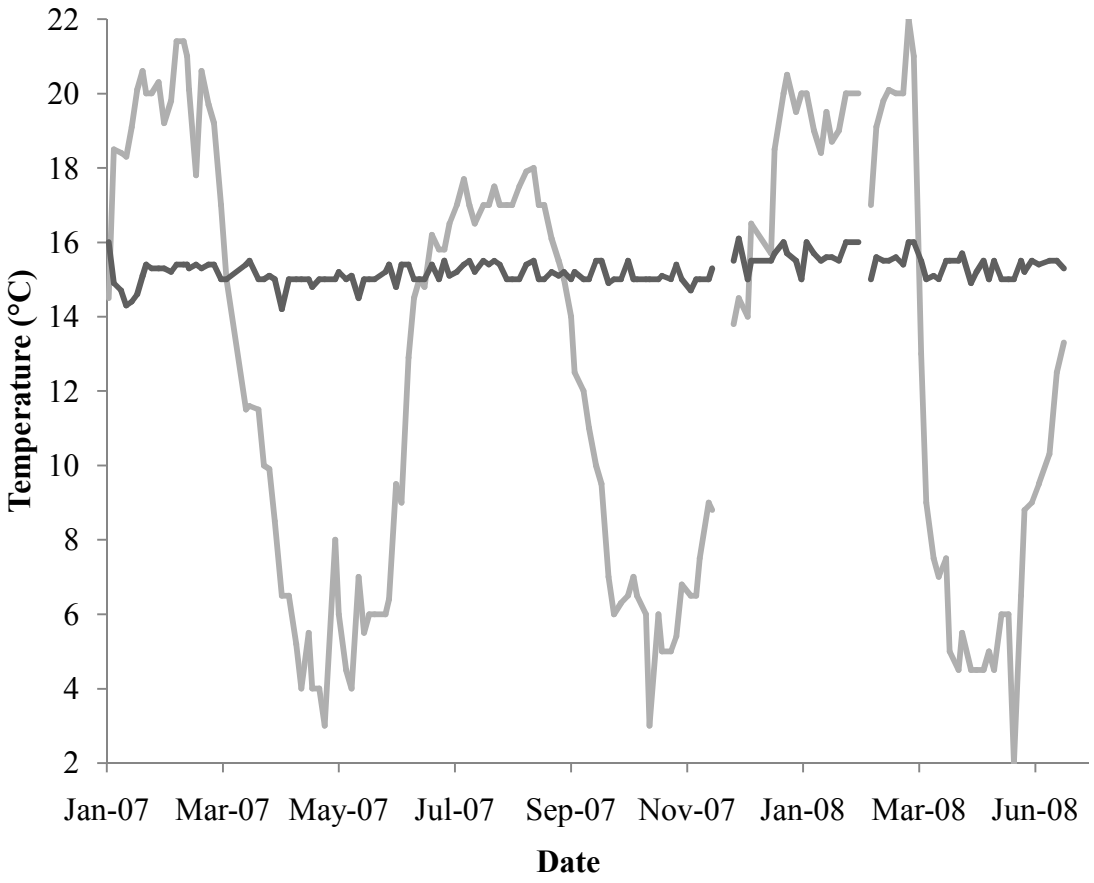

Figure 4.2: Temperature records for the constant temperature seawater system (dark) and the seasonal temperature seawater system (light).

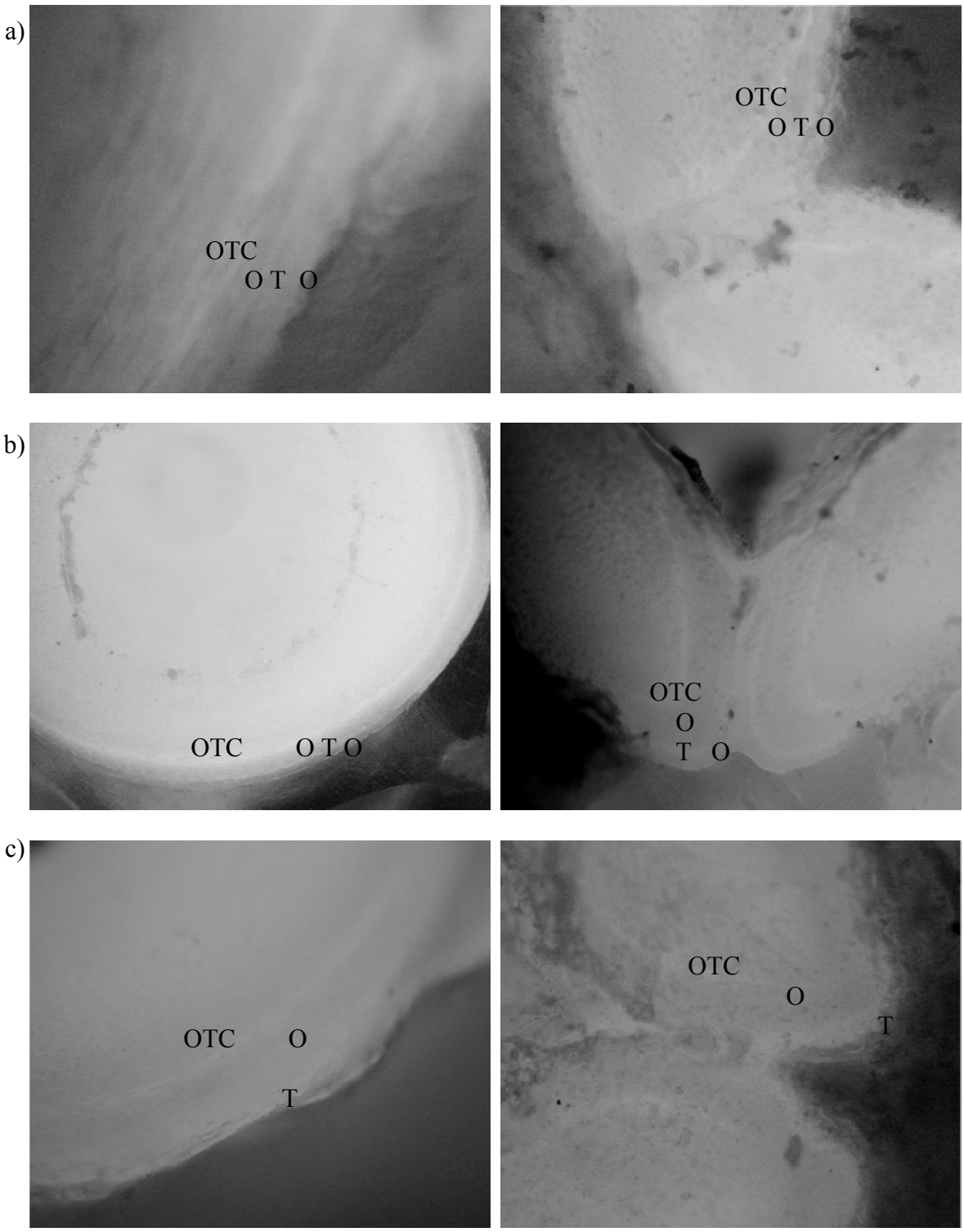

Figure 4.3: Band analysis for three little skate that survived entire experiment: (a), 21.6 cm TL skate in seasonal water temperature and seasonal light scheme; (b), 24.5 cm TL skate living in seasonal water temperature and constant light scheme and (c) 22.5 cm TL skate in constant water temperature and constant light.

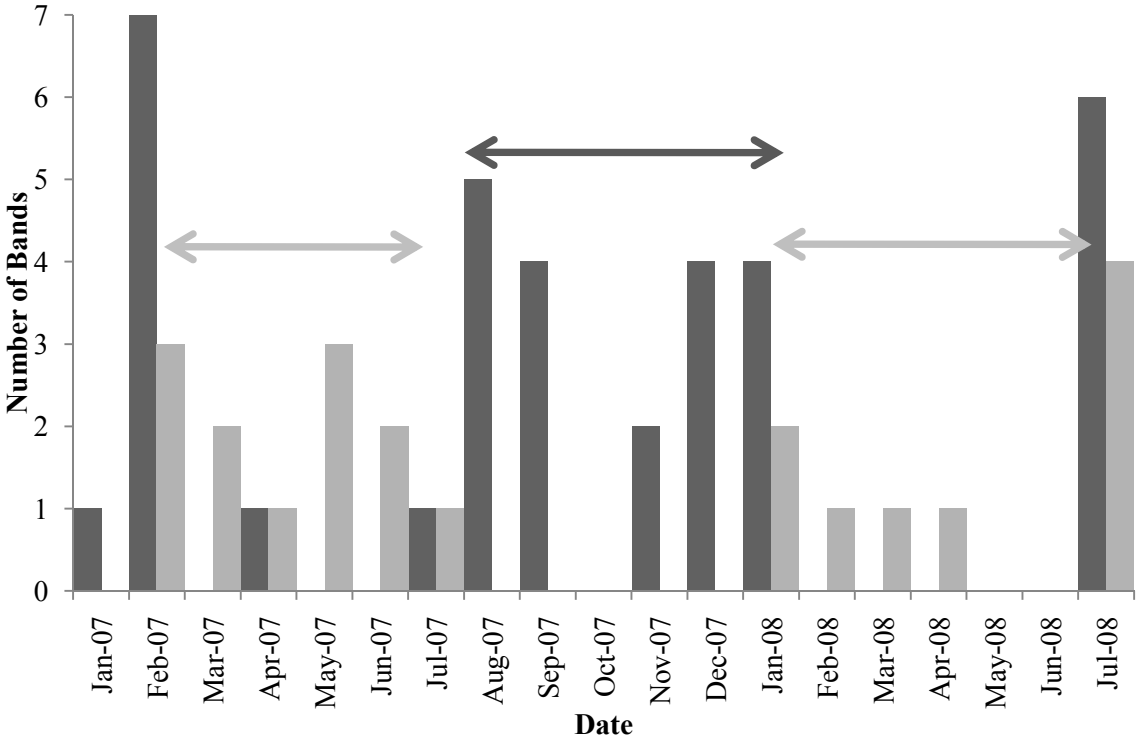

Figure 4.4: Analysis of centrum edges for 56 little skate by individual months during the 18 month experiment. Survival ranged from 1 month to 18 months. Dark bar represents opaque band and light band represents translucent band.

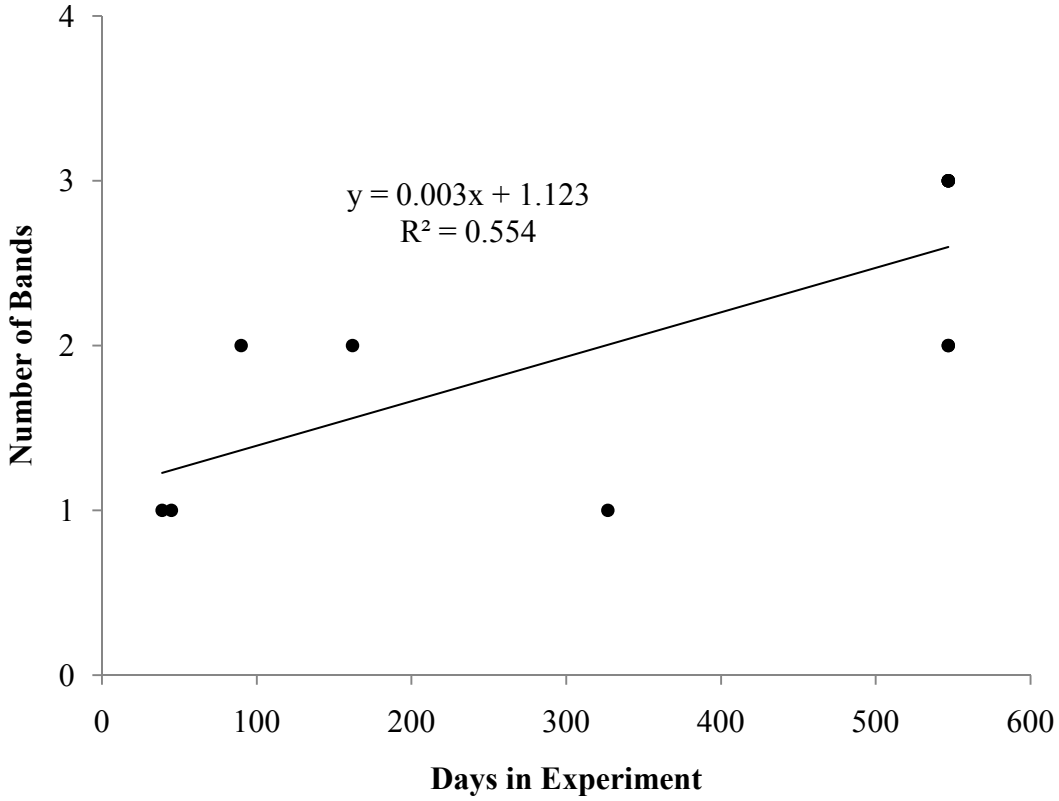

Figure 4.5: The number of bands versus time in experimental tank for 11 little skate exhibiting a discrete OTC mark.

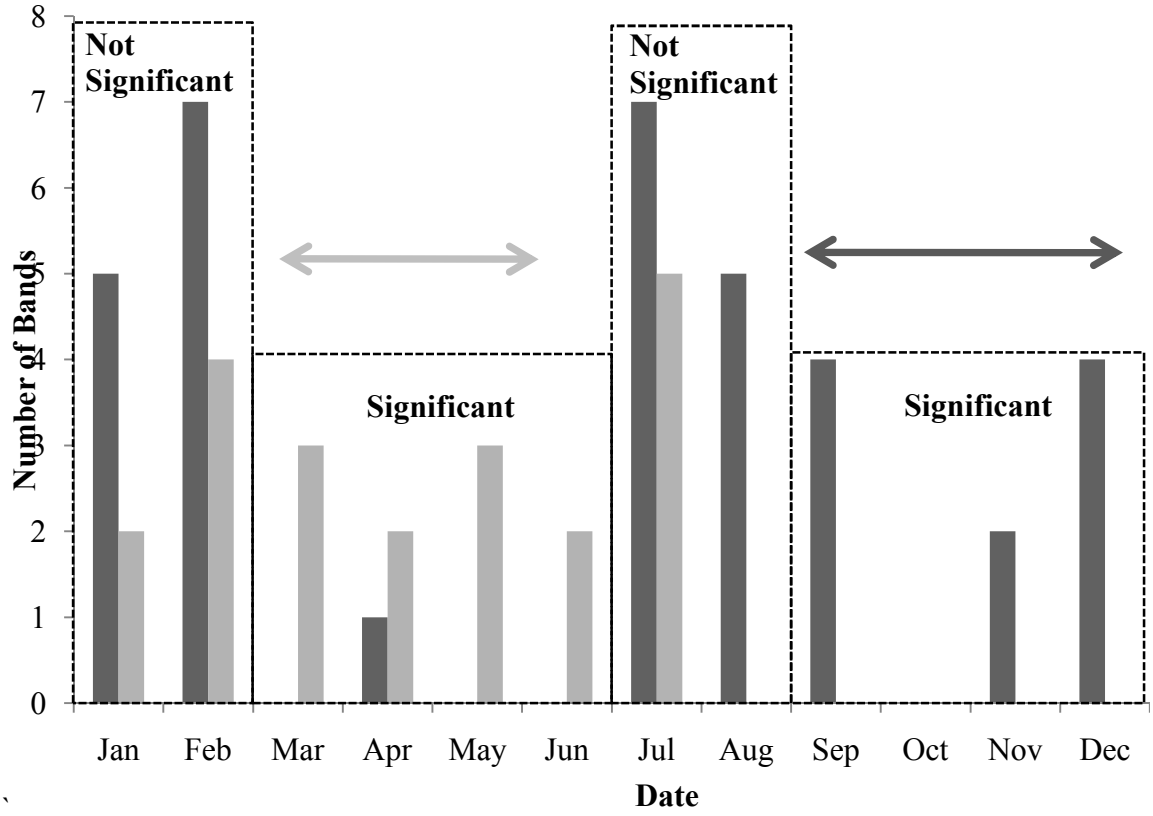

Figure 4.6: Analysis of frequencies of centrum edges for 56 little skate by month using a goodness of fit test. Survival ranged from 1 month to 18 months. Dark bar represents opaque band and light band represents translucent band.

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Chapter 5: Summary

Winter flounder, *Pseudopleuronectes americanus*, has held an important place in the maritime history of Long Island. Over the last few decades, the once plentiful and reliable winter flounder stock has declined, leaving a gap in both the ecosystem structure and fishing community of Long Island. This change seems to be most dramatic within the Long Island bays, where the inshore population of winter flounder has declined while the offshore population remains comparatively abundant (ASMFC 2009). To ensure managers are able to select the best strategies for recovery, they must be provided with accurate information on winter flounder demographics and potential predators.

The goals of this thesis are aimed at improving our knowledge of Long Island winter flounder movements, residency, abundance, and predation on young-of-the-year through acoustic telemetry and dietary analysis. Adult winter flounder were tracked using acoustic telemetry to observe the extent to which winter flounder utilize the bay. I also quantified the predation consumption on young-of-the-year winter flounder from piscivorous fish in Long Island bays as predation is thought to be the primary cause of juvenile flatfish mortality (Pihl and Van Der Veer 1992; Bailey 1994; Gibson 1994; Manderson et al. 2000). Lastly, I conducted an experiment to determine the effect of temperature and photoperiod on band formation during the aging process in fish. Results from this experiment have implications for understanding formation of growth bands in a wide range of taxa, including teleosts and elasmobranchs.

My second chapter investigated adult winter flounder movement patterns and abundance within a coastal bay of Long Island, NY using underwater acoustic telemetry. Forty adult winter flounder (> 24 cm) were tagged and passively tracked over 19 months, resulting in 94,250 detections. We have documented adult winter flounder occupying Shinnecock Bay during all seasons with a peak in abundance of tagged fish occurring during the summer. The majority of winter flounder acoustically tagged did not adhere to the commonly observed pattern of an autumn inshore migration followed by an offshore migration in spring (McCracken 1963). Most tagged fish remained in Shinnecock Bay with eighty-nine percent of the total detections occurring between May and October, supporting the historical notion of resident "bay fish".

Residency within the bay varied greatly with some fish residing within the bay for many months while others were only detected over a few days. The movement patterns of at least 5 fish are consistent with the historical notion of a separate stock of resident "bay fish" as these were detected sporadically in the bay over at least a 3 month period. Breakpoint analysis showed a decrease in flounder activity during dawn, day-time, and dusk for most fish. Overall, winter flounder in Shinnecock Bay can be classified into three common movement patterns of fish including the following: (1) fish remaining within the bay, (2) fish heading offshore through Shinnecock Inlet, and (3) fish exiting the bay through alternative paths including Shinnecock Canal and underneath Ponquogue Bridge. A majority of my fish (52%) remained within the bay with residence ranging from a few weeks to multiple months. Twenty-one percent consisted of fish exiting the bay while 17% remained near the inlet but did not leave. The remaining 10% of fish exited the bay through alternative routes including Shinnecock Canal and underneath

Ponquogue bridge. These results provide insight into flounder movements in a coastal bay of Long Island which may help identify potential reasons for a general decline in winter flounder; however, much work remains to fully understand the stock structure of this species.

In Chapter three, I quantified predation on YOY winter flounder by comparing percent index of relative importance for eight piscivorous species and classified their dietary habits. My analysis showed that winter flounder are currently not an important food source for piscivorous fish in Long Island bays. Winter flounder, once an abundant prey item in stomachs of piscivorous Long Island fish (Poole 1964; Schreiber 1973), contributed less than 0.5% to the percent index of relative importance and 1.6% to the percent by weight for the diets of summer flounder, striped sea robin, striped bass, and YOY bluefish and were absent from the diets of oyster toadfish, clearnose skate, scup, and windowpane flounder. This reduction in the contribution to the diets of primary predators reflects a decline of winter flounder in Long Island bays.

An overall decline in winter flounder abundance throughout the past few decades has forced piscivores to shift their diets to other prey items, such as crustaceans and small foraging fish. Currently, sand shrimp (*Crangon sp.)*, Atlantic silversides (*Menidia menidia*), and rock crabs (*Cancer irroratus*) are important prey items for piscivorous fish in Long Island Bays.

A MANOVA testing for differences in weight of prey items between species resulted in a highly significant difference meaning that there was a significant difference in diet composition. General diet trends differed with YOY bluefish and striped bass preferring fish, oyster toadfish preferring marine plant matter, scup preferring bivalves, and summer

flounder, windowpane flounder, striped sea robin, and clearnose skate feeding heavily on crustaceans. A MANOVA of the weight of prey items for YOY bluefish from each site found a highly significant difference; bay anchovy, sand shrimp, and Atlantic silversides made up a larger proportion of the bluefish diet from the south shore than from the north shore. In addition, my dietary analysis of adult scup is the first documenting their diet in coastal waters. Adult scup fed primarily on bivalves.

Using data obtained from measuring prey items, I investigated predator-prey relationships using linear regression for common prey items for each species. Overall, 6 of the 14 linear regressions between the length of a predator and individual prey were found to be significant, although many represented a weak relationship. Most significant relationships were positive, indicating that as predators increase in size, they consume larger prey items. However, some large predators did feed heavily on small crustaceans and juvenile fish. I am uncertain of the causes for certain species favoring abundant smaller prey and others favoring less abundant larger prey, but this is an issue that deserves further study.

For my last Chapter, I conducted an experiment to determine if photoperiod and temperature have an effect on the timing of vertebral band deposition in little skate. For 18 months, little skate experienced accelerated seasonal conditions of temperature and light to mimic 3 years of growth. Although high mortality of specimens hindered my original statistical analysis, we were able to show that seasonal photoperiod and temperature had no effects on timing of vertebral band deposition in little skate. Vertebral analysis of seven surviving skates showed that all produced two to three bands regardless of photoperiod or temperature treatment over 18 months. The number of

bands deposited during the experiment significantly increased with the time present in the experiment.

For those skates which died prematurely, I examined their terminal band, or centrum edge, and obtained a sufficient timeline of deposition during 18 months from January 2007 to July 2008. Centrum edge analysis also provided evidence that the timing of band deposition was not affected by treatments. The winter band (translucent) appeared in February 2007 and January 2008 while the summer band (opaque) began in July for both 2007 and 2008. Opaque bands were present from July to January/February while translucent bands were visible from January/February to July. A chi-square goodness of fit test provided additional evidence that my observed results for the periods of March to June and September to December were significantly different from the expected ratio of 1:1 opaque and translucent bands. January and July appear to be transition periods between band types as these months contained skates with both opaque and translucent centrum edges.

Although not experimentally manipulated, my findings suggest that band deposition may be regulated by an endogenous circadian rhythm, a theory which is supported by similar studies concerning teleosts (Tanaka et al. 1981; Campana and Neilson 1985; Bettencourt and Guerra 2001). Experimental results of this work have implications for understanding formation of annuli in a wide range of taxa including teleosts and elasmobranchs.

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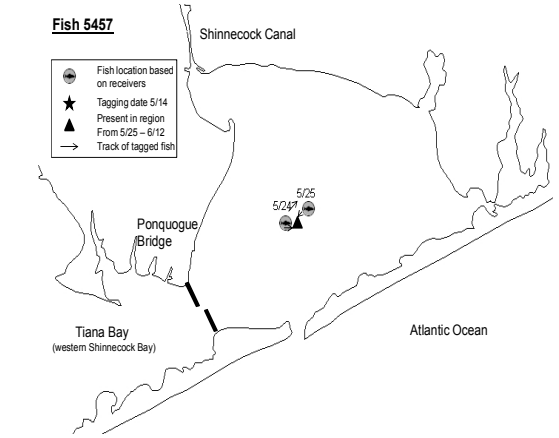
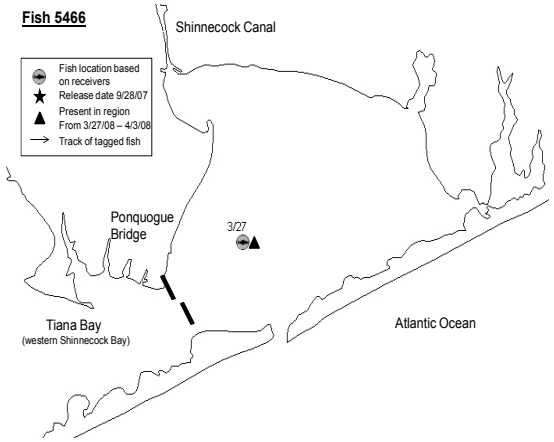
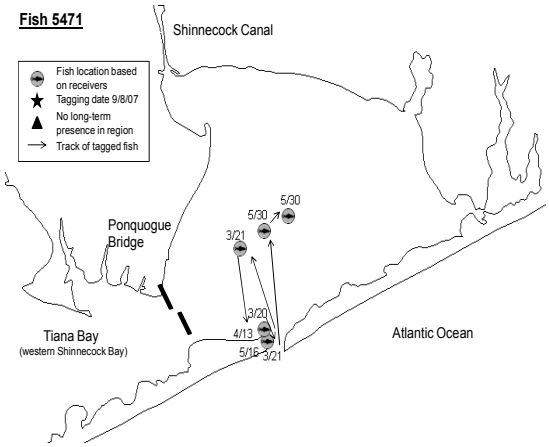
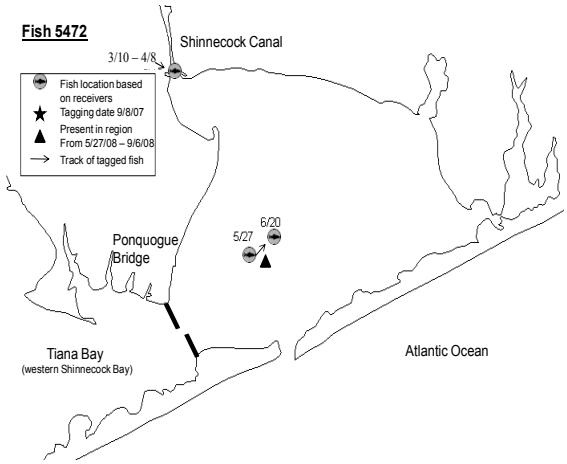
Appendix

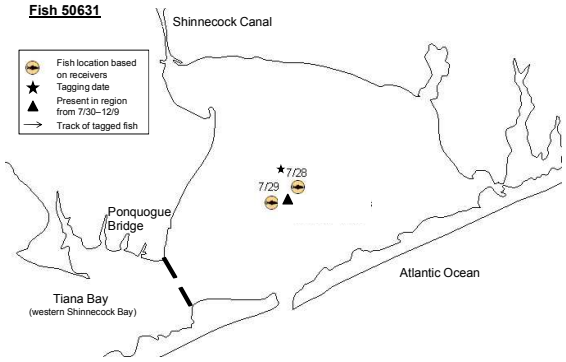
Appendix 2.1 A) Additional Fish Representing Inner Bay Movements with Varying Residence Times.

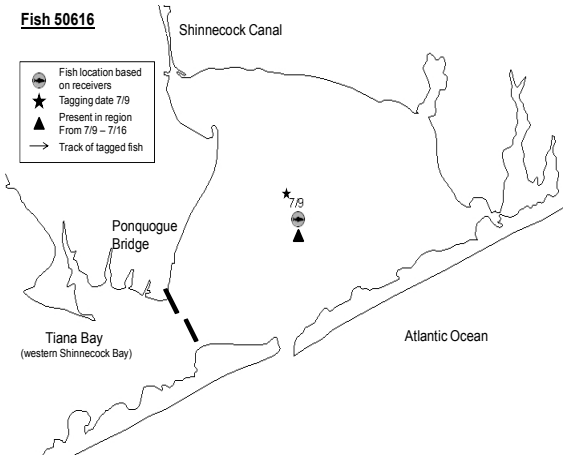


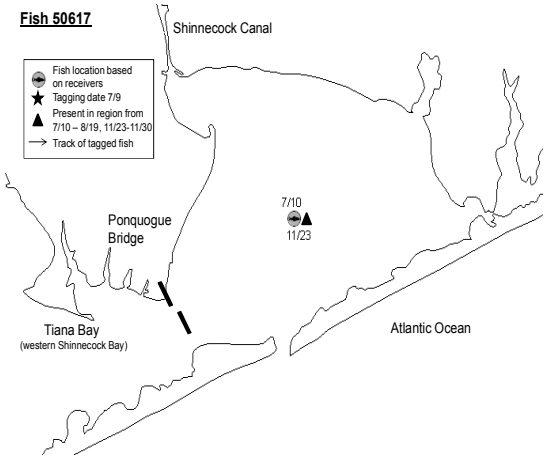








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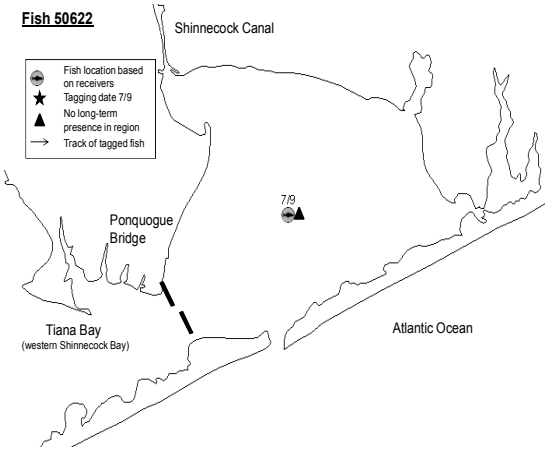
Shinnecock Canal
Fish location based on receivers
Tagging date 7/9
Present in region from 7/10 – 8/19, 11/23-11/30
Track of tagged fish
7/10
11/23
Ponquogue Bridge
Tiana Bay
(western Shinnecock Bay)
Atlantic Ocean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Fish location based on receivers
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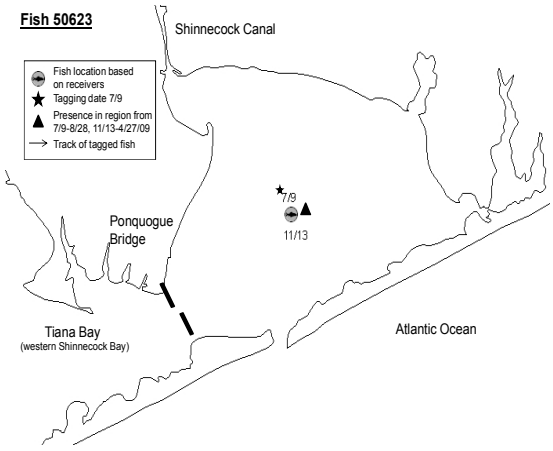
Track of tagged fish
7/9
Ponquogue Bridge
Tiana Bay
(western Shinnecock Bay)
Atlantic Ocean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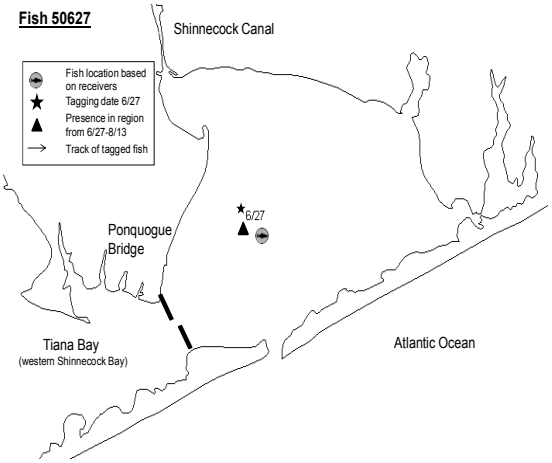
Track of tagged fish
7/9
11/13
Ponquogue Bridge
Tiana Bay
(western Shinnecock Bay)
Atlantic Ocean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Fish location based on receivers
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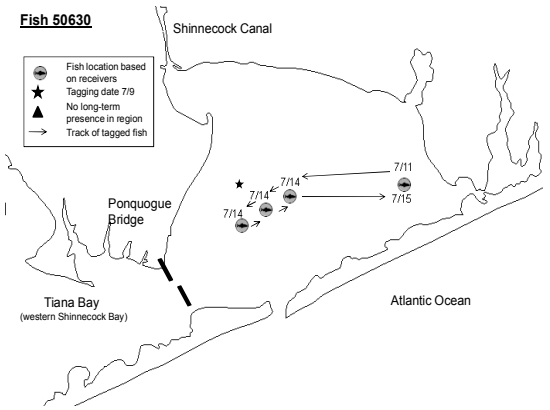
Track of tagged fish
6/27
Ponquogue Bridge
Tiana Bay
(western Shinnecock Bay)
Atlantic Ocean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Shinnecock Canal
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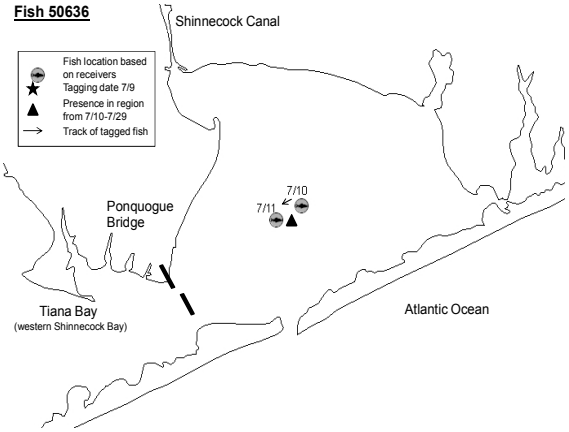
Track of tagged fish
7/11
7/14
7/14
7/14
7/15
Ponquogue Bridge
Tiana Bay
(western Shinnecock Bay)
Atlantic Ocean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Fish location based on receivers
Tagging date 7/9
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Track of tagged fish
7/10
7/11
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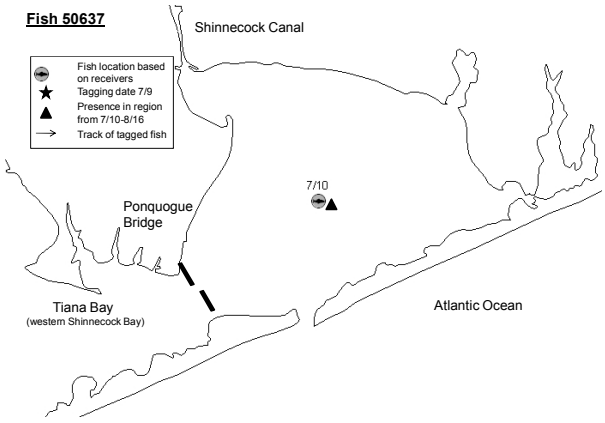
Tiana Bay
(western Shinnecock Bay)
Atlantic Ocean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Fish location based on receivers
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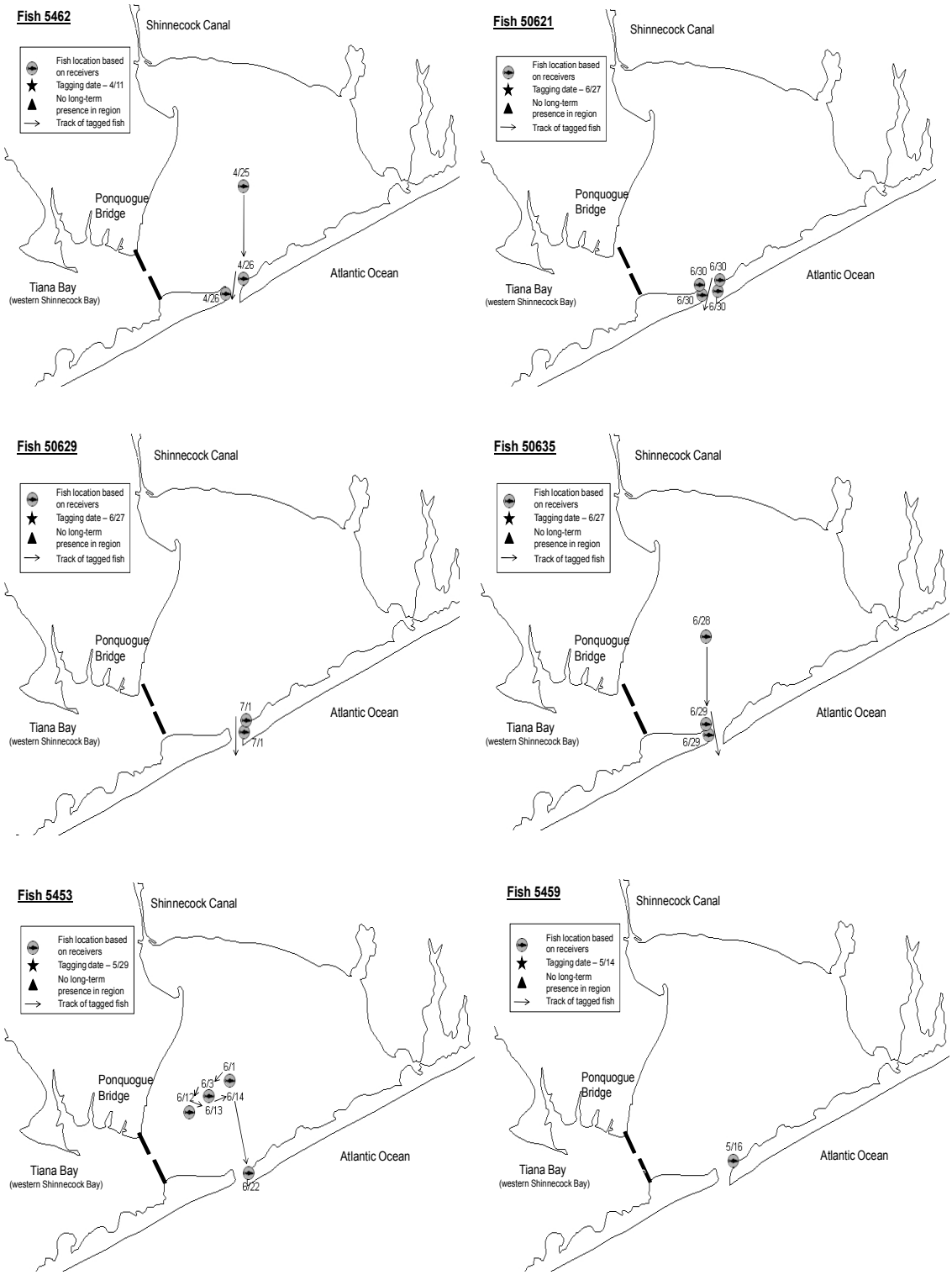
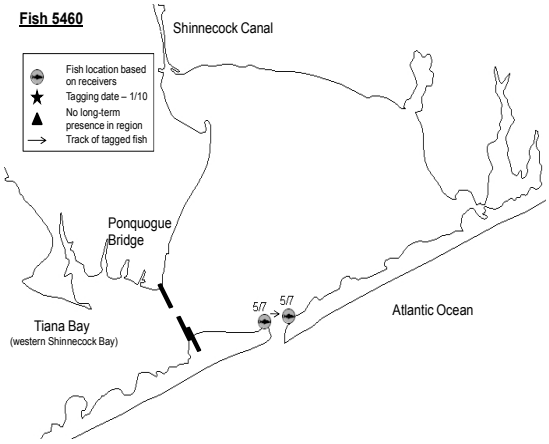
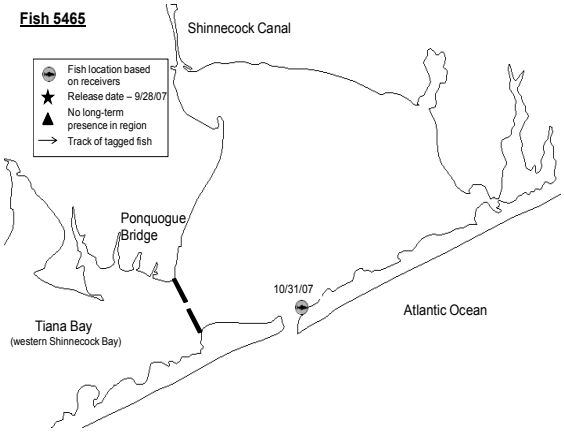
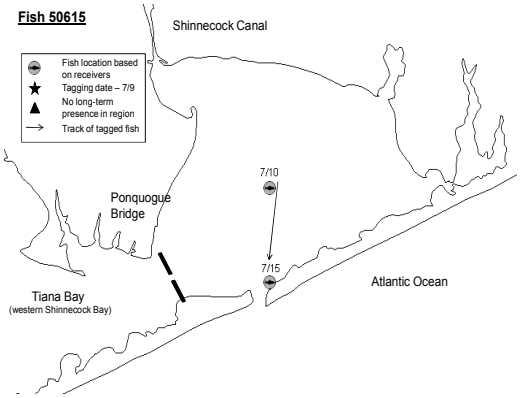
Track of tagged fish
7/10
Ponquogue Bridge
Tiana Bay
(western Shinnecock Bay)
Atlantic Ocean

Appendix 2.1 B) Additional Fish Representing Emigration to Offshore Waters.

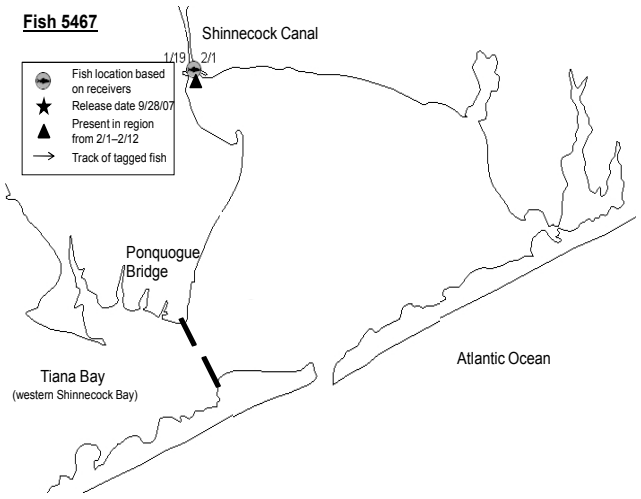



Fish 5460
Shinnecock Canal
Fish location based on receivers
Tagging date – 1/10
No long-term presence in region
Track of tagged fish
Ponquogue Bridge
5/7
5/7
Atlantic Ocean
Tiana Bay
(western Shinnecock Bay)


Fish 5465
Shinnecock Canal
Fish location based on receivers
Release date – 9/28/07
No long-term presence in region
Track of tagged fish
Ponquogue Bridge
10/31/07
Atlantic Ocean
Tiana Bay
(western Shinnecock Bay)


Fish 50615
Shinnecock Canal
Fish location based on receivers
Tagging date – 7/9
No long-term presence in region
Track of tagged fish
7/10
Ponquogue Bridge
7/15
Atlantic Ocean
Tiana Bay
(western Shinnecock Bay)

Appendix 2.1 C) Additional Fish Representing Connectivity to Other Inshore Areas.



Appendix 3.1 Data from Dietary Analysis

		Striped Bass					Bluefish				
Scientific Name	Common Name	%N	%W	%O	IRI	%IRI	%N	%W	%O	IRI	%IRI
Ammodytes sp.	Sand Lance	0	0	0	0	0	0	0	0	0	0
Anchoa mitchilli	Bay Anchovy	0	0	0	0	0	8.78	12.97	7.37	160.24	3.77
Brevoortia tyrannus	Atlantic Menhaden	0	0	0	0	0	19.95	31.55	23.68	1219.72	28.68
Caranx sp.	Jack (tropical)	0	0	0	0	0	0.27	0.40	0.53	0.35	0.01
Clupeidae	Clupeiform	0	0	0	0	0	0	0	0	0	0
Cynoscion regalis	Weakfish	0	0	0	0	0	1.86	7.54	3.68	34.63	0.81
Fundulus heteroclitus	Mummichug	0	0	0	0	0	0.27	0.11	0.53	0.20	0.01
Fundulus majalis	Striped Killifish	0	0	0	0	0	0.53	0.41	1.05	1.00	0.02
Gobiosoma bosci	Naked Goby	0.65	0.14	4.35	3.40	0.15	0	0	0	0	0
Menidia menidia	Atlantic Silverside	0.65	0.02	4.35	2.88	0.13	34.04	33.04	30.00	2012.47	47.32
Microgadus tomcod	Atlantic Tomcod	0	0	0	0	0	0	0	0	0	0
Morone saxatilis	Striped Bass	0	0	0	0	0	0.27	0.21	0.53	0.25	0.01
Myoxocephalus sp.	Sculpin	0	0	0	0	0	0	0	0	0	0
Paralichthys dentatus	Summer Flounder	2.58	45.12	13.04	622.15	28.00	0	0	0	0	0
Peprilus triacanthus	Butterfish	0	0	0	0	0	0	0	0	0	0
Prionotus evolans	Striped Sea Robin	0.65	14.78	4.35	67.05	3.02	0	0	0	0	0
Prionotus sp.	Prionotus sp.	0	0	0	0	0	0	0	0	0	0
Pseudopleuronectes americanus	Winter Flounder	0.65	0.30	4.35	4.10	0.19	0.27	0.74	0.53	0.53	0.01
Selene setapinnis	Moonfish	0	0	0	0	0	0	0	0	0	0
Sphoeroides maculatus	Northern Puffer	4.52	16.11	8.70	179.34	8.07	0	0	0	0	0
Stenotomus chrysops	Scup	0	0	0	0	0	0	0	0	0	0
Syngnathus fuscus	Northern Pipefish	0	0	0	0	0	0	0	0	0	0

		Striped Bass					Bluefish				
Scientific Name	Common Name	%N	%W	%O	IRI	%IRI	%N	%W	%O	IRI	%IRI
Tautoga onitis	Blackfish	0	0	0	0	0	0.27	0.85	0.53	0.59	0.01
Tautogolabrus adspersus	Cunner	0	0	0	0	0	0	0	0	0	0
-	Unid. Flatfish	1.29	1.52	8.70	24.44	1.10	0	0	0	0	0
-	Unid. Fish	5.16	3.21	21.74	181.99	8.19	16.49	8.63	27.37	687.50	16.17
Crangon septemspinosa	Sand Shrimp	52.90	3.37	8.70	489.36	22.02	5.59	2.68	8.95	73.92	1.74
Neomysis sp.	Brine Shrimp	0	0	0	0	0	0	0	0	0	0
Lysiosquilla sp.	Mantis Shrimp	0	0	0	0	0	0	0	0	0	0
Callinectes sapidus	Blue Crab	0	0	0	0	0	0	0	0	0	0
Cancer irroratus	Rock Crab	0	0	0	0	0	0	0	0	0	0
Carcinus maenas	Green Crab	0	0	0	0	0	0	0	0	0	0
Libinia emarginata	Spider Crab	0	0	0	0	0	0	0	0	0	0
Ovalipes ocellatus	Lady Crab	1.29	0.46	4.35	7.62	0.34	0	0	0	0	0
Pagurus sp.	Hermit Crab	2.58	0.28	8.70	24.90	1.12	0	0	0	0	0
Panopeus herbstii	Mud Crab	0.65	0.80	4.35	6.27	0.28	0	0	0	0	0
Amphipoda	Amphipod	0	0	0	0	0	0	0	0	0	0
Copepoda	Copepod	0	0	0	0	0	0	0	0	0	0
Isopoda	Isopod	0	0	0	0	0	0.27	0.01	0.53	0.15	0
-	Unid. Crustacean	16.13	9.07	8.70	219.10	9.86	2.13	0.20	2.11	4.90	0.12
-	Unid. Animal Remains	0	0	0	0	0	0	0	0	0	0
-	Unid. Annelid	0	0	0	0	0	0	0	0	0	0
Nereis sp.	Clam Worm	0	0	0	0	0	0	0	0	0	0
Pseudophyllidea	Cestode	0	0	0	0	0	0	0	0	0	0
-	Mud (tube worm)	0	0	0	0	0	0	0	0	0	0
Bivalvia	Clam	1.94	0.59	8.70	21.95	0.99	0	0	0	0	0
Crassostrea sp.	Oyster	0.65	0.35	4.35	4.32	0.20	0	0	0	0	0

		Striped Bass					Bluefish				
Scientific Name	Common Name	%N	%W	%O	IRI	%IRI	%N	%W	%O	IRI	%IRI
Crepidula sp.	Slipper Shell	0	0	0	0	0	0	0	0	0	0
Ensis directus	Razor Clam	0	0	0	0	0	0	0	0	0	0
Mytilus edulis	Blue Mussel	0	0	0	0	0	0	0	0	0	0
Lunatia heros	Moon Snail	0.65	0.07	4.35	3.11	0.14	0	0	0	0	0
Nassarius trivittatus	New England Dog Whelk	0	0	0	0	0	0	0	0	0	0
Cephalopoda	Squid	0	0	0	0	0	0	0	0	0	0
Zostera marina	Eel Grass	0	0	0	0	0	1.86	0.30	3.68	7.95	0.19
-	MPM	0.65	0.00	4.35	2.81	0.13	4.26	0.17	8.42	37.29	0.88
-	TPM (terrestrial)	0	0	0	0	0	0.27	0.02	0.53	0.15	0.00
-	Nonliving Matter	6.45	3.82	34.78	357.33	16.08	0.53	0.01	1.05	0.58	0.01
-	Unknown	0	0	0	0	0	2.13	0.17	4.74	10.90	0.26

		Summer Flounder					Windowpane				
Scientific Name	Common Name	%N	%W	%O	IRI	%IRI	%N	%W	%O	IRI	%IRI
Ammodytes sp.	Sand Lance	3.03	9.66	3.55	45.01	2.45	0	0	0	0	0
Anchoa mitchilli	Bay Anchovy	4.81	2.30	3.55	25.22	1.37	0.02	0.23	2.38	0.61	0.01
Brevoortia tyrannus	Atlantic Menhaden	0.94	1.09	1.42	2.88	0.16	0	0	0	0	0
Caranx sp.	Jack (tropical)	0	0	0	0	0	0	0	0	0	0
Clupeidae	Clupeiform	0.10	0.15	0.71	0.18	0.01	0	0	0	0	0
Cynoscion regalis	Weakfish	0.42	2.98	3.55	12.05	0.66	0	0	0	0	0
Fundulus heteroclitus	Mummichug	0	0	0	0	0	0	0	0	0	0
Fundulus majalis	Striped Killifish	0	0	0	0	0	0	0	0	0	0

		Summer Flounder					Windowpane				
Scientific Name	Common Name	%N	%W	%O	IRI	%IRI	%N	%W	%O	IRI	%IRI
Gobiosoma bosci	Naked Goby	0.10	0.08	0.71	0.13	0.01	0	0	0	0	0
Menidia menidia	Atlantic Silverside	2.93	3.94	5.67	38.98	2.12	0	0	0	0	0
Microgadus tomcod	Atlantic Tomcod	0.10	0.16	0.71	0.19	0.01	0	0	0	0	0
Morone saxatilis	Striped Bass	0	0	0	0	0	0	0	0	0	0
Myoxocephalus sp.	Sculpin	0	0	0	0	0	0	0	0	0	0
Paralichthys dentatus	Summer Flounder	0	0	0	0	0	0	0	0	0	0
Peprilus triacanthus	Butterfish	0.52	0.12	0.71	0.45	0.02	0	0	0	0	0
Prionotus evolans	Striped Sea Robin	0.10	0.81	0.71	0.65	0.04	0	0	0	0	0
Prionotus sp.	Prionotus sp.	0	0	0	0	0	0	0	0	0	0
Pseudopleuronectes americanus	Winter Flounder	0.52	1.60	3.55	7.54	0.41	0	0	0	0	0
Selene setapinnis	Moonfish	0.21	0.76	0.71	0.69	0.04	0	0	0	0	0
Sphoeroides maculatus	Northern Puffer	0	0	0	0	0	0	0	0	0	0
Stenotomus chrysops	Scup	0.52	4.42	1.42	7.02	0.38	0	0	0	0	0
Syngnathus fuscus	Northern Pipefish	0.21	0.08	1.42	0.42	0.02	0.02	0.08	2.38	0.25	0
Tautoga onitis	Blackfish	0	0	0	0	0	0	0	0	0	0
Tautogolabrus adspersus	Cunner	0.42	0.18	2.84	1.71	0.09	0	0	0	0	0
-	Unid. Flatfish	0	0	0	0	0	0	0	0	0	0
-	Unid. Fish	3.45	12.36	13.48	213.01	11.59	0.02	0.01	2.38	0.07	0
Crangon septemspinosa	Sand Shrimp	25.21	12.58	25.53	964.85	52.52	2.90	36.09	45.24	1763.84	14.90
Neomysis sp.	Brine Shrimp	39.54	1.09	2.13	86.44	4.70	96.49	59.90	64.29	10054.02	84.95
Lysiosquilla sp.	Mantis Shrimp	1.57	17.97	9.22	180.18	9.81	0	0	0	0	0
Callinectes sapidus	Blue Crab	0	0	0	0	0	0	0	0	0	0
Cancer irroratus	Rock Crab	5.96	13.93	8.51	169.32	9.22	0	0	0	0	0
Carcinus maenas	Green Crab	0.42	0.39	2.84	2.31	0.13	0	0	0	0	0

		Summer Flounder					Windowpane				
Scientific Name	Common Name	%N	%W	%O	IRI	%IRI	%N	%W	%O	IRI	%IRI
Libinia emarginata	Spider Crab	0	0	0	0	0	0	0	0	0	0
Ovalipes ocellatus	Lady Crab	0.63	0.76	2.84	3.93	0.21	0	0	0	0	0
Pagurus sp.	Hermit Crab	0.10	0.22	0.71	0.23	0.01	0	0	0	0	0
Panopeus herbstii	Mud Crab	0.10	0.08	0.71	0.13	0.01	0	0	0	0	0
Amphipoda	Amphipod	0.21	0.04	1.42	0.36	0.02	0.09	0.15	2.38	0.56	0.01
Copepoda	Copepod	0	0	0	0	0	0.13	0.16	4.76	1.40	0.01
Isopoda	Isopod	0	0	0	0	0	0	0	0	0	0
-	Unid. Crustacean	0	0	0	0	0	0	0	0	0	0
-	Unid. Animal Remains	0	0	0	0	0	0	0	0	0	0
-	Unid. Annelid	0	0	0	0	0	0	0	0	0	0
Nereis sp.	Clam Worm	1.57	2.90	5.67	25.35	1.38	0	0	0	0	0
Pseudophyllidea	Cestode	0	0	0	0	0	0.07	2.12	4.76	10.41	0.09
-	Mud (tube worm)	0.42	0.06	2.84	1.37	0.07	0	0	0	0	0
Bivalvia	Clam	0.10	0.01	0.71	0.08	0	0.02	0.02	2.38	0.11	0
Crassostrea sp.	Oyster	0	0	0	0	0	0	0	0	0	0
Crepidula sp.	Slipper Shell	0	0	0	0	0	0	0	0	0	0
Ensis directus	Razor Clam	0.21	0.41	1.42	0.88	0.05	0	0	0	0	0
Mytilus edulis	Blue Mussel	2.72	0.68	7.09	24.08	1.31	0.02	0.00	2.38	0.06	0
Lunatia heros	Moon Snail	0	0	0	0	0	0	0	0	0	0
Nassarius trivittatus	New England Dog Whelk	0.21	0.15	1.42	0.51	0.03	0	0	0	0	0
Cephalopoda	Squid	0.21	7.19	1.42	10.49	0.57	0	0	0	0	0
Zostera marina	Eel Grass	0.73	0.14	4.96	4.32	0.24	0.02	0.00	2.38	0.05	0.00
-	MPM	0.10	0.07	0.71	0.12	0.01	0.04	0.10	4.76	0.66	0.01
-	TPM (terrestrial)	0	0	0	0	0	0	0	0	0	0

		Summer Flounder					Windowpane				
Scientific Name	Common Name	%N	%W	%O	IRI	%IRI	%N	%W	%O	IRI	%IRI
-	Nonliving Matter	0.21	0.23	1.42	0.63	0.03	0.17	1.17	2.38	3.20	0.03
-	Unknown	0.73	0.30	2.84	2.94	0.16	0.02	0.06	2.38	0.18	0.00

		Striped Sea Robin					Clearnose Skate				
Scientific Name	Common Name	%N	%W	%O	IRI	%IRI	%N	%W	%O	IRI	%IRI
Ammodytes sp.	Sand Lance	1.17	1.78	2.78	8.19	0.08	0	0	0	0	0
Anchoa mitchilli	Bay Anchovy	0	0	0	0	0	0	0	0	0	0
Brevoortia tyrannus	Atlantic Menhaden	0	0	0	0	0	0	0	0	0	0
Caranx sp.	Jack (tropical)	0	0	0	0	0	0	0	0	0	0
Clupeidae	Clupeiform	0	0	0	0	0	0	0	0	0	0
Cynoscion regalis	Weakfish	0	0	0	0	0	0	0	0	0	0
Fundulus heteroclitus	Mummichug	0	0	0	0	0	0	0	0	0	0
Fundulus majalis	Striped Killifish	0	0	0	0	0	0	0	0	0	0
Gobiosoma bosci	Naked Goby	0	0	0	0	0	0	0	0	0	0
Menidia menidia	Atlantic Silverside	0.17	0.64	2.78	2.25	0.02	0.30	0.32	5.00	3.10	0.02
Microgadus tomcod	Atlantic Tomcod	0	0	0	0	0	0	0	0	0	0
Morone saxatilis	Striped Bass	0	0	0	0	0	0	0	0	0	0
Myoxocephalus sp.	Sculpin	0	0	0	0	0	0.30	0.68	5.00	4.88	0.04
Paralichthys dentatus	Summer Flounder	0	0	0	0	0	0	0	0	0	0
Peprilus triacanthus	Butterfish	0	0	0	0	0	0	0	0	0	0
Prionotus evolans	Striped Sea Robin	0	0	0	0	0	0	0	0	0	0
Prionotus sp.	Prionotus sp.	0	0	0	0	0	0	0	0	0	0

		Striped Sea Robin					Clearnose Skate				
Scientific Name	Common Name	%N	%W	%O	IRI	%IRI	%N	%W	%O	IRI	%IRI
Pseudopleuronectes americanus	Winter Flounder	0.17	0.41	2.78	1.61	0.02	0	0	0	0	0
Selene setapinnis	Moonfish	0	0	0	0	0	0	0	0	0	0
Sphoeroides maculatus	Northern Puffer	0	0	0	0	0	0	0	0	0	0
Stenotomus chrysops	Scup	0.17	1.11	2.78	3.54	0.03	0	0	0	0	0
Syngnathus fuscus	Northern Pipefish	0.17	0.22	2.78	1.08	0.01	0	0	0	0	0
Tautoga onitis	Blackfish	0	0	0	0	0	0	0	0	0	0
Tautogolabrus adspersus	Cunner	0	0	0	0	0	0	0	0	0	0
-	Unid. Flatfish	0	0	0	0	0	0	0	0	0	0
-	Unid. Fish	0.33	1.03	2.78	3.80	0.04	0.89	0.23	15.00	16.74	0.13
Crangon septemspinosa	Sand Shrimp	69.57	70.42	72.22	10109.89	97.42	42.01	9.85	65.00	3370.91	26.06
Neomysis sp.	Brine Shrimp	22.91	0.54	2.78	65.15	0.63	0	0	0	0	0
Lysiosquilla sp.	Mantis Shrimp	0	0	0	0	0	0	0	0	0	0
Callinectes sapidus	Blue Crab	0	0	0	0	0	0.30	0.29	5.00	2.91	0.02
Cancer irroratus	Rock Crab	1.84	1.33	8.33	26.41	0.25	38.17	64.59	85.00	8734.33	67.52
Carcinus maenas	Green Crab	0	0	0	0	0	0	0	0	0	0
Libinia emarginata	Spider Crab	0	0	0	0	0	1.78	14.69	25.00	411.67	3.18
Ovalipes ocellatus	Lady Crab	0.67	12.94	8.33	113.39	1.09	10.36	8.93	15.00	289.25	2.24
Pagurus sp.	Hermit Crab	0.17	8.73	2.78	24.72	0.24	0	0	0	0	0
Panopeus herbstii	Mud Crab	0	0	0	0	0	0.30	0.08	5.00	1.86	0.01
Amphipoda	Amphipod	0.33	0.11	2.78	1.23	0.01	0	0	0	0	0
Copepoda	Copepod	0	0	0	0	0	0	0	0	0	0
Isopoda	Isopod	0	0	0	0	0	0	0	0	0	0
-	Unid. Crustacean	0	0	0	0	0	0	0	0	0	0

		Striped Sea Robin					Clearnose Skate				
Scientific Name	Common Name	%N	%W	%O	IRI	%IRI	%N	%W	%O	IRI	%IRI
-	Unid. Animal Remains	0	0	0	0	0	0	0	0	0	0
-	Unid. Annelid	0	0	0	0	0	0	0	0	0	0
Nereis sp.	Clam Worm	0	0	0	0	0	0	0	0	0	0
Pseudophyllidea	Cestode	0	0	0	0	0	0	0	0	0	0
-	Mud (tube worm)	0	0	0	0	0	0.30	0.01	5.00	1.51	0.01
Bivalvia	Clam	0.67	0.05	5.56	4.02	0.04	0	0	0	0	0
Crassostrea sp.	Oyster	0	0	0	0	0	0	0	0	0	0
Crepidula sp.	Slipper Shell	0	0	0	0	0	0	0	0	0	0
Ensis directus	Razor Clam	0.17	0.12	2.78	0.79	0.01	0	0	0	0	0
Mytilus edulis	Blue Mussel	0	0	0	0	0	4.44	0.22	20.00	93.18	0.72
Lunatia heros	Moon Snail	0	0	0	0	0	0	0	0	0	0
Nassarius trivittatus	New England Dog Whelk	0	0	0	0	0	0	0	0	0	0
Cephalopoda	Squid	0	0	0	0	0	0	0	0	0	0
Zostera marina	Eel Grass	0.17	0.01	2.78	0.48	0.01	0.30	0.04	5.00	1.69	0.01
-	MPM	0.17	0.02	2.78	0.52	0.01	0.30	0.05	5.00	1.74	0.01
-	TPM (terrestrial)	0.17	0.20	2.78	1.03	0.01	0.30	0.03	5.00	1.61	0.01
-	Nonliving Matter	1.00	0.34	13.89	18.66	0.18	0	0	0	0	0
-	Unknown	0	0	0	0	0	0	0	0	0	0

		Oyster Toadfish					Scup				
Scientific Name	Common Name	%N	%W	%O	IRI	%IRI	%N	%W	%O	IRI	%IRI
Ammodytes sp.	Sand Lance	0	0	0	0	0	-	0	-	-	-
Anchoa mitchilli	Bay Anchovy	0	0	0	0	0	-	0	-	-	-
Brevoortia tyrannus	Atlantic Menhaden	0	0	0	0	0	-	0.96	-	-	-
Caranx sp.	Jack (tropical)	0	0	0	0	0	-	0	-	-	-
Clupeidae	Clupeiform	0	0	0	0	0	-	0	-	-	-
Cynoscion regalis	Weakfish	0	0	0	0	0	-	0	-	-	-
Fundulus heteroclitus	Mummichug	0	0	0	0	0	-	0	-	-	-
Fundulus majalis	Striped Killifish	0	0	0	0	0	-	0	-	-	-
Gobiosoma bosci	Naked Goby	0	0	0	0	0	-	0	-	-	-
Menidia menidia	Atlantic Silverside	0	0	0	0	0	-	0	-	-	-
Microgadus tomcod	Atlantic Tomcod	0	0	0	0	0	-	0	-	-	-
Morone saxatilis	Striped Bass	0	0	0	0	0	-	0	-	-	-
Myoxocephalus sp.	Sculpin	0	0	0	0	0	-	0	-	-	-
Paralichthys dentatus	Summer Flounder	0	0	0	0	0	-	0	-	-	-
Peprilus triacanthus	Butterfish	0	0	0	0	0	-	0	-	-	-
Prionotus evolans	Striped Sea Robin	0	0	0	0	0	-	0	-	-	-
Prionotus sp.	Prionotus sp.	0	0	0	0	0	-	0	-	-	-
Pseudopleuronectes americanus	Winter Flounder	0	0	0	0	0	-	0	-	-	-
Selene setapinnis	Moonfish	0	0	0	0	0	-	0	-	-	-
Sphoeroides maculatus	Northern Puffer	0	0	0	0	0	-	0	-	-	-
Stenotomus chrysops	Scup	0	0	0	0	0	-	0	-	-	-
Syngnathus fuscus	Northern Pipefish	0	0	0	0	0	-	0	-	-	-
Tautoga onitis	Blackfish	0	0	0	0	0	-	0	-	-	-
Tautogolabrus adspersus	Cunner	0	0	0	0	0	-	0	-	-	-

		Oyster Toadfish					Scup				
Scientific Name	Common Name	%N	%W	%O	IRI	%IRI	%N	%W	%O	IRI	%IRI
-	Unid. Flatfish	0	0	0	0	0	-	0	-	-	-
-	Unid. Fish	1.12	16.73	9.09	162.28	2.29	-	2.09	-	-	-
Crangon septemspinosa	Sand Shrimp	0	0	0	0	0	-	2.46	-	-	-
Neomysis sp.	Brine Shrimp	0	0	0	0	0	-	2.64	-	-	-
Lysiosquilla sp.	Mantis Shrimp	0	0	0	0	0	-	0	-	-	-
Callinectes sapidus	Blue Crab	0	0	0	0	0	-	0	-	-	-
Scientific Name	Common Name	%N	%W	%O	IRI	%IRI	%N	%W	%O	IRI	%IRI
Cancer irroratus	Rock Crab	1.12	2.21	9.09	30.34	0.43	-	0.13	-	-	-
Carcinus maenas	Green Crab	0	0	0	0	0	-	0	-	-	-
Libinia emarginata	Spider Crab	0	0	0	0	0	-	0	-	-	-
Ovalipes ocellatus	Lady Crab	0	0	0	0	0	-	0	-	-	-
Pagurus sp.	Hermit Crab	0	0	0	0	0	-	0.68	-	-	-
Panopeus herbstii	Mud Crab	11.24	56.73	27.27	1853.64	26.2	-	5.81	-	-	-
Amphipoda	Amphipod	0	0	0	0	0	-	0	-	-	-
Copepoda	Copepod	0	0	0	0	0	-	0	-	-	-
Isopoda	Isopod	0	0	0	0	0	-	0.01	-	-	-
-	Unid. Crustacean	0	0	0	0	0	-	1.44	-	-	-
-	Unid. Animal Remains	0	0	0	0	0	-	5.49	-	-	-
-	Unid. Annelid	0	0	0	0	0		10.34			
Nereis sp.	Clam Worm	0	0	0	0	0	-	0	-	-	-
Pseudophyllidea	Cestode	0	0	0	0	0	-	0	-	-	-
-	Mud (tube worm)	0	0	0	0	0	-	0	-	-	-
Bivalvia	Clam	0	0	0	0	0	-	62.30	-	-	-
Crassostrea sp.	Oyster	0	0	0	0	0	-	0	-	-	-
Crepidula sp.	Slipper Shell	0	0	0	0	0	-	0.07	-	-	-

		Oyster Toadfish					Scup					
Scientific Name	Common Name	%N	%W	%O	IRI	%IRI	%N	%W	%O	IRI	%IRI	
Ensis directus	Razor Clam	0	0	0	0	0	-	0		-	-	-
Mytilus edulis	Blue Mussel	0	0	0	0	0	-	0		-	-	-
Lunatia heros	Moon Snail	0	0	0	0	0	-	0		-	-	-
Nassarius trivittatus	New England Dog Whelk	0	0	0	0	0	-	0		-	-	-
Cephalopoda	Squid	0	0	0	0	0	-	0		-	-	-
Zostera marina	Eel Grass	0	0	0	0	0	-	0		-	-	-
-	MPM	86.52	24.33	45.46	5038.41	71.12	-	0.03		-	-	-
-	TPM (terrestrial)	0	0	0	0	0	-	0		-	-	-
-	Nonliving Matter	0	0	0	0	0	-	0		-	-	-
-	Unknown	0	0	0	0	0	-	5.55		-	-	-