Abundance, Mortality, Age and Growth of Young of the Year Winter Flounder (*Pseudopleuronectes americanus*) in Two Locations on Long Island

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Abstract of the Thesis

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Winter flounder (*Pseudopleuronectes americanus* Walbaum) are a commercially and recreationally important species of fin-fish that have experienced a precipitous decline in abundance during the last decade. In Long Island waters, there appears to be a failure in recruitment of young of the year (YOY) fish to the adult fishery and population structure of this life-stage is poorly understood. To gauge vital rates of YOY, abundance, instantaneous mortality rates, age, growth and settlement date frequency were estimated. Fish were collected with beach seines and a 1 m. beam trawl in two contrasting bays of Long Island, Shinnecock Bay and Port Jefferson Harbor. These bays represent the key habitat differences between the south shore and north shore of Long Island. CPUE values for each gear type and year were estimated for each location and mortality was estimated by implementing catch-curve analysis for each location, gear and year of sampling. Age was estimated by counting daily increments deposited on otoliths. To calculate growth rate, field-derived and otolith-derived growth rates were estimated and compared. Finally, mortality rate, age and the change in cumulative mortality with age over time were combined to conduct a settlement date and modal analysis.

Abundance was higher in 2007 for both locations. Mortality rates were not significantly different between locations and years and ranged from 0.02-0.03/day,

indicating a 2-3% chance that an individual YOY may die per day. Growth rates were not significantly different either between locations and years as well. Settlement date and modal analysis indicated that each site contained 2-3 cohorts of newly settled winter flounder.

Winter flounder in Long Island bays are experiencing high mortality rates which would not be expected with low abundance. Compared to other studies along the eastern seaboard our mortality rates are higher or are within the upper range of mortalities experienced by YOY at high population densities. A possible explanation for this is predation. A previous diet study conducted in Long Island bays indicated that YOY were a component of piscivorous fish diets and if predator abundance was high it could cause a substantial loss of YOY due to predation (Sagarese, 2009). Growth rates, although not significantly different, were slightly lower in 2008 which is also counter to expectations. Results of field-growth were inconsistent and combined with results of settlement date analysis, indicate otolith-derived growth rates are a more appropriate method for Long Island bays since the presence of multiple cohorts may skew field based estimates.

Further research is necessary to fully understand the dynamics of these systems. This includes further acoustic tagging, genetic studies and correlations with abiotic environmental factors as well as habitat characterization. The results of this Thesis suggest ecosystem-based management may be appropriate in these systems since predation may be a key factor in the apparent recruitment failure of winter flounder in Long Island waters.

Dedication

This thesis is dedicated to my loving and supportive parents, John and Julie Yencho. They have seen me through all the hardships and joys of life and my entire academic experience. Their pride in me has been an inspiration to strive to be the best I can in whatever I attempt.

I would also like to dedicate this work to my grandparents, Tillman and Athlene Hagar, who have always stressed the importance of being an educated young lady and always encouraged me to peak over the next mountaintop. You are remembered everyday and it has been an honor to make you proud.

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The winter flounder project was started from scratch and a large field database was necessary. I could definitely not have finished my field sampling without the support of my lab mates, especially Skylar Sagarese. She and I started as first years and saw each other through many challenges and I am grateful for her assistance. Other lab mates that were instrumental to the conclusion of this project include: Matthew Nuttal, Chris Martinez, Carolyn Hall and Keith Dutton.

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Introduction to Project:

Throughout the world, many fisheries are in decline and continuing research is needed to understand population dynamics which could lead to management improvements and recovery of stocks. A local example of this problem is the winter flounder (*Pseudopleuronectes americanus*) fishery on Long Island. The winter flounder found in Long Island waters belong to the Southern New England/Mid-Atlantic Bight stock which has experienced a precipitous decline in the last two decades with commercial catches of 11,000+ mt in 1981 to 1,200 mt in 2005 and recreational catches of 5,800 mt in 1984 to 120 mt in 2005 (Pereira et al., 1999; Hendrickson et al., 2006). Currently, the National Marine Fisheries Service estimates that the SNE/MAB winter flounder population is at 9% of its target level and federal waters are closed to winter flounder fishing in areas south of Cape Cod (Atlantic States Marine Fisheries Commission Press Release, 2009). Catches of winter flounder in Long Island have mirrored the trends observed in the SNE/MAB stock at large.

Winter flounder spend the first two years of life in the shallow bays and estuaries in which they are spawned (Bigelow and Schroeder, 1953). Adult winter flounder are migratory and spend summers in deep water temperature refugia and return to shallow waters to spawn in the winter (Pereira et al., 1999). However, population dynamics are poorly understood. For example, historically, Long Island winter flounder on the south shore have been thought to be comprised of two stocks: an inshore resident population (“bay fish”) in addition to the migratory contingent (Lobell, 1938).

Another aspect of winter flounder population dynamics that is poorly understood is the apparent recruitment failure occurring between settlement (completion of metamorphosis from the fusiform free swimming stage to depressiform benthic form) and year 1 (Bigelow and Schroeder, 1953; Socrates and Colvin, 2006). Understanding the basic population statistics of young of the year (YOY) winter flounder is vital in understanding the processes which are effecting recruitment into later life stages.

The project aims to quantify mortality, age, growth and abundance of YOY winter flounder that reside within the waters of Long Island. Two contrasting environments will be studied in order to gauge similarities and differences between vital rates between the south and north shore. The south shore was represented by Shinnecock Bay, a shallow coastal bay with softer sediment bottoms, sea grass and warmer temperatures with a direct connection to the Atlantic Ocean. The north shore site was Port Jefferson Harbor, an area with deeper cool water refugia in addition to rockier bottoms with patches of soft sediments and marsh grass. Port Jefferson Harbor is connected to Long Island Sound. Furthermore, historical studies have indicated that Shinnecock Bay was once home to a population of “bay fish” which have experienced drastic declines and anecdotal evidence suggested “bay fish” are close to local extinction (Sagarese, 2009; Lobell, 1938).

The study spans two years (2007 and 2008) in order to investigate if there are annual differences in vital rates among the study areas. Mortality was quantified using a catch-curve analysis, a method commonly utilized in fisheries management, which gives an estimate of mortality by tracking the decrease in a cohort over time. Fish age was determined by counting daily growth rings of otoliths obtained from fish caught during field sampling. This data was also used to estimate growth rates for each year and location. Changes in length over time were also used to calculate field data based estimates of growth. To gauge abundance, CPUE values were calculated for each location, year and gear.

Comparing results obtained from each site will give insight into what factors might be effecting development and recruitment of winter flounder, which areas might be more beneficial to recruitment and how vital rates vary temporally. Analyses will also give insight into the population dynamics of the YOY winter flounder as well as the activity of spawning adults. The results of this study will aid in the overall understanding of the population dynamics of YOY winter flounder on both coasts of Long Island. This data could potentially aid managers in making decisions regarding the Long Island winter flounder fishery.

Abundance, Mortality, Age and Growth of Young-of-Year Winter Flounder (*Pseudopleuronectes americanus*) in Two Locations on Long Island

Introduction

Winter Flounder (*Pseudopleuronectes americanus* walbaum) are a right-eyed flounder with a geographic range that extends from Labrador, Canada to Georgia, United States (Bigelow and Schroeder, 1953). Throughout the northeastern US range, winter flounder supports recreational and commercial fisheries with management recognizing the following three stocks: Gulf of Maine, Southern New England/Mid-Atlantic Bight and Georges Bank (Brown and Gabriel, 1998). Historically, the highest domestic fisheries landings were peaks of 12,000 mt in the mid 1960's and over 11,000 mt in 1981 (Hendrickson et al., 2006). However, landings declined thereafter and reached a low of 1,200 mt in 2005 (Hendrickson et al., 2006). Recreational landings have also decreased from 5,800 mt in 1984 to just 120 mt in 2005 (Hendrickson et al., 2006). In 2009, National Marine Fisheries Service's stock assessment indicated that the SNE/MAB winter flounder population was at 9% of its target level and a closure south of Cape Cod was enacted in Federal waters to support rebuilding of the stock (Atlantic States Marine Fisheries Commission Press Release, 2009). Due to location, populations of winter flounder along the coast of Long Island, NY, are considered part of the southern New England/Mid-Atlantic (SNE/MAB) stock (Pereira et al., 1999). The declining size of the SNE/MAB stock has been mirrored in winter flounder populations associated with Long Island.

While the Bays and shores of Long Island have supported commercial and recreational winter flounder fisheries since the early 1900's (Lobell, 1938), fisheries catches and abundance indices of populations in Long Island Bays have reached record lows and the species is nearly absent in areas once supporting active fisheries (Sagarese, 2009; Socrates and Colvin, 2006). In addition to the documented overfishing of the species, other theories of winter flounder's decline include the following: overfishing of spawning adults, environmental change, and predation by crustaceans and finfish (Fairchild and Howell, 2000; Taylor and Collie, 2003; Manderson et al., 2000; Scharf et al., 2006). Winter flounder recruitment to the age of settlement has increased in recent years in Long Island waters, a response expected from a population at low abundance. Population renewal theory states that density-dependant processes compensate for decreased abundance through higher survivorship, growth and improved recruitment (Walters and Martell, 2004). Mortality generally decreases with age and thus, on the basis of settlement recruitment, populations should be increasing. However, all indicators suggest that winter flounder in the Bays of Long Island are not successfully recruiting to older age classes and the population and fishery show no signs of a recovery (NEFSC, 2009; Socrates and Colvin, 2006).

Recruitment is defined as the addition of new individuals into a later life stage or fishery (Caley et al., 1996). The early life history of fishes, in particular, is marked by high and variable growth and mortality (Sogard et al., 2001; Houde 1989; Miller et al., 1988) as a result of increased susceptibility to fluctuations in local abiotic and biotic factors that alter growth rates of newly spawned and juvenile fish including: environmental quality, prey availability, density of competitors (both other species and conspecifics), temperature, salinity and dissolved oxygen (Sogard, 1992; Meise et al., 2003; DeLong et al., 2001; Bejda et al., 1992). Anthropogenic factors, such as pollution, and the presence of man-made structures in nursery grounds also affect growth rates (Meise et al., 2003; Able et al., 1999) and hence survival. It is important to acknowledge that growth rates in young fish can be variable due to large scale factors (e.g. temperature, entrainment) as well as local environmental constraints (Sogard et al., 2001; Houde, 1989). In declining species, such as the winter flounder, it is important to understand which of these causal factors are responsible for reducing recruitment and, most importantly, what management actions can be taken to help stocks recover.

Growth rates can be affected by the environment and this in turn can alter the population dynamics of YOY winter flounder (Sogard, 1992). Rates of growth and mortality are closely linked during early life history stages of fish (Miller et al., 1988) such that larger fish tend to experience lowered rates of mortality (Houde, 1989; Pepin 1991; Houde, 1997). Thus, individuals reaching a larger size earlier in life have a higher probability of surviving into the next year, known as the “bigger is better hypothesis” (Miller et al., 1988; Houde 1987). This may be due to “outgrowing” predators, increased ability to tolerate environmental changes and decreased chance of starvation (Sogard, 1997). The process whereby larger size offers protection from a certain range of predators, as well as aid in foraging and evasive movements, is known as size-dependent mortality (Taylor, 2004; Miller et al., 1988). In addition, juvenile fish experiencing slower grow may spend more time vulnerable to predators than faster growers and may also have a competitive disadvantage when it comes to feeding (growth-dependent mortality). Growth during the juvenile stage can remain high and variable (Sogard et al., 2001; Houde 1989; Pepin, 1993) until a slowing of growth rate as fish attain larger sizes (Meise et al., 1999). Due to the importance of size in the early life history of fish, variations in the growth of young fish can have far reaching consequences. Furthermore, changes in growth rate need not be large to have an impact during early life stages. For example, Houde (1989) found that growth variations as small as 5% per day can ultimately cause survivability to fluctuate by an order of magnitude in some species. Changes on the scale of orders of magnitude affect recruitment to later age classes and ultimately, the fishery.

In addition to growth, age is another aspect that is important in understanding population dynamics and recruitment. Knowing the age of fish can give insight into the timing of important life events (hatching, metamorphosis, spawning events) as well as indicate fluctuations in growth not easily deduced by field data alone. Furthermore, many fisheries models rely on accurate ageing for assessment or forecasting because classic models based on length of fish alone ignore important changes in vital rates which occur over time. For example, researchers have called for the addition of ageing data into mortality studies of young fish due to the fact that mortality and growth rates can change as fish age and grow, thus altering estimates of vital rates, over a relatively short time frame (Pepin, 1993). Furthermore, calculations based on length frequency and/or studies pooling individuals may at times introduce bias to estimates, ignore small fluctuations with time or cover over individual variations which may prove important (Pepin, 1993; Miller et al., 1988).

Fish otoliths are a powerful ageing tool. These calcified structures serve as a record of age, growth and even location (Campana, 2001). Numerous validation studies have shown that the otoliths of many larval and juvenile fish contain rings corresponding to daily age and that measurements of the widths between these rings correspond to daily somatic growth (Campana and Neilson, 1985). Once a relationship between somatic and otolith growth has been established, a researcher has a means to calculate variations in growth on a much finer scale than is usually available with length-based measures alone. This is invaluable in terms of comparisons of vital rates both within and among study locations as well as over time.

Validation studies have shown that YOY winter flounder do produce otolith rings that correspond to daily age and can be used to back calculate somatic growth (Sogard, 1991). However, there are a few key differences between the information available in a flatfish otolith versus a fusiform fish otolith. Winter flounder otoliths contain two growth centers, or primordia, due to the fact that as larvae hatch they are free swimming and pelagic but gradually metamorphose to a flat bottom-oriented juvenile. Metamorphosis includes a complex re-working of skeletal structures as fish change from a bilaterally symmetric fusiform shape to a depressiform shape oriented to the benthic envornment. Modifications in skull structure cause otoliths to shift from being perpendicular in orientation to the benthos to being parallel in orientation (Sogard, 1991). This time period is preserved in the otolith by the formation of a secondary growth center and the presence of this structure can be used to age winter flounder to settlement date (Sogard, 1991). Settlement occurs roughly two to three months after larvae hatch (depending on temperature) thus making estimation of spawning events possible as well (Sogard, 1991; Pereira et al., 1999).

Spawning normally occurs during the late winter throughout the spring (Pereira et al., 1999). Once fertilized, demersal eggs hatch in roughly 2 to 3 weeks (Pereira et al., 1999). Upon hatching, winter flounder larvae remain pelagic eventually becoming more benthic as metamorphosis approaches. Metamorphosis is complete when the left eye migrates to the right side of the body, which is typically completed at 8 weeks of age, when winter flounder larvae reach a total length of 9-13 mm (Pereira et al., 1999). It is after this process that the fish is considered fully settled (Bigelow and Schroeder, 1953). The young fish overwinter inside coastal bays and estuaries during their first year of life reaching a total length of 100 mm, and begin movements into the open ocean after the second summer (Bigelow and Schroeder, 1953). Generally, adult winter flounder are migratory, inhabiting cool offshore waters during the summer months returning to inshore bays and estuaries when temperatures cool; however, some fish do remain close to spawning grounds throughout the entire year (Pereira et al., 1999). Stock structure on Long Island appears to be complex and poorly understood with fisheries targeting fish from both an inshore (resident or "bay fish") and offshore (migratory) contingent or population of winter flounder (Poole, 1969; Sagarese, 2009; Lobell, 1938). A recent acoustic tagging study supports the continued existence of a remnant of the inshore resident winter flounder population, but it remains unclear whether resident and migratory fish are separate genetic populations or one population with complex spatial behavior (Sagarese, 2009). Although winter flounder are considered a migratory species, there is evidence that not all adults leave spawning areas in the summer and that certain groups of adults maintain residency in these shallow areas year round (Pereira et al., 1999; Lobell, 1938; Sagarese, 2009). The population dynamics of winter flounder are highly complex and further research is necessary to understand factors hindering stock recovery and spawning and settlement dynamics.

Young-of-the-year (YOY) winter flounder, those that have settled and are in the first year of life, continue to be subject to high mortalities and variable survival into the juvenile stage (Periera et al., 1999). It is estimated that overall mortality in the larval and juvenile stages of winter flounder can reach 99% or more (Pearcy, 1962). Individual estimates of instantaneous YOY mortality have ranged from 0.24 to 1.21 per month for various areas in Connecticut and additional monthly mortality estimates in Connecticut have been reported to be as high as 0.31 (Meise et al., 1999; Pearcy, 1962). DeLong et al., (2001) analyzed ten years of monthly survey data to estimate YOY growth and mortality of winter flounder in Narragansett Bay, Rhode Island. They found evidence that growth and mortality were density-dependent and that neither was limiting recovery of winter flounder in Narragansett Bay. If the Connecticut estimates apply to Long Island, it appears that the period between settlement and recruitment to the adult population is limiting population recovery. However, no estimates of YOY mortality post-settlement have been conducted in Long Island, and the causes of recruitment failure remain uncertain. To properly manage fisheries by adjusting exploitation rates requires research on early life history, especially mortality and growth. Further, the data gained in this study will provide insight into the stock structure and migratory dynamics of winter flounder. It is imperative to understand the population dynamics, including larval and juvenile stages, in order to ascertain causes of fluctuations and trends in recruitment of individuals to the fishery. Commercial fishing supports local fishermen and recreational fishing drives a thriving tourist market which benefits local summer communities. Throughout the range of this species, stock numbers are declining. Numerous factors may play a role in this; including, overfishing, predation and declining habitat quality.

This study aims to quantify abundance and mortality rates for two contrasting locations on Long Island to gain insight into patterns and causes of varying mortality for YOY winter flounder. Furthermore, mortality rates will be compared to length and growth rates in order to ascertain the relationship between mortality and size in differing coastal bays in relatively close proximity. The results of this study will gauge the health of the YOY winter flounder population and yield further studies on factors effecting mortality and the linkage of mortality with growth. An additional objective of this study is to quantify age and growth of YOY winter flounder by implementing field based length frequency observations and otolith methodology. Using length frequency observations, it will be possible to calculate growth over larger time scales and track the development of the YOY class. This method can also be used to find evidence of population structure and dynamics. Ageing data from otoliths can be used to gain information on fish age and growth on the scale of the individual, thus illuminating fine-scale variations in the population. Winter flounder have historically been of great economic importance to the Long Island community. It is imperative to further understand what is effecting recruitment in this region so that measures can be taken to preserve this declining species.

Methods

Study Location:

Samples of YOY winter flounder (*Pseudopleuronectes americanus* walbaum) were obtained from two locations: Port Jefferson Harbor, and Shinnecock Bay, New York (Figure 1). These locations were chosen to represent two different habitat types, temperature regimes, depth profiles and levels of protection for YOY fish. Port Jefferson Harbor is a deep, well stratified bay with cool water refuge during the summer months. In contrast, Shinnecock Bay is a shallow well-mixed bay with little temperature refuge during the warm summer months. Also, historically, Shinnecock Bay has produced high yields of winter flounder (New York Conservation Department, 1938). Port Jefferson Harbor is located on the North Shore of Long Island and is connected to Long Island Sound, whereas Shinnecock Bay is on the South Shore and is directly connected to the Atlantic Ocean (Figure 1).

Sampling Regime:

Field sampling commenced in March and continued until mid-November in 2007 and ran from May to November in 2008. In the 2007 field season, a 60.96 m long and 3.05 m high large beach seine with 6 mm mesh size was used in Port Jefferson Harbor and Shinnecock Bay. A 30.48 m and 3.05 m high small beach seine was also used at times in Shinnecock Bay. Additionally, a 1 m beam trawl with 6 mm mesh was utilized in a specific area of Shinnecock Bay characterized by sea grass. The beam trawl was first used in June 2007 and was continued until October. In the 2008 season, beam trawling was extended to Port Jefferson Harbor and the geographic range was extended in

Shinnecock Bay from a specific "hot spot" area to the bay at large. Each tow was three minutes in duration.

In the 2007 season, beach seining was conducted on a bi-weekly schedule with each location sampled once on alternating weeks. Beam trawling in Shinnecock Bay began in June 2007 and was performed once a week until Mid-October. In 2008, beam trawling and beach seining commenced in May and ended in November. Beam trawling was conducted bi-weekly with each location sampled once during the week. Due to suggestions from the 2007 data that beam trawling yielded higher resolution of trends compared to seining, seining was implemented at each location once per month from May to November.

Station selection:

Two regimes were utilized for establishing random sampling sites based on gear type within each location. For trawling, a grid was overlain atop maps of each respective sampling area. A random number generator in Excel v.07 (© 2007 Microsoft Corporation) supplied numbers to correspond with different boxes on the grid, each representing a random sampling site. For seining, the bay perimeter was divided into 500 m sampling station intervals. A random number generator supplied numbers corresponding to sampling station intervals. However, once in the field, some seining locations had to be slightly altered due to feasibility.

Abundance:

Catch per unit effort (CPUE) was calculated to estimate relative abundance. Effort was defined as 1 pull of the large seine and minutes towed for beam trawling. Three types of CPUE were calculated: overall CPUE, bi-weekly CPUE (schedule permitting) and daily CPUE. The overall CPUE consisted of one value for each gear by year and location. Bi-weekly CPUE's were also calculated for each gear by year and location. Finally, an individual CPUE was calculated for each site within a location for each week by location, gear and year. Bi-weekly CPUE's were used for mortality estimates by catch-curve analysis, whereas overall and daily CPUE's were used for statistical comparison of abundance between and among sites and year.

Length Frequency Analysis:

To conduct length frequency analysis, the data from 2007 and 2008 were separated by location and gear type and histograms were constructed. Length distribution for YOY winter flounder were plotted as a time series to illustrate changes in length with time and observe whether one or multiple cohorts of YOY were present. The cut off for YOY was set at 10 cm early in the season and progressed over time. The entire sampling period was plotted to detect when the majority of YOY settled and were selected to the fishing gear.

Mortality:

To calculate mortality estimates, catch-curve analysis was employed. Values of Ln (*CPUE*) were plotted over time resulting in a piece-wise linear relationship with two segments. The ascending segment represents increasing selectivity to the gear until full selectivity is reached at the peak. Following the peak the descending arm represents losses resulting from natural mortality (Quinn and Deriso, 1999). Abundance estimates corrected for selectivity (see below) were plotted against time and regression analysis was used to estimate the slope of the descending limb of the catch. The slope of the line corresponds to the value of M. When applied to adult fish in a fishery, the estimate of mortality is a combination of natural and fishing mortality. However, the estimates in this study are strictly from natural mortality as YOY are not vulnerable to recreational or commercial fishing gear.

Catch-curve analysis required several assumptions. These were that: (1) all age classes have equal mortality; (2) all fish are fully selected to the gear; and (3) the population is closed with no emigration or immigration. To assure these assumptions were not violated: (1) a settlement date analysis was performed to estimate the duration of spawning/settling to evaluate age structure; (2) the selectivity correction was applied to catch data; and (3) we conducted numerous surveys throughout the area to determine if YOY winter flounder were migrating out and/or into the sampling area.

The following equation was employed to correct abundance data for selectivity:

$$s_x = \frac{1}{1 + exp^{(-g(l-lh)}}$$

where s_x is selectivity for length interval x, *g* is the shape parameter and *lh* is the length at 50% selectivity. The parameters were estimated by reducing sum of squares using Solver in Microsoft Excel v.07 (© 2007 Microsoft Corporation). This equation was applied to each fish caught during surveys and the corrected values were summed to obtain an overall corrected abundance value for each sampling event. Several steps were taken to ensure that spawning/settlement had ended at the time indicated by the peak of the curve (i.e. no newly recruited YOY were entering the sampling areas after selectivity was reached). First, dates corresponding with the peak in the catch-curve were compared with field data to see if small fish were continuing to appear in the gear after selectivity was reached. Fish greater than 10 cm were excluded from early dates (size indicates fish greater than 1 year old). Ageing data was also used to corroborate findings from field data.

Mortality at length:

Mortality was estimated with the following equation:

$$M = ln\frac{\left(\frac{N_{t+1}}{N_t}\right)}{\Delta t}$$

where *M* is mortality at length, and *t* is time. The relationship between length and mortality was examined by plotting mortality against the average length for the corresponding sampling date and constructing a regression line. Only data corresponding with the period post-settlement and after full selection by the sampling gear, determined in the catch-curve analysis (usually in early to mid-June) were included in this regression analysis.

Growth:

Two growth estimates were calculated; those derived from field data and those from otolith based measurements. Growth from field data was calculated by taking the difference between average lengths obtained from sampling dates over time:

$$G = \frac{L_2 - L_1}{t_2 - t_1}$$

where L_2 is the average length at time t_2 and L_1 is the average length at time t_1 yielding growth estimated as cm/day. Values were obtained for each location by year and gear type. Data was not corrected for selectivity in this analysis. Otolith derived growth estimates were obtained by plotting total length against the daily age as obtained by daily increment counts. A regression line was constructed and the slope represented the growth rate. These values were calculated for each year by location.

Otolith preparation:

Analyses were performed on left sagittal otoliths because they yield the best increment width measurements (Sogard, 1991). Otoliths were dissected from YOY winter flounder by peeling away the operculum with a scalpel and removing the cranial bones. After extraction, accessory otoliths and remaining membrane attached to the sagitta were removed. The sagittal otoliths were then placed on slides and dried for a period of 24 hours. After drying, cyanoacyrlate glue was used to affix otoliths to a clean slide. Dissection, removal of accessory otoliths and membranes, and glueing was conducted under a Nikon Eclipse 80i dissection microscope. Otoliths were polished in the sagittal plane with 3 and 30 micron lapping film.

A Nikon Digital Camera model DX1200C attached to a compound microscope was used to take photographs of each otolith. Photographs were analyzed with Image Pro-Plus Version 6.0 software. Image Pro-Plus was used to make daily increment counts and to measure widths between increments. Width measurements were made on the rostral radius in approximately the same area for each left otolith. Due to the presence of secondary growth primordia, ageing could only be conducted from the age of settlement as the formation of the secondary primordial correlates with time of settlement (Sogard, 1991). Each otolith was read in a random order three times. Each reading was given a qualitative measure of reliability ranging from 1 (least confidence in reading) to 5 (most confidence in reading). A random subsample of 30 otoliths was chosen and read by an additional reader to verify the precision of reads for daily age.

Ageing precision was estimated using Average Percent Error (APE) (Campana and Jones, 1992). APE within the age determinations of reader 1was estimated with the following equation:

$$APE_j = 100\% \bullet \frac{1}{R}\sum_{i=1}^{R}\frac{\left|X_{ij} - \overline{X}_j\right|}{\overline{X}_j}$$

where X_{ij} is the i_{th} reading of the j_{th} fish, R is the number of readings and $\overline{X}_j$ is the mean of readings of the j_{th} fish (Campana, 2001).

APE values were calculated for each otolith, otoliths pooled per read and one overall APE value taking account of all otoliths for each read. All otoliths were included in the ageing counts as per the methods of Frisk and Miller (2006). However, only otoliths with APE values less than 5 were included in the increment width analysis. APE was calculated as per the method of Campana and Jones, 1992 and Frisk and Miller,

2006. Averages were taken of the three individual reads to obtain one average age for each fish studied. Weighted averages taking confidence grade into account were also calculated but a t-test comparing the difference between regular average and weighted average indicated that there was no significant difference between the two estimates. Therefore, the regular averages were utilized for further analysis. Plots of total length versus age were constructed for Shinnecock Bay and Port Jefferson Harbor fish for each year of sampling. Age versus total length was also compared between sites and years by ANCOVA. Furthermore, total length was plotted against otolith radius length and the resulting relationship was estimated using linear regression and compared with ANCOVA.

Settlement date analysis:

In order to estimate settlement date the following data and equations were used. Cumulative mortality rates each captured YOY winter flounder were exposed to were calculated. Additionally, daily mortality was adjusted to reflect decreasing mortality with age/size. We assumed mortality declined at a rate of 0.001 per day to account for the change of mortality with age (DeLong et al., 2001). This value came from previous work completed on YOY winter flounder over a ten year period (DeLong et al., 2001). Abundance at settlement was calculated with the following equation:

$$N_s = N_c \bullet exp^M$$

where N_s is abundance at settlement, N_c is the abundance at capture and M is the cumulative mortality from capture to settlement. Abundance at settlement was estimated for every fish captured using selectivity corrected catch values. A histogram was then constructed and modal analysis was performed to see if significant multiple modes were present indicating multiple cohorts or spawning cycles. The modal analysis was based on utilizing maximum likelihood to fit a multinomial distribution of expected frequencies compared to observed frequencies of settlement date (Haddon, 2001). The inherent assumption with this analysis is that each detected mode correlates with a separate discrete cohort or settlement group (Haddon, 2001). The frequency of settlement dates and modal analysis were calculated for each year, gear type and location.

Results

Abundance:

In the 2007 sampling season, 89 large beach seines were completed in Port Jefferson Harbor and 39 and 33 pulls were completed in Shinnecock Bay, using the small and large seines, respectively (Table 1). A total of 98 beam trawls were completed in Shinnecock Bay for a total of 352 minutes of tow time. During the 2008 season, 48 large beach seines were conducted in Port Jefferson Harbor and 20 small and 22 large pulls in Shinnecock Bay. A total of 163 beam trawls with a total of 494 minutes of tow time and 48 beach seines were completed in Port Jefferson Harbor and in Shinnecock Bay, 32 beach seines and 174 beam trawls with a total of 527 minutes of tow time were completed.

A total of 1532 YOY winter flounder were captured during the 2007 and 2008 sampling seasons (Table 1). During 2007, 679 YOY were captured by beach seining in Port Jefferson Harbor, 202 YOY in Shinnecock Bay and an additional 358 in Shinnecock Bay by beam trawling. In 2008, 48 YOY were captured by beach seining in Port Jefferson Harbor and 114 YOY were captured in Shinnecock Bay. During the 2008 season beam trawling captured 63 and 68 YOY winter flounder in Port Jefferson Harbor and Shinnecock Bay, respectively. CPUE estimated for beach seining was higher in both locations during the 2007 season (Figure 2). YOY were more abundance in Port Jefferson Harbor during 2007 and in 2008 YOY were more abundance in Shinnecock Bay; however abundance decreased in both locations in 2008. Abundance derived from beam trawling indicated a decrease in CPUE in Shinnecock Bay in 2008 compared to beam trawl CPUE in 2007 and abundance was lower for Port Jefferson Harbor compared to values for 2007 but there was no beam trawl figure in Port Jefferson Harbor in 2007 to make a direct comparison of fishing methods (Figure 3).

Length Frequency Analysis:

Length frequencies for Shinnecock Bay were plotted for all gear types and years (Figures 4-10). Since beam trawling was carried out on a weekly basis, finer scale changes in frequency and length could be observed compared to beach seining. YOY in Shinnecock Bay were captured by beam trawl in a relatively small area and seem to be comprised mostly of fish of similar size (Figure 4). There is a consistent increase in fish length over time without the appearance of multiple modes. On the first date of beam trawling YOY ranged 2.2-5 cm and steadily increased over the sampling season. However, the smallest size classes continued to enter the gear until the end of June.

Beach seining commenced earlier than beam trawling in Shinnecock Bay with the first date on April 24th. Although fish that were likely YOY were first captured on 4/26, they did not start consistently appearing in the beach seine until the beginning of June (Figure 5). YOY 4-5 cm in length suggest that spawning and settlement occurred sometime before sampling was initiated. Beam trawling and beach seining yielded progressive increases in fish length. This can be seen beginning in July and continuing until August, the last date YOY were caught in the beach seine. Fish of similar lengths are caught in both the beam trawl and beach seine; however, larger fish are caught at higher frequencies in the seine (Figures 4 and 5). Like beam trawling, seining indicated the presence of one major group of new settlers for 2007 with a prolonged appearance of newly settled YOY.

Trends in length frequencies were more difficult to ascertain from the beam trawl data for 2008 due to the small number of fish that were captured in Shinnecock Bay (Figure 6). Like 2007, YOY did not appear until early June and included larger sized individuals (Figures 6 and 7). Overall, the progression of fish sizes was similar to beam trawling and beach seining for the previous year. Shinnecock Bay beach seining data for 2008 are similar to 2008 beam trawling data.

The data for Port Jefferson Harbor beach seining 2007 showed a range of YOY lengths in early June and the distribution of the catches indicate the potential of two to three modes from 6/21 to 7/19 (Figure 8). Small, newly settled, YOY were present in early June and appeared consistently in large numbers until the end of July (Figure 8). YOY 4-5 cm in length suggest that spawning and settlement occurred sometime before sampling was initiated. Like Shinnecock Bay, trends are less apparent due to smaller catches for Port Jefferson Harbor in 2008 (Figures 9 and 10). YOY appeared in the beam trawl in early June as in 2007 and in Shinnecock Bay 2007 and 2008 (Figure 9). However, the first date of seining in early June did not yield any YOY winter flounder in 2008 (Figure 10). No newly settled YOY were caught in Shinnecock Bay or Port Jefferson Harbor indicating settlement occurred before sampling was initiated. The length of new settlers steadily increased in the same fashion as in 2007, and the same range of sizes were covered throughout the season; however, due to the small size of catches trends were more difficult to detect (Figures 9 and 10).

Mortality:

Gear selectivity curves were estimated for beach seining and beam trawl gear and were used to correct for the effects of gear selection on abundance estimates (Seining: *lh* = 4.97, *g* = 0.95; Beam trawl: *lh* = 5.05, *g* = 1.30). The instantaneous mortality rate estimated from beach seining data in 2007 ranged from M = 0.029/day ± 0.039 in Port Jefferson Harbor to M = 0.036/day ± 0.024 in Shinnecock Bay (Table 2; Figures 11 and 12). The lowest instantaneous mortality rate was calculated for beam trawling in Port Jefferson Harbor in 2008 (M = 0.022/day ± 0.021) (Figure 12b). In 2007, estimates of M between beach seining and beam trawling in Shinnecock Bay were very similar and not statistically different (M_{BT} = 0.030/day ± 0.013, M_S=0.036/day ± 0.024) (Table 2, Figure 11a and Figure 11b).

The date when selection to the fishing gear occurs (i.e. size selection to the gear and no observations of new recruits in the catch) is similar across locations and years occurring during the first week of July. In 2007, selection occurred on July 5th for seining in Port Jefferson Harbor, July 3rd for seining in Shinnecock Bay and July 2nd for Shinnecock Bay beam trawling. Selection in 2008 occurred later in the season on the 8th of July for beam trawling in Port Jefferson Harbor and July 21st for Shinnecock Bay beam trawling.

Length frequency analysis indicated the possible presence of a second cohort of YOY winter flounder in Port Jefferson Harbor 2007. Upon removing the second cohort, the instantaneous mortality rate estimated increased from M = 0.029 to M = 0.033 and the relationship improved from an r^2 = 0.52 to r^2 = 0.62 (Table 2, Figure 12c). Note: The results from seining in both locations for the 2008 sampling season were not included as it was difficult to determine the date when settlement (recruitment) was completed due to scarcity of data points.

Figure 13 displays the slope values (black squares) and confidence intervals (hatch marks) for each catch-curve analysis for each location, year and gear. Mortality values varied little between locations and years. Due to the overlapping nature of the estimate distributions, I did not report statistics for non-significant comparisons between estimates for locations and years.

Average length and age:

The average length and age of YOY winter flounder for each week was estimated. Averages of YOY during April were 4.5 cm; however, the majority of YOY did not appear consistently until June 5th. Size varied by date between sampling locations. YOY captured in November of 2007 in Port Jefferson Harbor averaged 7.01 cm whereas fish in Shinnecock Bay in 2007 averaged 7.00 cm as early as August 14th. As expected, there was a consistent increase in average length over time with the only anomaly observed in Port Jefferson Harbor on August 30th when only two YOY were captured that averaged 3.60 cm in total length. During 2007 YOY in Port Jefferson Harbor were smaller and older compared to YOY in Shinnecock Bay. The same trends are not as apparent for the 2008 season. The values for average length were utilized to construct Figure 14.

Mortality at Length:

Length specific mortality was estimated for both sampling locations and gear types. Relationships between mortality and length were not significant for Shinnecock Bay 2007 and 2008 or for Port Jefferson Harbor 2007. Only the estimate for Port Jefferson Harbor 2008 was significant and thus was the only analysis included (Figure 14).

Field Growth:

Field growth estimates yielded interesting patterns between sampling methods. Although field growth estimates are limited to a coarser time scale than otolith based growth rates, changes in growth rate can be seen over time. Growth in Shinnecock Bay was variable over time, ranging from high rates of 0.25 cm/day to negative rates of -0.06 cm/day throughout the season (Figure 15). Beam trawling 2007 indicated that the fastest growth occurred during the end of June and there is a decline and some negative growth later in the season (Figure 15a). Growth estimates from beach seining 2007 start earlier, showing negative growth in the beginning of April and highest growth in May and again in the end of June (Figure 15b). In 2008, similar patterns were seen with the beam trawl and the beach seine with highest growth rates in June and lower growth rates in July (Figure 15c and d). In August 2008, there is a deviation in the similarities between beam trawling and beach seining with a slightly higher estimate in growth obtained from the beach seine. However, the growth rates estimated in August 2008 were consistently lower than those for August 2007.

The trends displayed in Port Jefferson Harbor beach seining 2007 were similar to those of Shinnecock Bay with highest growth occurring in the end of June (Figure 16a). As the season progressed, negative growth was observed in the beginning of July with another increase in growth later in July (Figure 16a). The results from 2008 were similar between the beam trawl and beach seine (Figure 16 b and c). Highest growth was observed in mid-July and lowest growth was observed in September (Figure 16 b and c).

Otolith growth estimates:

A total of 100 otoliths were processed and read for each year at each location. After checking for accuracy and precision, sixty otoliths were included in the analysis for Shinnecock Bay 2007, 84 for Port Jefferson Harbor 2007, 88 for Shinnecock Bay 2008 and 82 for Port Jefferson Harbor 2008. The overall APE (after exclusion of samples deemed unreliable) for the three otolith readings for 2007 was 5.623 and the overall APE for 2008 was 4.696. Otolith reads between two different readers were also compared to give a measure of precision (Figure 17). There is no obvious bias between readers (slope = 0.99, R^2 = 0.77) and reads do not differ significantly from a 1:1 relationship (perfect agreement between readers).

Significant relationships were found between total length of the fish (somatic growth) and radius length of the otolith for both sites and years (Table 4). For both years in Shinnecock Bay, the relationship between length and otolith radius length was linear (Figure 18a). The fit was better for 2008 (r^2 = 0.85) compared to 2007 (r^2 = 0.76); however, both years yielded significant relationships. The relationships between total length and otolith radius length for Port Jefferson Harbor were also significant for both years (r^2_{2007} = 0.81, r^2_{2008} = 0.82) (Figure 18b). The slope value for 2007 was 0.0073 compared to 0.0061 for 2008; however, they were not significantly different (Figure 18b). The finding of significance between otolith radius and total length indicates that somatic growth and otolith growth were correlated.

The length vs. age relationship for Shinnecock Bay was estimated to provide an estimate of otolith derived growth rates (slope) for 2007 and 2008 (Figure 19a). Growth rate was 0.0542 ± 0.009 cm/day for 2007 and 0.0468 ± 0.015 cm/day for 2008. There is a stronger fit to the data for 2008 (r^2 = 0.642) compared to 2007 (r^2 = 0.403). In Port Jefferson Harbor, growth was 0.0591 ± 0.010 cm/day in 2007 and 0.0484 ± 0.021 cm/day in 2008 (Figure 19b). The linear fits were stronger in Port Jefferson Harbor compared to Shinnecock Bay for both years (r^2_{2007} = 0.669, r^2_{2008} = 0.691). Figure 20 illustrates a comparison of slopes (black squares) and confidence intervals (hatch marks) for results from the regression relationships obtained from the otolith derived growth rates. Like the comparison completed for the catch-curve analysis, the ranges of all locations and years overlap indicating no significant difference (Figure 20).

Settlement Date:

Peaks in settlement for Shinnecock Bay in 2007 occurred in late March and mid-April with additional peaks in late May (Figure 21a). For the Shinnecock Bay 2007 beach seine data, three modes were suggested, with means of 89, 100 and 135 days and with variance values of 3.47, 8.18 and 13.12. Relative noise values were also calculated: 0.16, 0.13 and 0.07. The third mode for this location and year was difficult to fit, possibly due to the broad variance and small number of late settlers. Although there is a level of uncertainty in this third estimation, there is evidence that a slight increase in settlement was occurring late in the season. Therefore, estimates of the third mode were included. In 2008, peak settlement in Shinnecock Bay occurred during mid-March and late April (Figure 21b). For Shinnecock Bay 2008 (Figure 21b), modes were indicated at 77 and 118 days with variance values of 14.6 and 6.0. Relative noise was 1.80 and 0.09.

Peak settlement periods for Port Jefferson Harbor 2007 occurred in late April to early May, late May to early June and in late July (Figure 22a). The modal analysis found three modes in settlement dates occurring at 118, 148 and 207 days. Variance values were 10, 6 and 7.23 with relative noise values of 0.41, 0.09 and 0.20. In 2008, peak settlement occurred in early April and late May (Figure 22b). The two modes were found at 101 and 143 days with variance values of 10.0 and 7.6. Relative noise values were 1.47 and 0.43.

Discussion

This research provides the first assessment of abundance, growth and mortality of YOY winter flounder from Long Island Bays including Port Jefferson Harbor and Shinnecock Bay, New York. Vital rates of growth and instantaneous natural mortality were successfully estimated; however, despite decreases in abundance (CPUE) no significant differences were observed between locations or years. The mortality rates found in this study fall into the range of mortality rates estimated for the Connecticut River and New Haven Harbor in the late 1990's (Meise et al., 1999). The lower estimates of daily mortality for Port Jefferson Harbor coincide with the upper range of mortality estimates calculated for Rhode Island (DeLong et al., 2001). However, this study estimated mortality rates for Shinnecock Bay and Port Jefferson Harbor that were much higher than previous estimates for the Niantic River, New Jersey and the Mystic River Estuary, Connecticut (Rose et al., 1996; Pearcy, 1962). A summary of results from other studies compared to results of this study is shown in Table 6.

What is striking about our results coinciding with the upper range of mortality rates observed in Rhode Island is that those estimates coincide with high YOY winter flounder abundance (DeLong et al., 2001). There is evidence of density-dependence control in that system, which is experiencing a compensatory response expected by fish populations at high densities. In Long Island, surveys indicate that YOY reaching settlement and points thereafter are not recruiting into later life stages or the fishery (ASMFC, 2009). At some point, it would be expected that Long Island populations at low abundance would experience the opposite compensatory response than Rhode Island, which would include higher growth and lower mortality leading to increasing populations. Evidence suggests that a bottle-neck between settlement and survival to the second year of life is occurring.

Another possibility is that some other factor, other than density-dependence, may be exerting control over YOY population dynamics. One possible cause of the high mortality rates experienced in Long Island is predation, common during life-stages that are experiencing density-independent mortality. Although a study of piscivory in Long Island indicated a low occurrence of YOY winter flounder in predator stomachs, abundant predators may still have a large impact on YOY winter flounder at historic low densities (Sagarese, 2009). The study by Sagarese (2009) indicated the presence of YOY winter flounder in bluefish (*Pomatomus saltatrix*), summer flounder (*Paralichthys dentatus*) and striped bass (*Morone saxatilis*) stomachs. Summer flounder are documented winter flounder predators in other systems and it has been shown that in the summer months these predators inhabit the shallow bays utilized by newly settled winter flounder (Manderson, et al., 2000; Manderson et al., 2004). In Massachusetts, it was observed that an increase in juvenile winter flounder injuries coincided with the appearance of YOY bluefish (Howe et al., 1976). In the summer months, YOY bluefish appear in the same locations utilized for this study (Sagarese, 2009). Furthermore, there has been a decade long population explosion of striped bass in the eastern Atlantic region (ASMFC, 2004). Even if the occurrence of winter flounder in predator stomachs was low, predation mortality may still be high because many predators are extremely abundant.

Predation on YOY winter flounder by crustaceans, like sand shrimp (*Crangon septemspinosa*) and green crabs (*Carcinus maenas*), has been documented as well (Taylor 2004; Taylor 2005). Due to the feeding style of crustaceans, it is difficult to positively identify fish parts in stomachs and thus they were not included in the study of predation on Long Island (Sagarese, 2009). However, crustaceans are documented predators of YOY winter flounder in other systems and dominated the frequency of diet items of fish species in Long Island bays (Sagarese, 2009). This indicates a high abundance of crustacean predators, which have potential of impacting winter flounder survival rates. In addition to eggs, small winter flounder were detected in the stomachs of sand shrimp in May to early June (Taylor, 2004). There is evidence that green crabs begin to prey on YOY in late spring and early summer and that these crabs may account for 0.4-7.7% of daily mortality (Taylor, 2005). Estimates have also indicated that 1.1-32.3% of the year class could potentially be consumed and that variation in the abundance and size of green crabs coincides with variability in YOY winter flounder survival (Taylor, 2005). Diet studies of crustaceans in Long Island bays are required to further understand the severity of this mortality.

Growth rates from Port Jefferson Harbor and Shinnecock Bay are comparable to those calculated for other locations near Long Island (Table 7). Otolith derived growth rates across locations and years fall into the range observed in New Jersey Bays, with results from Port Jefferson Harbor in 2007 almost identical to growth rates observed in that study in 2001 (Sogard and Able, 1992; Sogard et al., 2001). Further, our otolith derived growth rates fall into the range of field derived estimates in Connecticut (Meise et al., 1999). However, the average otolith derived growth rate in New Jersey (Meise et al., 2003) was higher than those observed for all locations and years on Long Island (Table 7).

Two size groups can clearly be seen in the length frequency analysis and modal analysis of settlement abundance resulting in two modes in the distribution. It is not clear whether these cohorts are the result of one group of adults experiencing a prolonged spawning season or, as in the case of Port Jefferson Harbor, of different groups of spawners entering the bay to spawn at different times. It is also interesting to note the differences in the distribution of settlement dates of YOY winter flounder between years and locations. Settlement occurs in approximately two to three months, depending on temperature, after larvae hatch and marks the completion of metamorphosis from a free swimming lifestyle to a strictly benthic one (Pereira et al., 1999;Sogard,1991). Due to the consistency in time frame of the settlement process, date of settlement can be used as a proxy for spawning activity in addition to giving insight into the dynamics of the YOY class itself (Sogard, 1991; Pereira et al., 1999). There are some striking differences and similarities among and within sampling locations and years. Our results indicate that spawning in 2007 began in late January and continued until mid-March in Shinnecock Bay. In Port Jefferson Harbor, there appeared to be three clear spawning events with the first beginning in late February and ending in early March, the second beginning in late March and ending in early April and the third beginning in late May to early June. With the exception of the third peak of activity in Port Jefferson Harbor, the other dates fall within the normally accepted time frame for winter flounder spawning. Adult winter flounder normally spawn from the winter to the spring with peaks observed in February and March along the northern range and earlier in the southern range during November to April (Bigelow and Schroeder, 1953; Collette and Klein-MacPhee, 2002).

It has also been documented that winter flounder have settled as late as July (spawning event in April) in New Jersey with juvenile settlement occurring over a wide range of dates (Meise et al., 2003). Why an additional spawning event occurred later in the summer warrants further research. Some interesting questions that could be posed include whether this has happened before in Port Jefferson Harbor or other areas of Long Island. If it has, what are the possible triggers and what is the over winter survival rate of the YOY produced from each group? Furthermore, what is the origin of the adults forming this late spawning group and what are the cues that cause delayed spawning events?

Assumptions-Mortality:

As previously stated, mortality rates between bays and years are not significantly different and the high rates found are counter to what is expected when fish are at low abundance levels. Although high rates of predation may be responsible, the lack of detectable differences may also be due to a paucity of time series data. Two years of comparison gives some insight but may not yield enough data to make statistical analyses powerful enough to detect significant differences. Furthermore, more frequent sampling during a season may make it possible to include additional data points in catch-curve analyses and improve fits, thus increasing statistical power.

Yet another reason significant differences were not found may be due to the complex nature of winter flounder population dynamics. There was evidence found of two or more cohorts of newly settled individuals in both Shinnecock Bay and Port Jefferson Harbor. This could confound basic applications of catch-curve analysis and field growth estimates. However, if more data were obtained the effects of stock structure could be elucidated further and additional analyses could be conducted.

Assumptions-Growth and Settlement Date

A striking finding of the field-derived growth rates was the indication of negative growth rates which is in contrast to previous studies on winter flounder growth (Meise et al., 1999; Sogard and Able, 1992; Meise et al., 2003; Sogard et al., 2001). These discrepancies are probably due to the nature of the field data. Modal analysis of settlement abundance, and to a lesser extent length frequency analysis, indicates the presence of at least two cohorts of newly settled YOY which are apparent throughout the course of the sampling season. The presence of two cohorts of differing sizes would alter the size structure of the stock, thus making field estimates unreliable as the presence of small fish on the same day as large fish will alter the average lengths utilized for field based growth estimates. The appearance of two cohorts may be due to the presence of both “bay fish” and migratory adults in Shinnecock Bay (Sagarese, 2009). In Port Jefferson Harbor, it is unclear whether there is one group of adults returning to the area and experiencing protracted spawning or if there is the possibility of multiple groups of adults migrating into the Harbor at different times.

Although the results of this study raise some questions about YOY and adult population dynamics, what is clear is that the presence of two cohorts could alter results of field derived growth. Additionally, the presence of two cohorts would affect the outcome of catch-curve analyses, if mortality was strongly size dependent, and data would need to be separated into cohorts for calculation of more accurate mortality rates.

Implications and Further Research:

The apparent presence of two cohorts in both Shinnecock Bay and Port Jefferson Harbor, suggests that otolith derived growth estimates are more appropriate measures than field data derived growth estimates. Otolith measurements are on the scale of the individual so the pooling that occurs in field growth calculations would not occur. Time scale is also finer with otoliths as there is a record of daily growth and calculations are not limited to the coarse time scale offered by field data. Otoliths also have the advantage of serving as a record of past growth over time and can yield information for specific points in time. These finer scale growth changes can be correlated with more specific measurements of environmental factors which may not be possible with field data. Due to the lack of environmental data in this study, the correlation of otolith growth and physical parameters was not possible. Field growth calculations are limited to the time scale of the sampling effort and details regarding fine scale changes in the environment could be lost.

More research is necessary to thoroughly understand the population dynamics of YOY winter flounder and what processes are controlling recruitment in Long Island. A powerful tool would be increased acoustic monitoring. As mentioned above, acoustic tagging studies in Shinnecock Bay indicated the presence of “bay fish”. Our field data and results of the settlement date analysis indicate that multiple cohorts of newly settled YOY are occurring. Perhaps the presence of spawning migratory adults and “bay fish” are causing these multiple cohorts of YOY, especially if these groups are spawning at different times. Increased acoustic effort could yield further insight into the “bay fish” group as well as increased understanding into habitat usage of adults. Habitat usage by adults has implications for new settlers as areas in which settled YOY occur can be used as a proxy for spawning ground (Pereira et al., 1999; Saucerman and Deegan,1991).

Acoustic tagging would be invaluable in Port Jefferson Harbor as well. If adult spawners could be tagged, return patterns could be tracked. If two cohorts of YOY were observed again, movements of adults could be correlated to peaks in abundance. The presence of two cohorts with continued acoustic returns would indicate protracted spawning by one group whereas two cohorts with only one set of acoustic returns could indicate the presence of two different groups of spawning adults. It might also be possible to ascertain where adults are coming from if receiver arrays could be placed in Long Island sound. This, combined with genetic studies, would prove invaluable in determining which adults were returning and contributing most to surviving YOY cohorts.

Bottom sediment sampling, bottom type classification and prey enumeration studies could also prove to be valuable. Previous studies have indicated links between vital rates of YOY winter flounder and the type of bottom sediments, occurrence of vegetation, bottom structure, abundance of prey items and even the presence of anthropogenic structures (Phelan et al., 2001; Howell et al., 1999; Sogard 1992; Scharf et al., 2006; Meise et al., 2003; Lazzari, 2008; Goldberg et al., 2002;Able et al., 1999). Since winter flounder are dependent on the benthos for survival, a more detailed classification of sampling area may make it possible to infer which areas in Long Island

Bays are more favorable for YOY survival. YOY density per sampling site within a bay could be calculated from catch data and then correlations with bottom type could be investigated.

Perhaps most importantly though would be the collection of more detailed abiotic environmental parameters. It has been shown that factors such as temperature, dissolved oxygen and salinity can have definite effects on growth rates of YOY winter flounder (Meise et al., 2003; Bejda et al., 1992; Armstrong 1997; Sogard et al., 2001). Growth rates, in turn, affect mortality rates and abundance (Miller et al., 1988; Houde 1987). Environmental variables have the ability to directly affect the physiology of fish which can alter population health and structure. It is therefore imperative to gather environmental information in order to investigate causal mechanisms of variation in vital rates. Additionally, if the environment was more thoroughly understood than the effects of anthropogenic changes could be ascertained and management strategies could be implemented as necessary.

Although there is documented evidence of the decline of mortality over time in relation to increase in length and growth over time (Houde 1989), it was difficult to ascertain whether this was occurring in our study. There was a significant negative relationship between mortality rate and length in Port Jefferson Harbor during 2008, however the relationships estimated for Port Jefferson Harbor in 2007 and Shinnecock Bay in 2007 and 2008 did not yield significant differences. The lack of significant findings does not necessarily indicate a lack of relationship between mortality and length in Long Island bays, due to the constraints mentioned above (population size, data resolution, predation).

Our study indicates that YOY winter flounder experience substantial mortality rates during the duration of the season. Mortality rates for Long Island Bays were between 0.02-0.03/day indicating that a fish has a 2-3% chance of dying per day. Cumulatively, the same fish has roughly a 60-90% chance of dying in a month. These rates indicate that a large portion of YOY will be extirpated before the first winter, where fish experience additional losses due to winter mortality. If the large losses of YOY fish preclude the recovery of the adult population, and the fishery, recovery efforts will have to focus on reducing predatory and environmental impacts on survival. It is not clear what immediate steps are possible to this end.

Furthermore, the mortality rates found in our study were high compared to other areas which serve as nurseries for YOY winter flounder. These studies encompassed varying geographic locations with differences in bays as well as being conducted over large time scales. Recent studies in these same areas need to be conducted to see if mortality rates have increased with time. If mortality rates have stayed relatively constant, it would be possible to deduce that increased mortality is a phenomenon specific to Long Island waters. By doing so, sources of mortality on winter flounder can be partitioned amongst large scale or regional and local environmental constraints. Further research is required to ascertain major factors in determining the high mortality rates inhibiting population recovery.

I hypothesize the cause of high mortality in Long Island bays is predation rates. Linkages in the food web warrant further research as the abundance of predators in these systems may hinder the recovery of adult winter flounder. An ecosystem-based management approach may demand measures to control predator numbers in order to achieve the goal of winter flounder population recovery.

Conclusion:

The results of this study indicated that there are no significant differences in instantaneous mortality or growth rates between YOY winter flounder populations located in two contrasting bays on Long Island for both years studied. However, the mortality rates estimated in this study are generally higher than those observed in other systems in the northeastern United States. Mortality rates for Long Island bays coincided with the upper range of mortality rates calculated for areas in Connecticut, New Jersey and Rhode Island (Meise et al., 1999; Rose et al., 1996; Pearcy, 1962; Delong et al., 2001). In the systems in Rhode Island, the upper range of mortality rates coincided with a high abundance of YOY, and thus indicated density-dependent control (DeLong et al., 2001). The available data in the New York region suggests that winter flounder are currently at record lows in adult abundance (ASMFC, 2009). The abundance at settlement appears to be slightly increasing; however, this increase is not resulting in increased numbers of YOY surviving the summer (Socrates and Colvin, 2006). It appears that compensatory increases in productivity to settlement are not resulting in overall population increases.

A recent study of predation occurring in Long Island bays indicated the presence of winter flounder in the stomachs of piscivorous fish (Sagarese, 2009). In that study, there was a low occurrence of YOY predation; however, predation could still be a significant factor in increasing mortality rates if the abundance of predators is high which studies have indicated for certain piscivorous fish in Long Island waters (ASMFC, 2009). Furthermore, predation by crustaceans was not analyzed by Sagarese (2009); but surveys conducted in the region suggest high crustacean abundance (Frisk and Munch, unpublished data 2008).

Settlement date analysis in this study yielded evidence of two to three cohorts of newly settled YOY winter flounder for each bay. Since it takes approximately two months for metamorphosis to reach completion, it is possible to back-calculate spawning time and gain insight into the spawning behavior of adult winter flounder. It has been documented that winter flounder normally spawn in early winter to early spring, but our study indicated spawning events occurring in late spring with gaps as long as three months between periods of settlement (Pereira et al., 1999). These findings suggest the spatial and temporal behavior of winter flounder adults and YOY are poorly understood and that more research is necessary in order to truly gauge how winter flounder are utilizing bays of Long Island.

Additional research that would prove beneficial includes increased acoustic tagging, genetic sampling and studying environmental factors. A recent acoustic tagging study in Shinnecock Bay indicated that there is the presence of “bay fish”, winter flounder that do not undergo summer-winter migrations and reside in shallow bays year round (Sagarese, 2009). The presence of “bay fish” might be one of the factors influencing the appearance of multiple cohorts of settling winter flounder. In Port Jefferson Harbor, adult tagging would yield insight into whether the same group of adults was responsible for protracted spawning events or whether multiple groups of adults were returning to spawn. Genetic studies would be able to give insight into the stock structure of “bay fish” and help determine the contribution of “bay fish” and migratory fish to observed YOY cohorts.

Due to the poikilothermic nature of fish, growth and development is highly tied to the environment, especially regarding temperature, and previous studies have indicated that factors such as temperature, dissolved oxygen and salinity can affect YOY growth rates (Meise et al., 2003; Bejda et al., 1992; Armstrong 1997; Sogard et al., 2001). Furthermore, bottom type, abundance of prey items, presence of vegetation and even presence of anthropogenic structures have been shown to effect the abundance and distribution of YOY winter flounder (Phelan et al., 2001; Howell et al., 1999; Sogard 1992; Scharf et al., 2006; Meise et al., 2003; Lazzari, 2008; Goldberg et al., 2002; Able at al., 1999). Increased understanding of growth and morality in relation to environmental variables would give additional insight to the vital rates of YOY winter flounder. This could in turn lead to further understanding of what management measures would be most successful in aiding the recovery of this economically important species.

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Appendix 1

Table 1: Summary of catch and sampling effort for all gears and year for each location. Tows correspond to pulls of the seine or number of tows of the beam trawl.

Year	Location	Gear	Tows	Time Towed	Total YOY WF
2007	Port Jefferson	Beach seine	89	NA	679
2007	Shinnecock	Beach seine	52.5	NA	202
2007	Shinnecock	1 m. Beam Trawl	98	352	358
2008	Port Jefferson	Beach seine	48	NA	48
2008	Port Jefferson	1 m. Beam Trawl	163	494	63
2008	Shinnecock	Beach seine	32	NA	114
2008	Shinnecock	1 m. Beam Trawl	174	527	68
				Total	1532

Table 2: Statistical analysis of catch-curve results where Shin is Shinnecock Bay, PJ is Port Jefferson Harbor, n is number of observations, M is the slope value or the instantaneous mortality rate, y is the y-intercept, L95% is the lower 95% confidence limit and U95% is the upper confidence limit.

Location	Gear	Year	n	M	y	L95%	U95%	R-squared	F values	p
Shin	Beam Trawl	2007	7	-0.0297	1169.95	-0.0424	-0.017	0.878	36.06	0.0018
Shin	Seine	2007	5	-0.0357	1406.57	-0.06	-0.0114	0.88	21.92	0.0184
Shin	Beam Trawl	2008	4	-0.0346	1372.15	-0.0706	0.0013	0.896	17.19	0.0535
PJ	Beach Seine	2007	6	-0.029	1141.09	-0.068	0.01	0.516	4.26	0.108
PJ	Beam Trawl	2008	6	-0.0224	884.98	-0.0433	-0.0014	0.687	8.77	0.0415

Table 3: Statistical analysis of mortality versus length analysis where Shin is Shinnecock Bay, PJ is Port Jefferson Harbor, n is number of observations, y is the y-intercept, L95% is the lower 95% confidence limit, and U95% is the upper confidence limit.

Location	Gear	Year	n	Slope Value	y	L95%	U95%	R-squared	F values	p
Shin	Beam Trawl	2007	3	-0.0034	0.036	-0.151	0.144	0.078	0.085	0.819
Shin	Seine	2007	2	-0.023	0.159	-0.0225	-0.0225	1	NA	NA
Shin	Beam Trawl	2008	2	-0.085	0.692	-0.0855	-0.0855	1	NA	NA
PJ	Beach Seine	2007	3	-0.0325	0.268	-0.567	0.502	0.374	0.598	0.581
PJ	Beam Trawl	2008	3	-0.031	0.245	-0.451	0.39	0.46	0.854	0.525

Table 4: Results of statistical analysis on total length versus otolith radius length analysis where Shin is Shinnecock Bay, PJ is Port Jefferson Harbor, n is number of observations, y is the y-intercept, L95% is the lower 95% confidence limit, and U95% is the upper confidence limit. Results correspond to each location and year.

Location	Year	n	Slope Value	y	L95%	U95%	R-squared	F values	p
Shinn	2007	1964	0.0092	-1.072	0.009	0.0094	0.765	6401.6	0
Shinn	2008	3270	0.009	-0.405	0.0088	0.0091	0.853	18890.4	0
PJ	2007	3213	0.0073	0.0099	0.0071	0.0074	0.809	13577	0
PJ	2008	2337	0.0061	1.37	0.006	0.0062	0.822	10767.8	0

Table 5: Results of statistical analysis on otolith derived growth rates where Shin is Shinnecock Bay, PJ is Port Jefferson Harbor, n is number of observations, y is the y-intercept, L95% is the lower 95% confidence limit, and U95% is the upper confidence limit. Results correspond to each location and year.

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Location	Year	n	Slope Value	y	L95%	U95%	R-squared	F values	p
Shinn	2007	87	0.0543	1.203	0.0456	0.0631	0.642	152.33	<0.0001
Shinn	2008	61	0.0468	2.197	0.032	0.0617	0.403	39.79	<0.0001
PJ	2007	76	0.0591	-0.0285	0.0495	0.0688	0.669	149.57	<0.0001
PJ	2008	82	0.0484	1.602	0.0412	0.0556	0.691	178.81	<0.001

Table 6: Comparison of mortality rates along geographic range of YOY winter flounder. All values converted to rate of mortality/day in order to be directly comparable. M denotes value as originally reported in text, whereas common value is the result of converting published value to a rate/day. M-type indicates whether mortality rate in original publication was in the scale of days or months.

Study	Location	M	M-type	Common Value (M/day)
Our Study 2007	Shinnecock Bay, NY	0.030-0.036	Daily-instantaneous	0.030-0.036
Our Study 2007	Port Jefferson, NY	0.029	Daily-instantaneous	0.029
Our study 2008	Shinnecock Bay, NY	0.035	Daily-instantaneous	0.035
Our study 2008	Port Jefferson, NY	0.022	Daily-instantaneous	0.022
Pearcy, 1962	Mystic River Estuary, CT	0.37	Monthly	0.012
Meise et al.,1999	CT River and New Haven, CT	0.3-0.9	Monthly	0.01-0.03
Rose et al., 1996	Niantic River, NJ	0.015-0.012	Daily	0.015-0.012
Delong et al., 2001	Rhode Island	0.3-0.7	Monthy	0.01-0.02

Table 7: Growth rates obtained from our study and other studies in YOY winter flounder range. All rates have been converted to cm/day for ease of comparison but original units in published literature are different in some cases. Type indicates whether growth rate ranges obtained from otolith derived relationships, from field data or laboratory data.

Study	Location	Growth rate (cm/day)	Type
Our study 2007	Shinnecock Bay, NY	0.0543	Otolith derived
Our study 2007	Port Jefferson Harbor, NY	0.0591	Otolith derived
Our stury 2008	Shinnecock Bay, NY	0.0468	Otolith derived
Our study 2008	Port Jefferson Harbor, NY	0.0484	Otolith derived
Our study 2007	Shinnecock Bay, NY	-0.05-0.155	Field derived
Our study 2007	Port Jefferson Harbor, NY	-0.001-0.06	Field derived
Our stury 2008	Shinnecock Bay, NY	-0.001-0.250	Field derived
Our study 2008	Port Jefferson Harbor, NY	0.005-0.120	Field derived
Meise et al., 1999	CT River and New Haven, CT	0.023-0.053	Field derived
Sogard and Able, 1992	New Jersey	0.06-0.125	Otolith derived
Meise et al., 2003	Navesink River-Sandy Hook Bay, NJ	0.017-0.027	Laboratory derived
Meise et al., 2003	Navesink River-Sandy Hook Bay, NJ	0.102	Otolith derived
Sogard et al., 2001	New Jersey	0.035-0.139	Otolith derived

Appendix 2

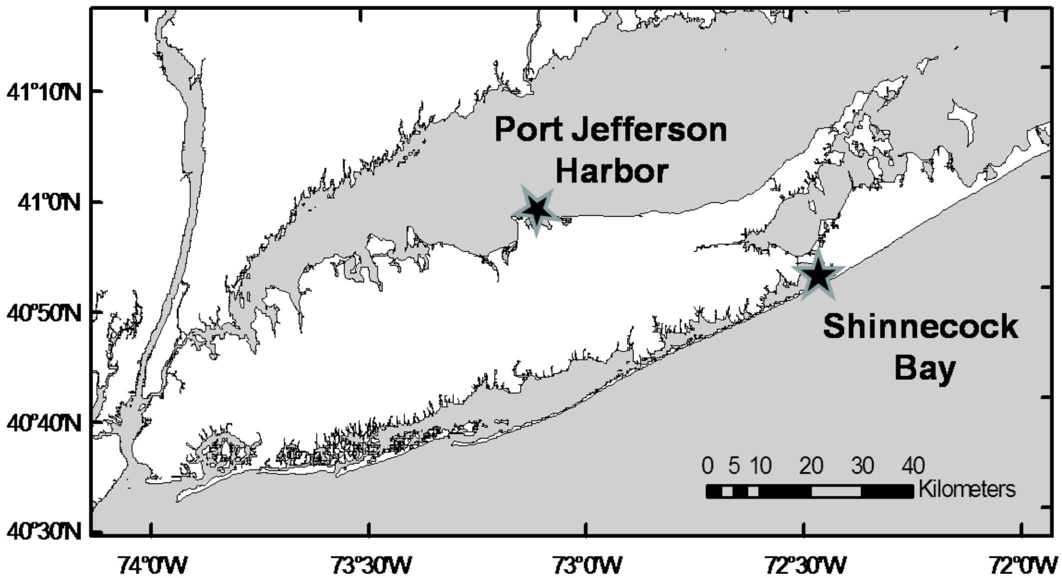


Figure 1: Map of sampling locations in Long Island. Stars represent the geographic area in which sampling was completed with Port Jefferson Harbor to the north and Shinnecock Bay to the south.

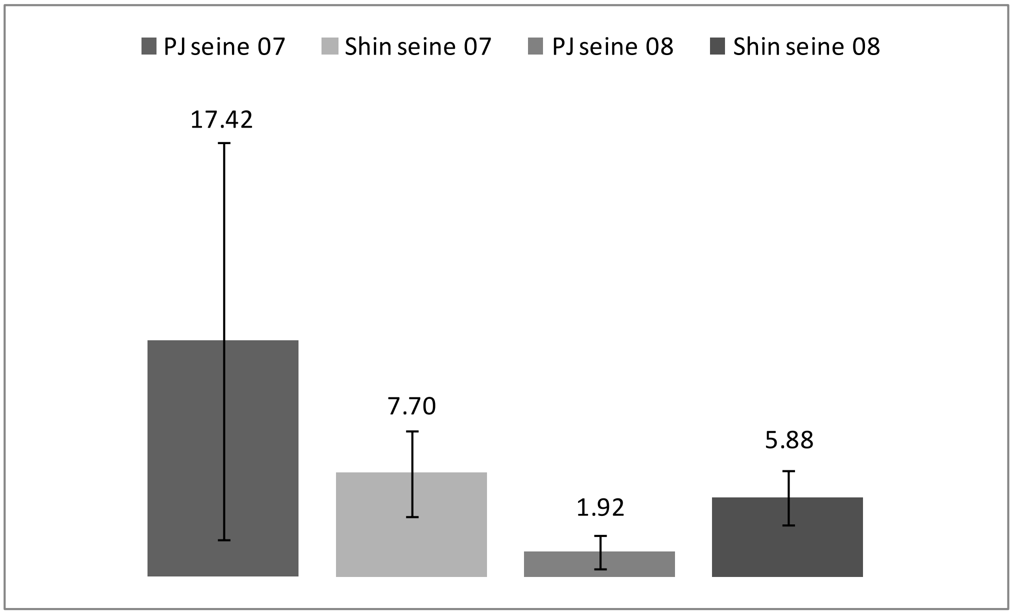


Figure 2: CPUE results for beach seining where the first bar represents Port Jefferson Harbor for 2007; the second bar represents Shinnecock Bay for 2007; the third bar represents Port Jefferson Harbor for 2008 and the fourth bar represents Shinnecock Bay 2008. Ninety-five percent confidence intervals were calculated using corrected abundance values.

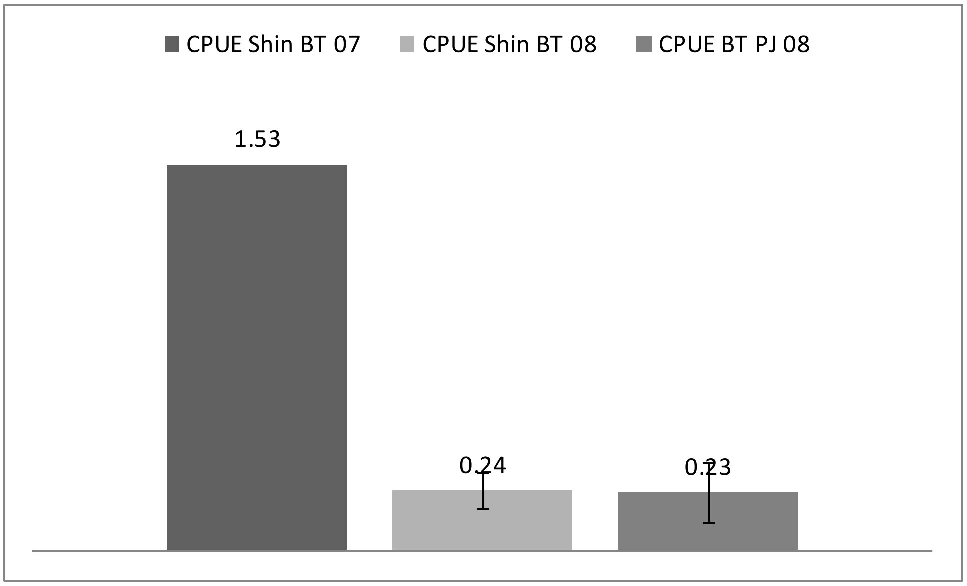


Figure 3: CPUE results for beam trawling where the first bar represents Shinnecock Bay for 2007; the second bar represents Shinnecock Bay for 2008 and the third bar represents Port Jefferson Harbor 2008. Ninety-five percent confidence intervals were calculated using corrected abundance values. 95% confidence intervals not included for Shinnecock Beam Trawl 2007 as data was collected as a running tally for a day, not separated into stations.

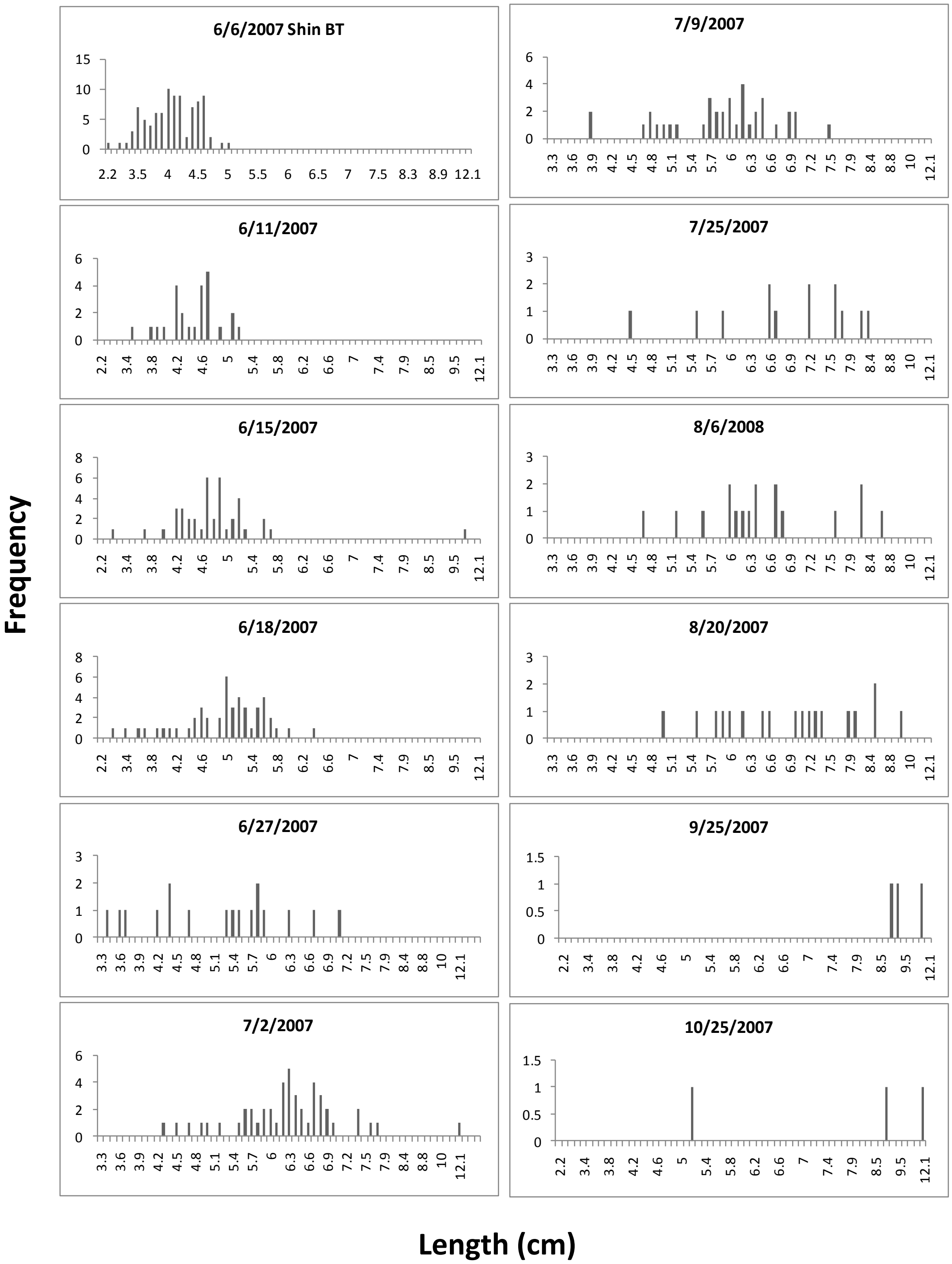


Figure 4: Length frequency diagrams over time for Shinnecock Beam Trawl 2007. The x-axis represents length in cm and the y-axis represents frequency. Value on the x-axis has been standardized to 12.1 cm, while the y-axis is scaled to the data.

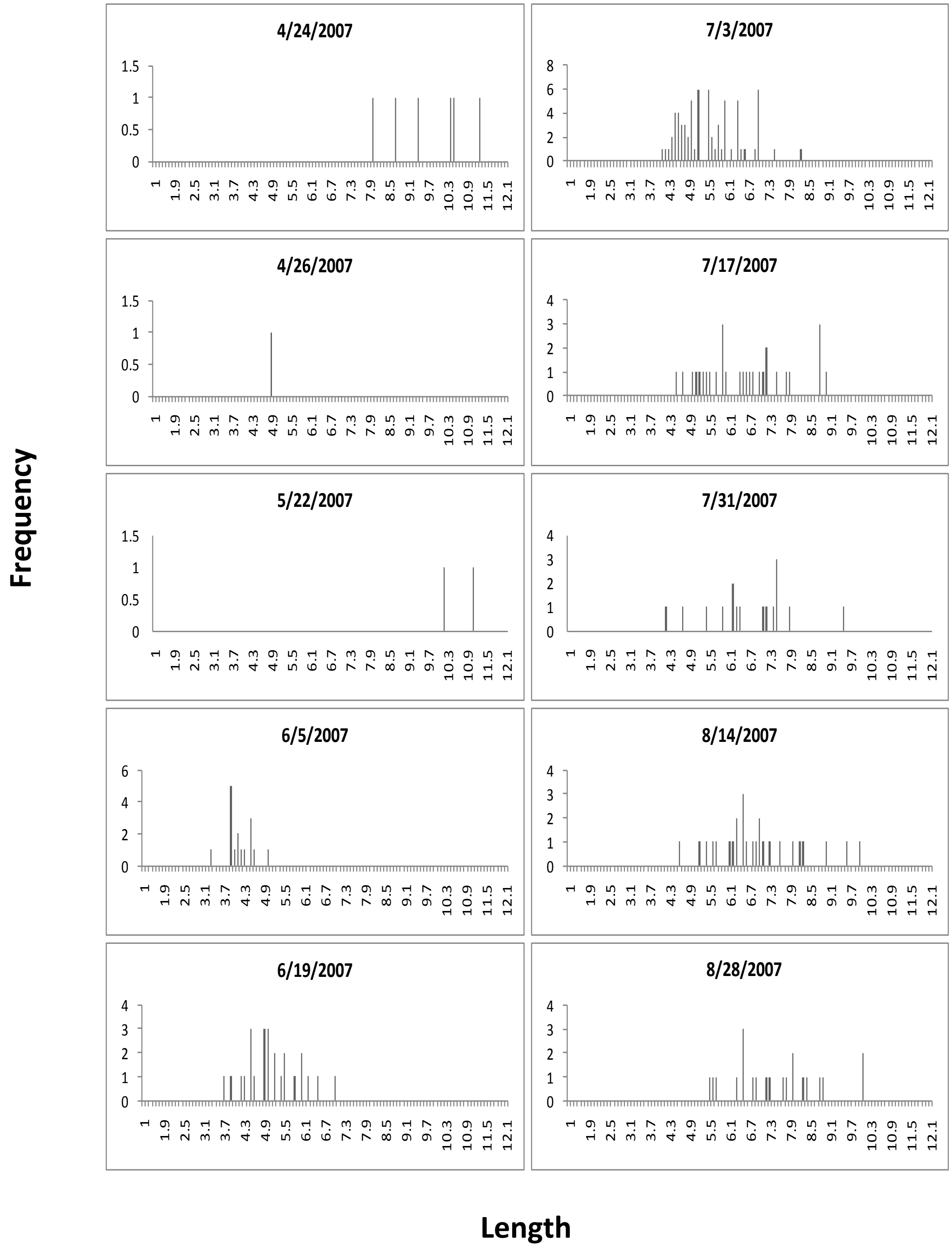


Figure 5: Length frequency diagrams over time for Shinnecock Beach Seine 2007. The x-axis represents length in cm and the y-axis represents frequency. Values on the x-axis are standardized to 12.1 cm, while the y-axis is scaled to the data.

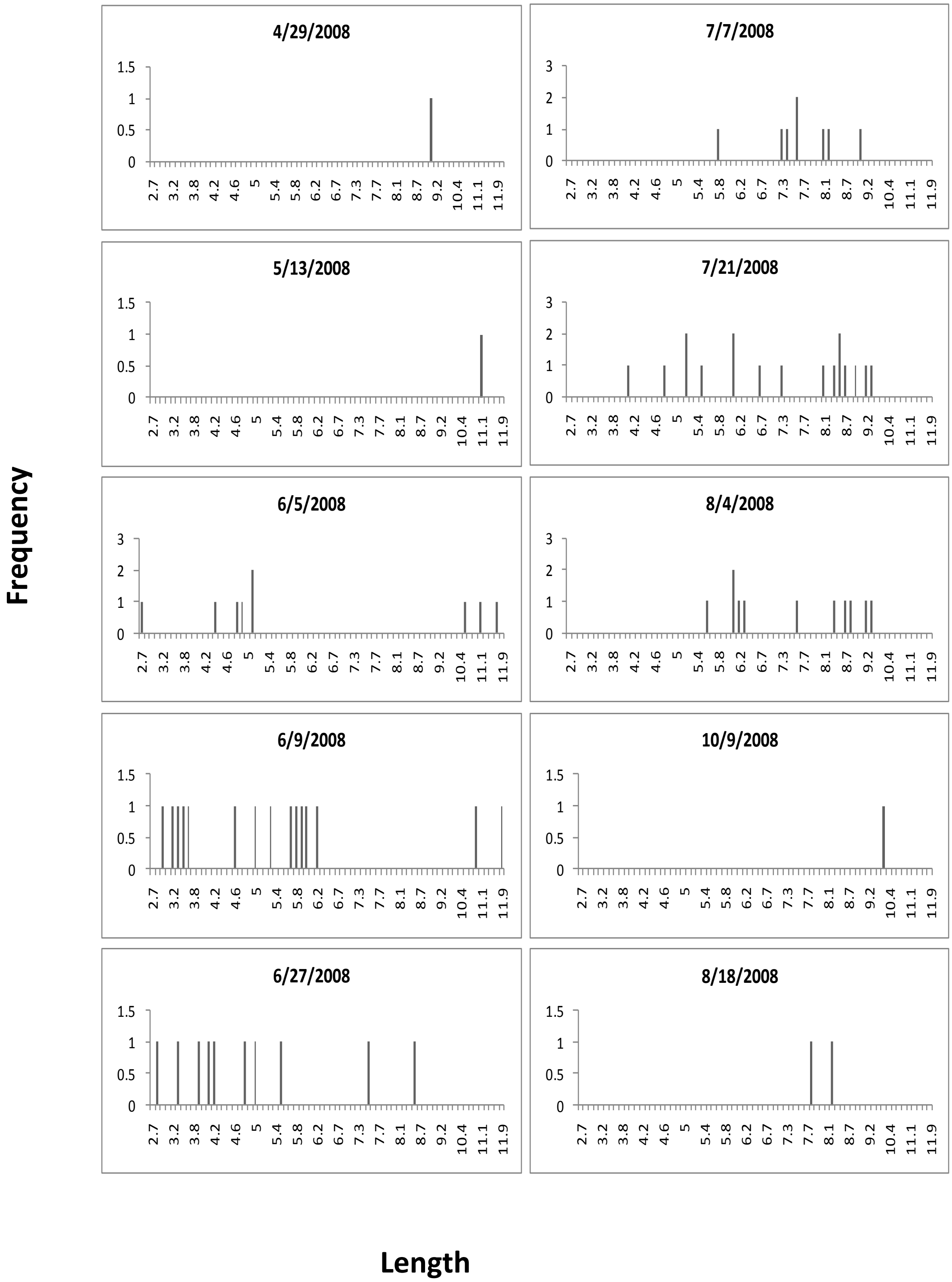


Figure 6: Length frequency diagrams over time for Shinnecock Beam Trawl 2008. The x-axis represents length in cm and the y-axis represents frequency. Values on the x-axis are standardized to 12.1 cm, while values the y-axis is scaled to the data.

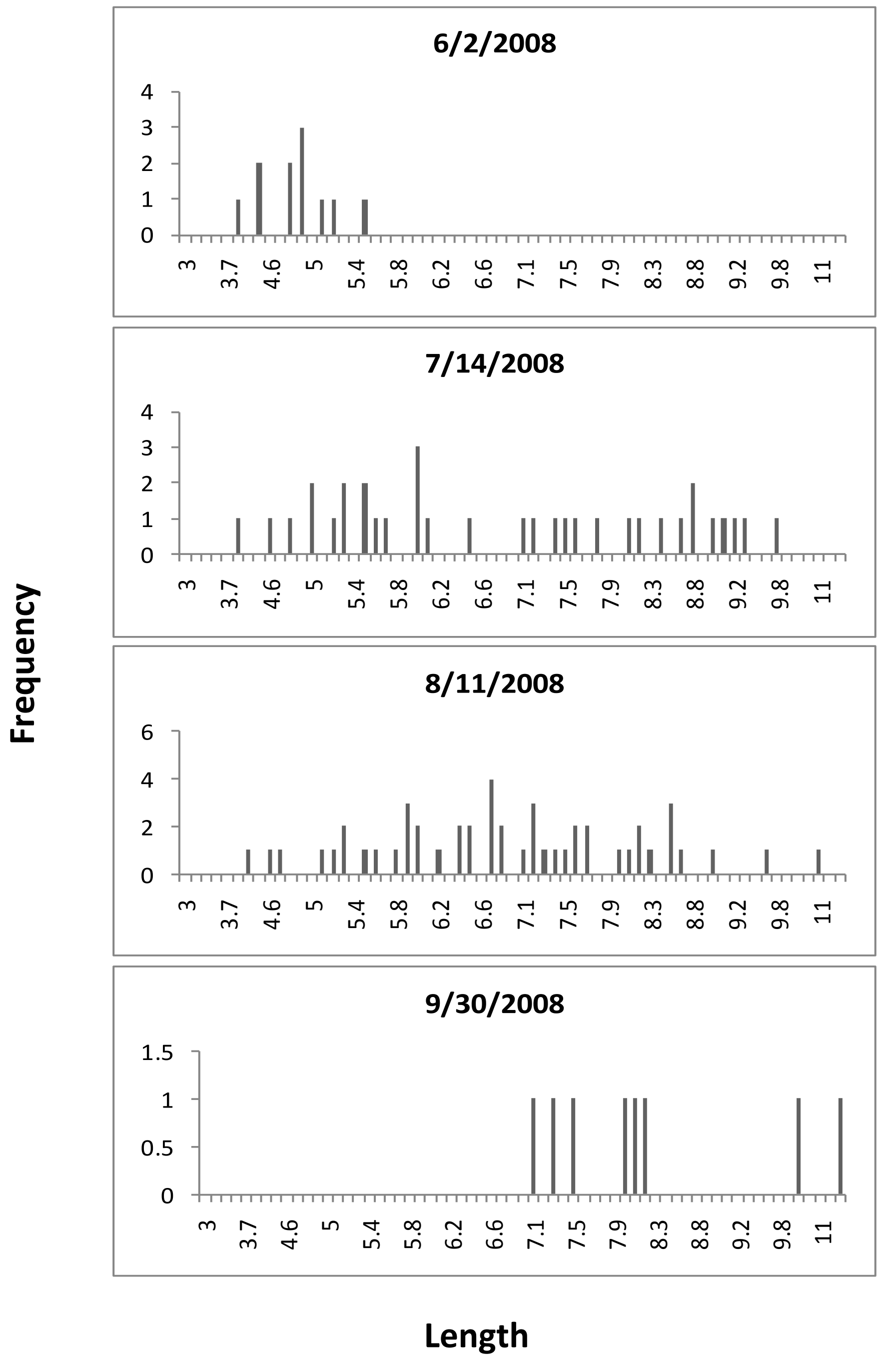


Figure 7: Length frequency diagrams over time for Shinnecock Beach Seine 2008. The x-axis represents length in cm and the y-axis represents frequency. Values on the x-axis are standardized to 11.0 cm, while the y-axis is scaled to the data.

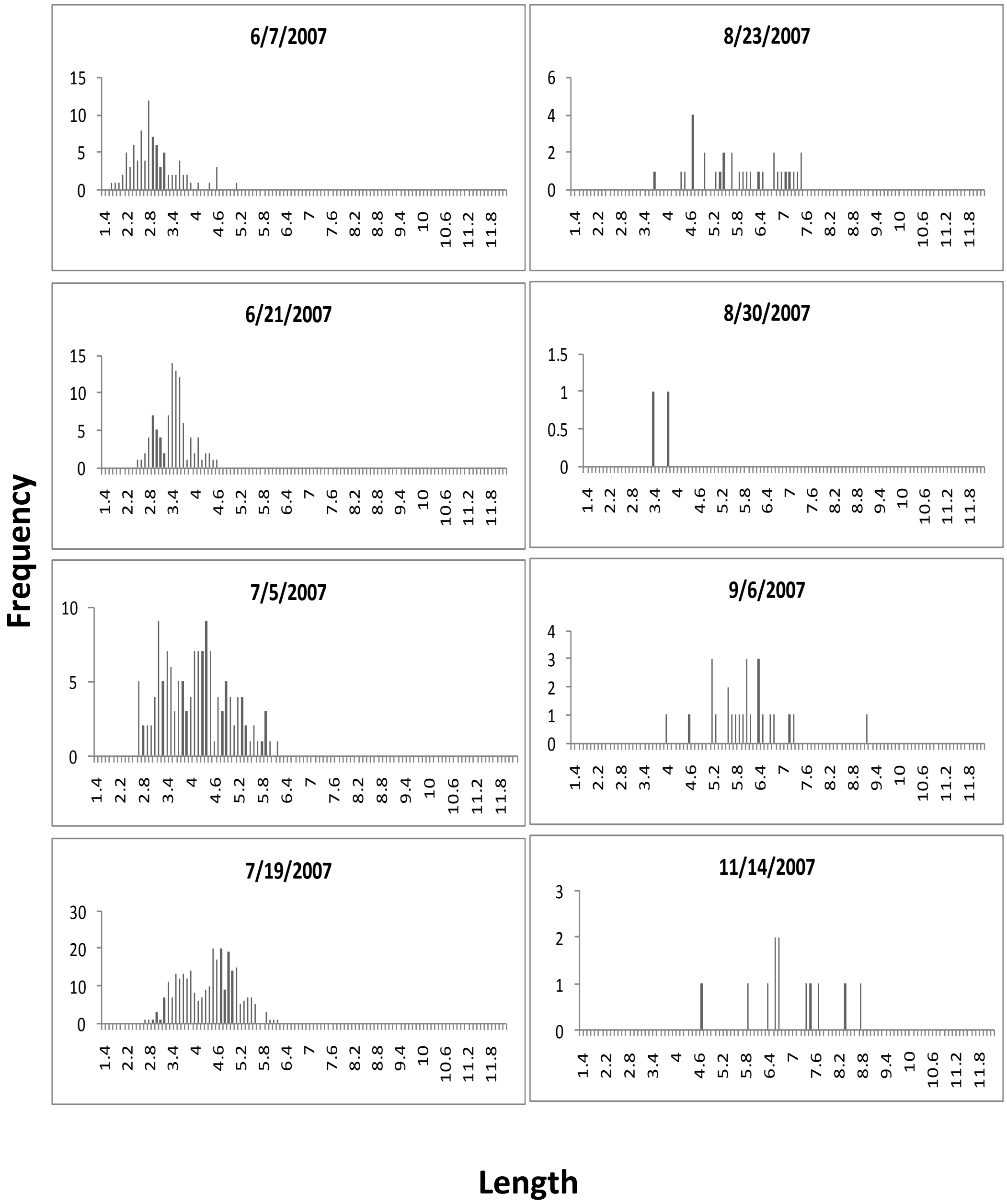


Figure 8: Length frequency diagrams over time for Port Jefferson Harbor Beach Seine 2007. The x-axis represents length in cm and the y-axis represents frequency. Values on the x-axis are standardized to 11.8 cm, while the y-axis is scaled to the data.

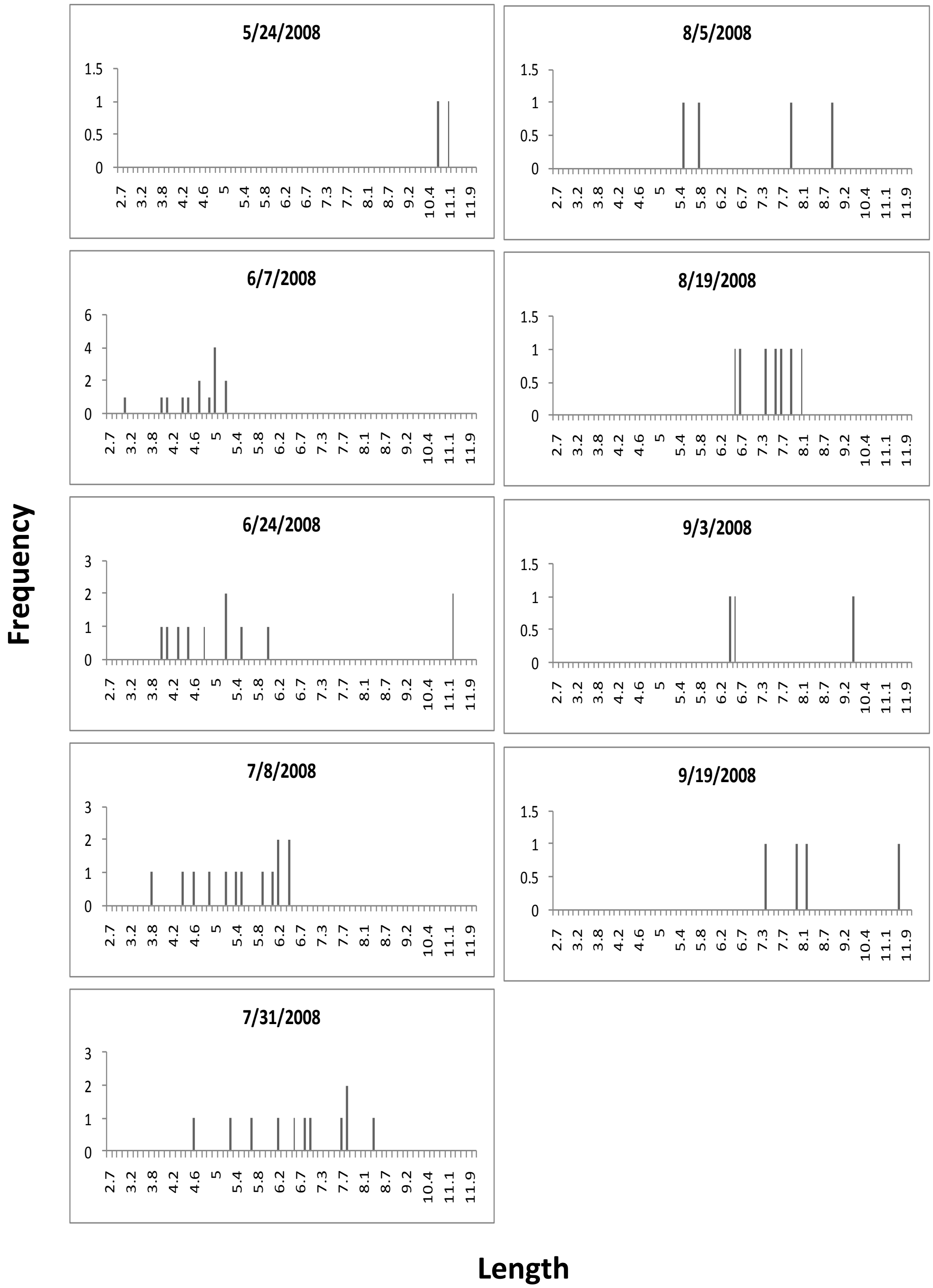


Figure 9: Length frequency diagrams over time for Port Jefferson Harbor Beam Trawl 2008. The x-axis represents length in cm and the y-axis represents frequency Values on the x-axis are standardized to 11.9 cm, while the y-axis is scaled to the data.

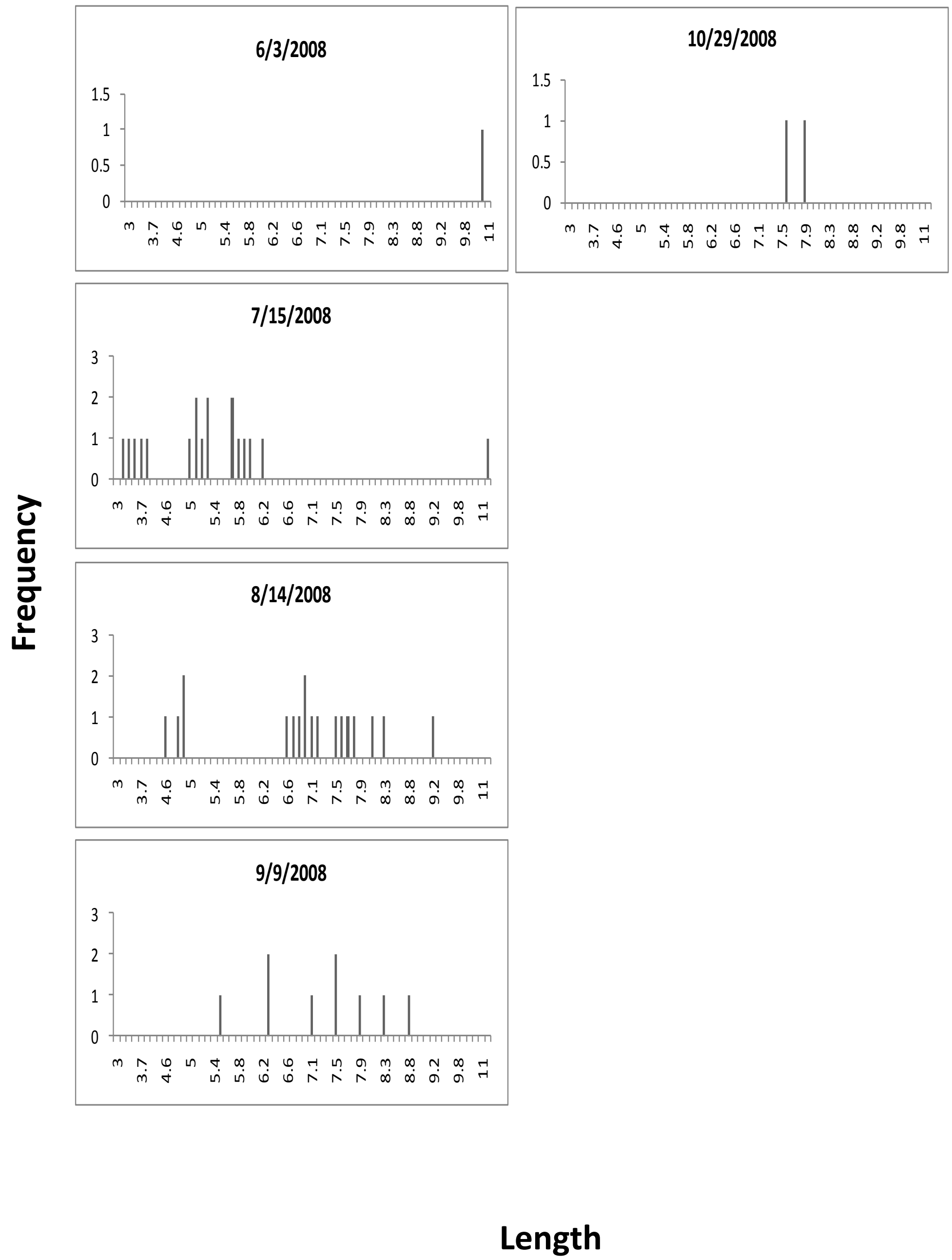


Figure 10: Length frequency diagrams over time for Port Jefferson Harbor Beach Seine 2008. The x-axis represents length in cm and the y-axis represents frequency. Values on the x-axis are standardized to 11.0 cm, while the y-axis is scaled to the data.

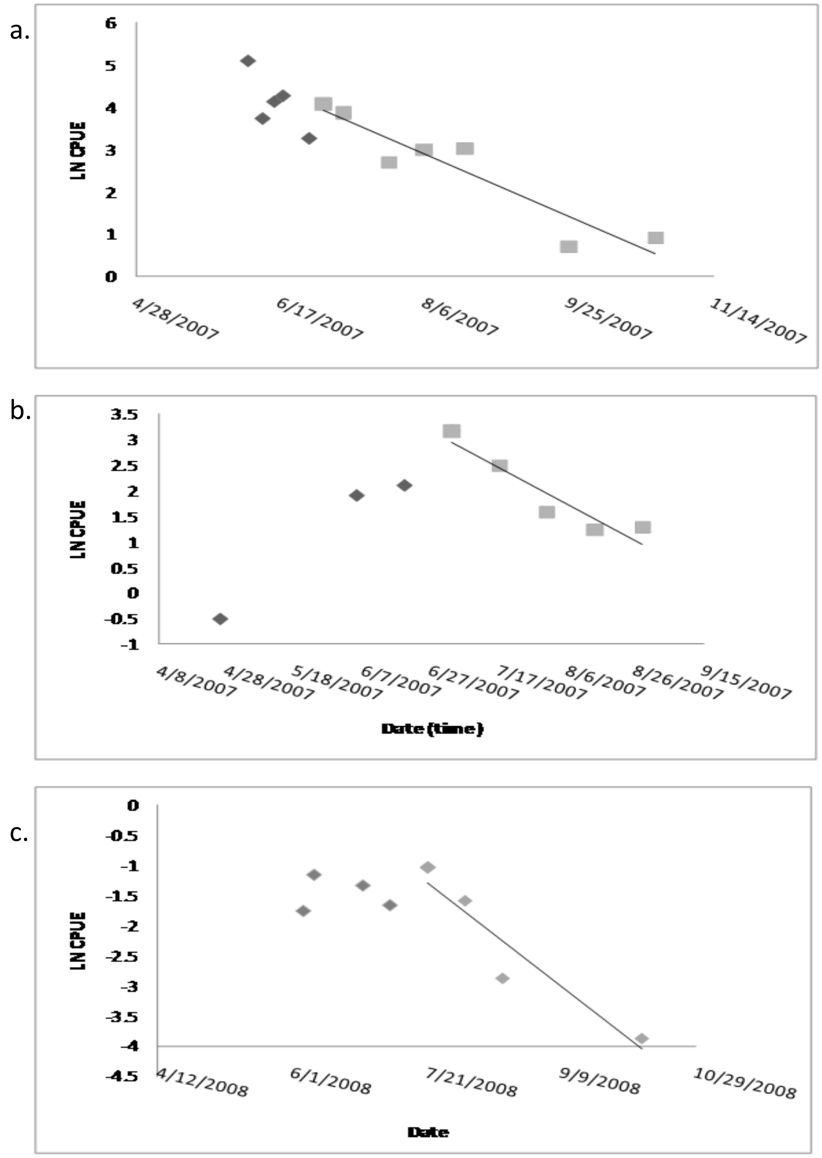


Figure 11: Catch-curve analysis for Shinnecock Bay. Panel a represents results from Beam Trawl 2007. Panel b represents Beach Seine 2007. Panel c represents Beam Trawl 2008. The x-axis is a time series of sampling dates. Y-axis is LN CPUE. Regression line fit to descending arm. Light grey squares represent time period YOY still recruiting to gear and dark grey diamond represent decline in fully selected fish due to mortality. Slope values and R^2 values reported in text.

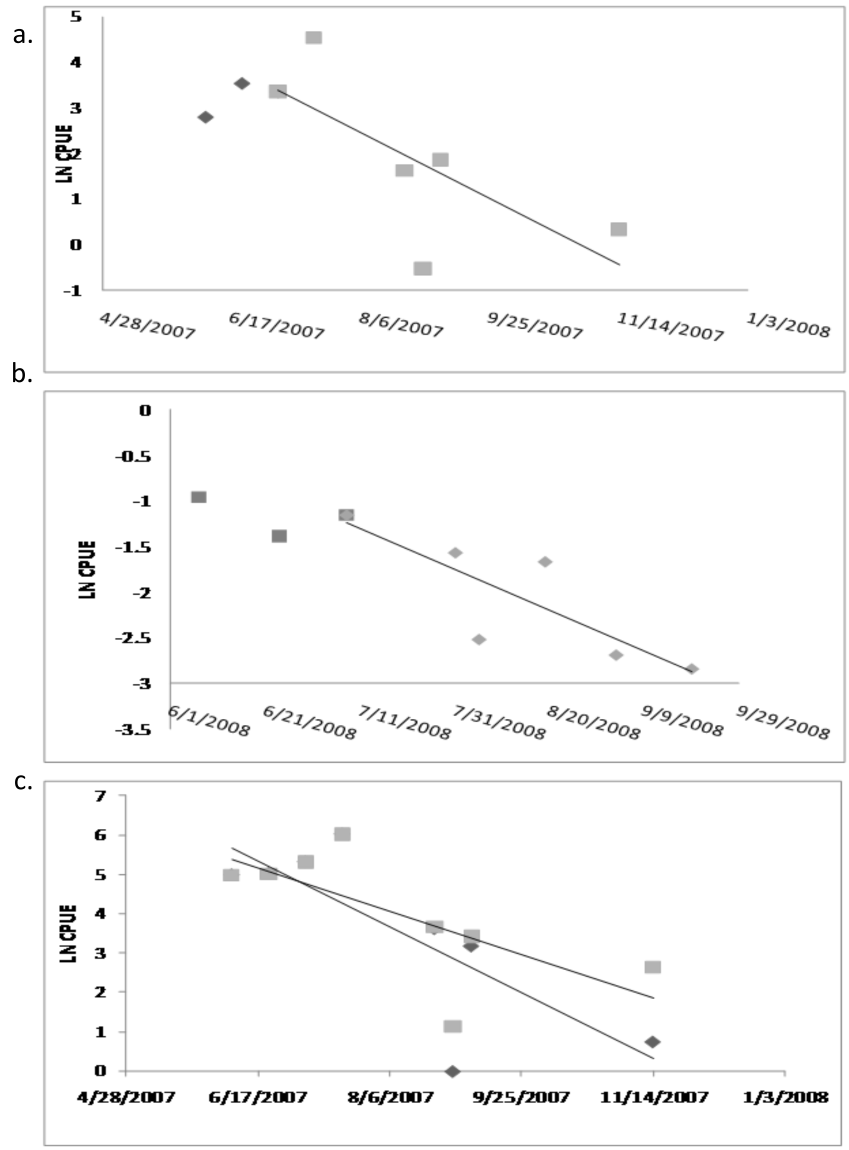


Figure 12: Catch-curve analysis for Port Jefferson Harbor. Panel a represents results from Beach Seine 2007. Panel b represents Beam Trawl 2008. Panel c represents results from cohort specific estimates. The x-axis is a time series of sampling dates. Y-axis is LN CPUE. Regression line fit to descending arm and slope corresponds to instantaneous mortality rate. The regression lines in panel c represent the original regression compared to the regression obtained from separating out cohorts. Light grey squares represent time period YOY still recruiting to gear and dark grey diamond represent decline in fully selected fish due to mortality. Slope values and R^2 values reported in text.

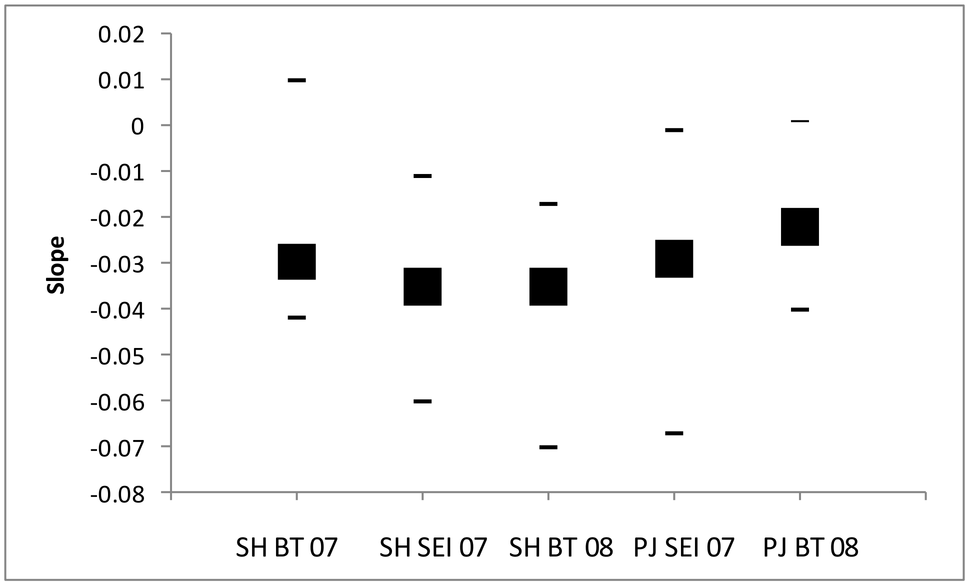


Figure 13: Confidence intervals for each catch-curve analysis. Black squares represent the slope value (M estimate) for each location and year and gear. Dashes represent the 95% confidence interval. No significant differences are found as there is overlap between each data point. Beam Trawl is abbreviated with BT, beach seining is abbreviated by SIE. “07” and “08” correspond to sampling years. Shinnecock Bay is abbreviated with SH and Port Jefferson Harbor is abbreviated with PJ.

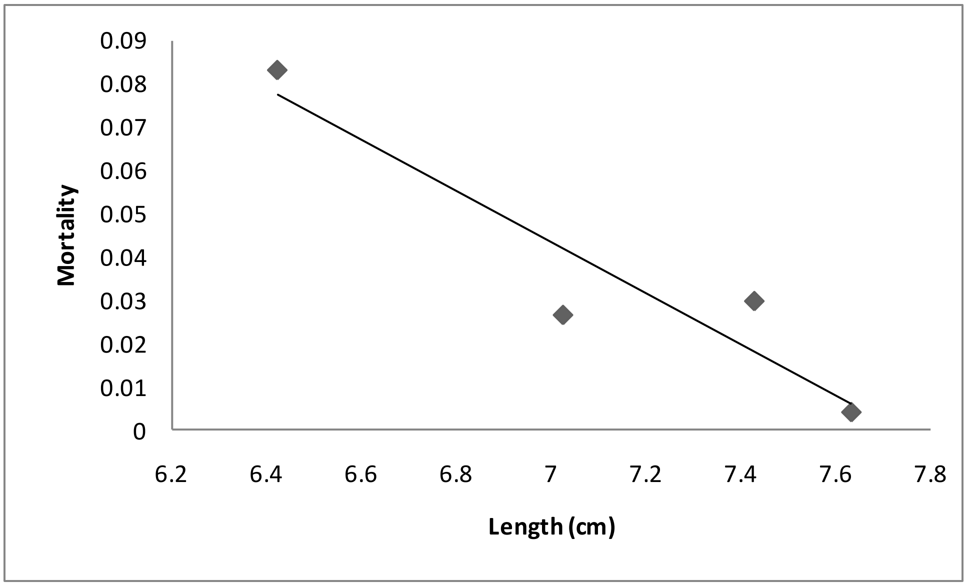


Figure 14: Observed mortality versus length for Port Jefferson Harbor beam trawl 2008, the only location, year and gear to result in a significant relationship.

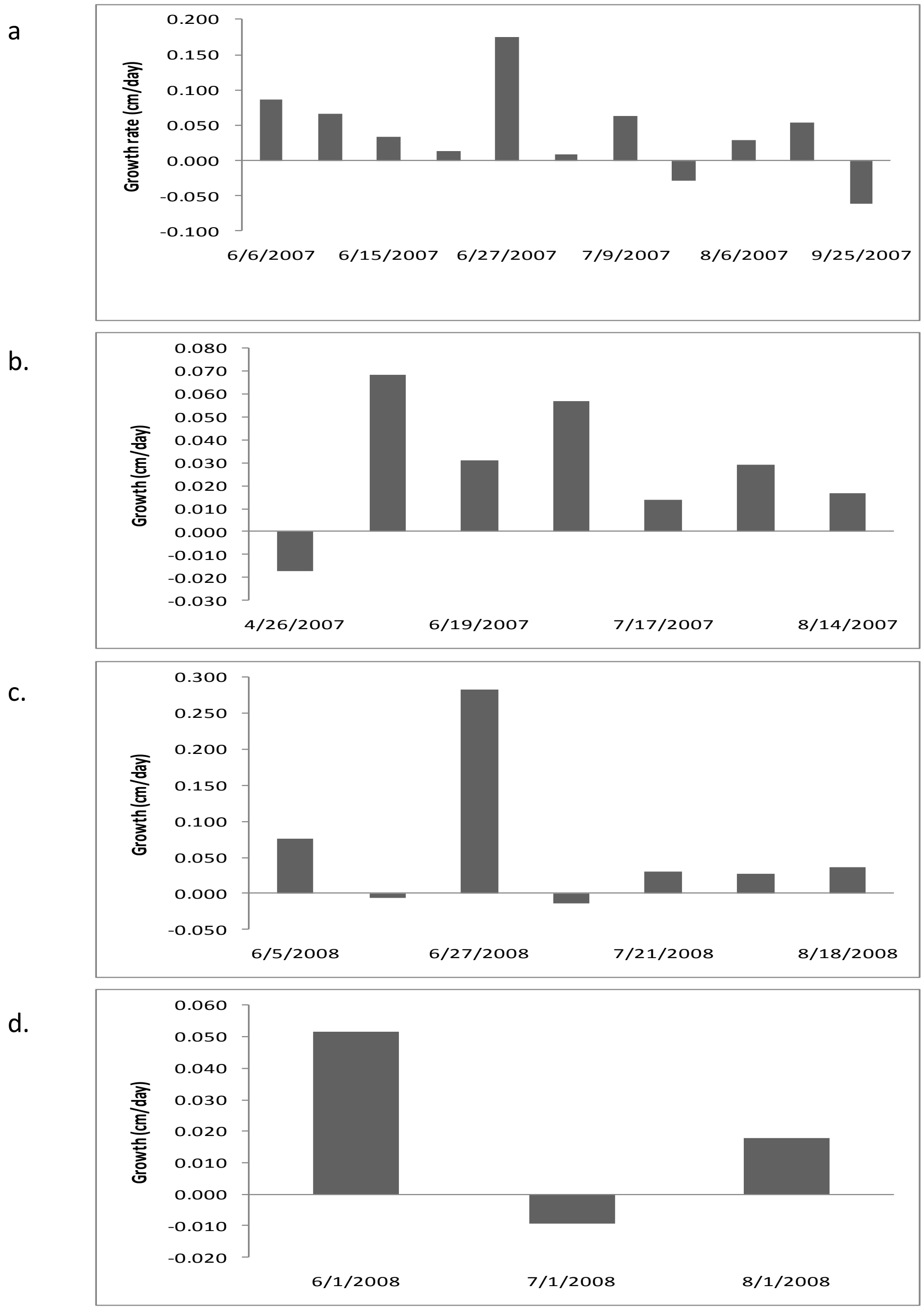


Figure 15: Field growth estimates for Shinnecock Bay. Panel a represents Beam Trawl 2007, panel b Beach Seine 2007, panel c Beam Trawl 2008 and panel d Beach Seine 2008. Growth is in units of cm/day.

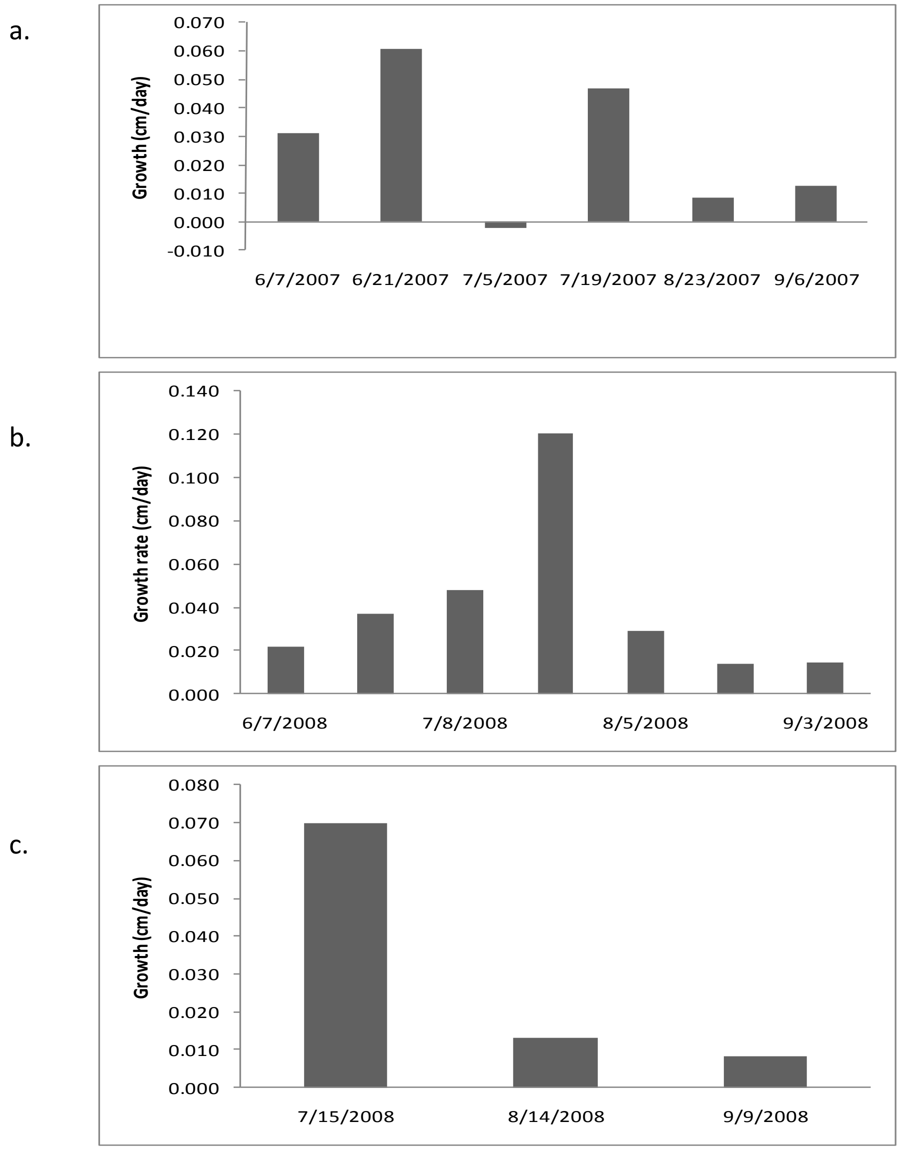


Figure 16: Field growth estimates for Port Jefferson Harbor. Panel a represents Beach Seine 2007, panel b Beam Trawl 2008 and panel c Beach Seine 2008. Growth is in units of cm/day.

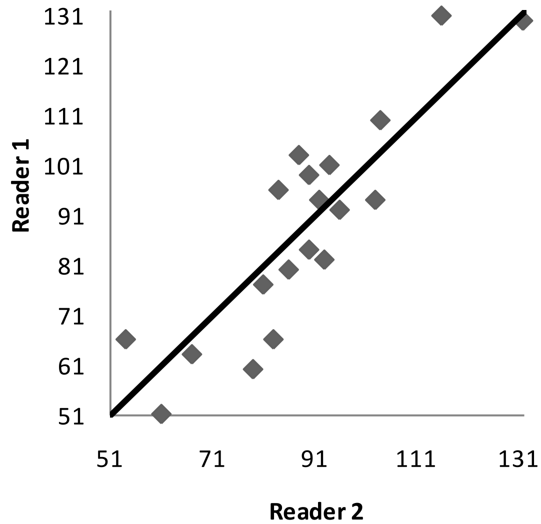
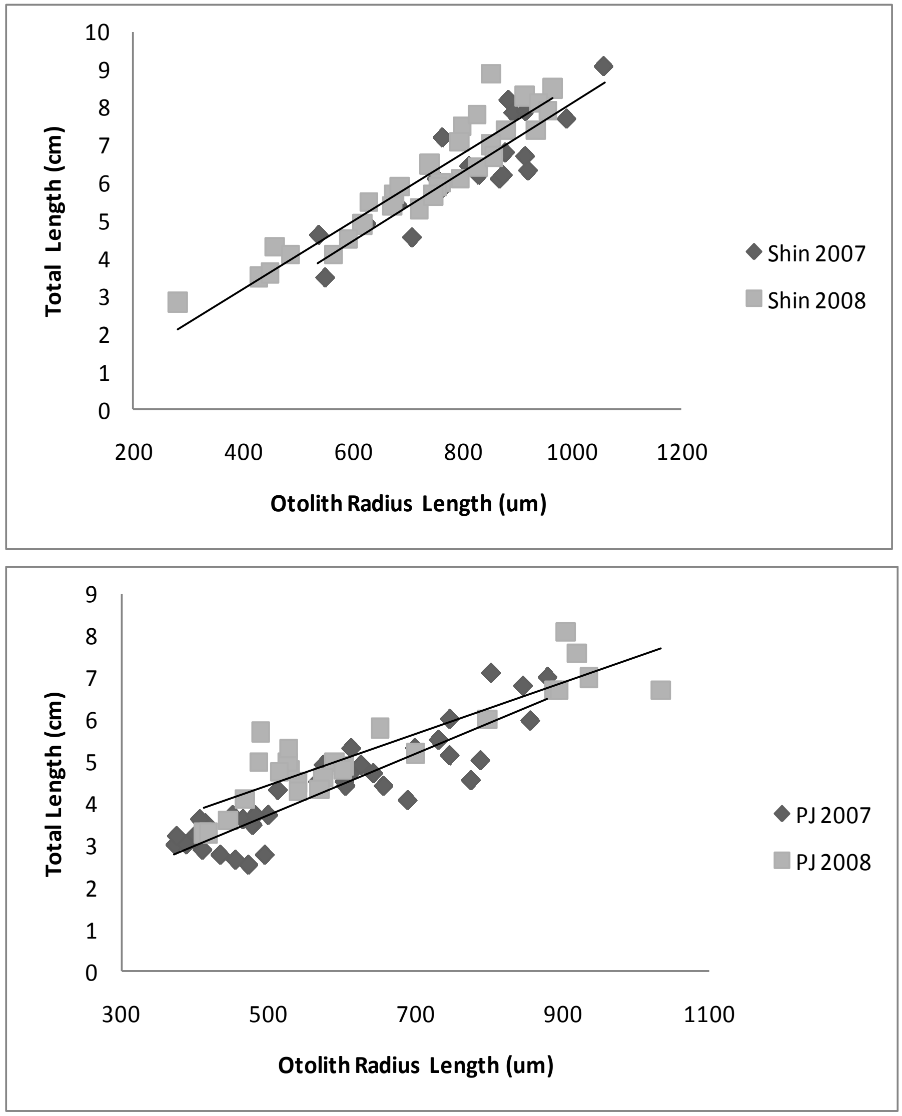


Figure 17: Comparison of reader 2 versus reader 1. Dots indicate relationship between readers. Solid line represents a 1:1 line of perfect agreement.

a.



b.

Figure 18: Total length versus (cm) otolith radius length (um). Panel a represents Shinnecock Bay. Dark gray diamonds indicate 2007 while light grey squares indicate 2008. Panel b represents Port Jefferson Harbor. Symbols are the same as panel a.

a

b

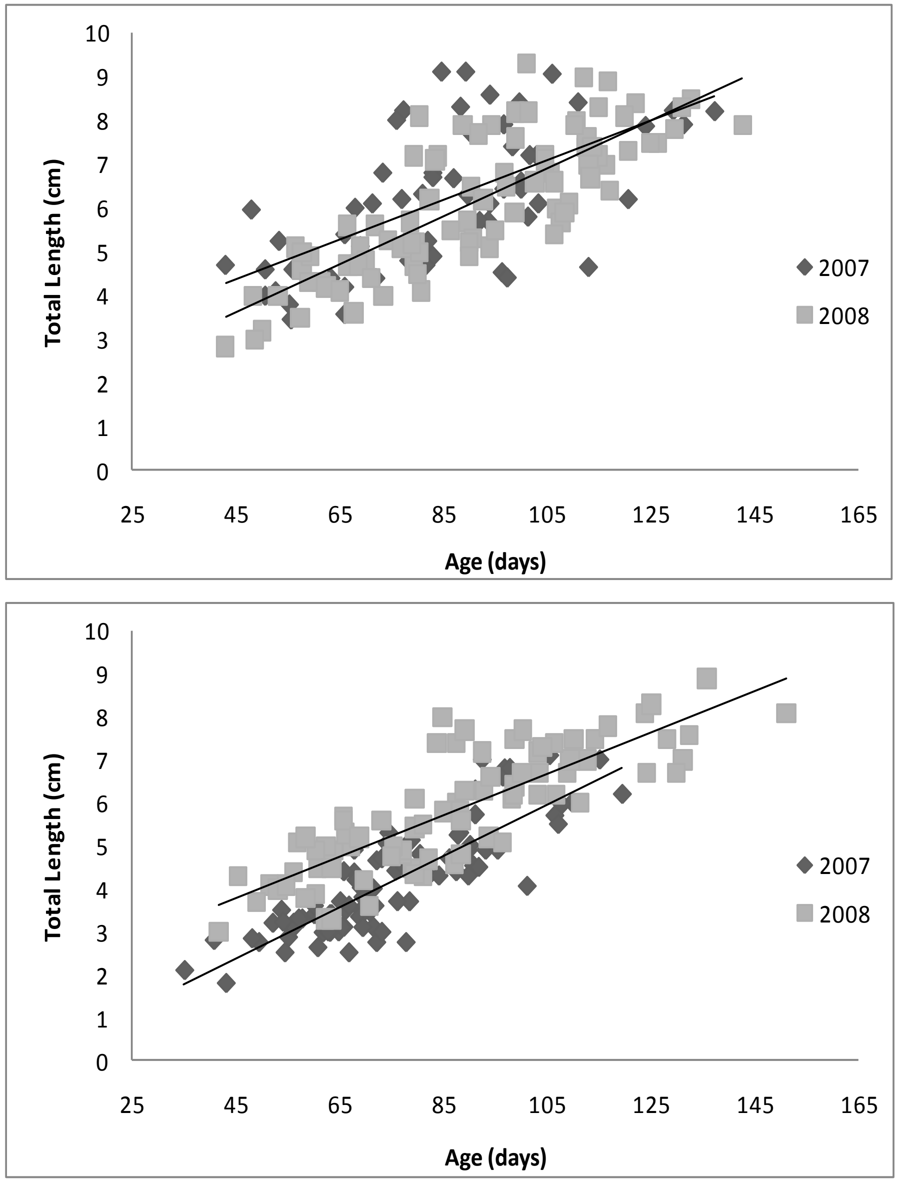


Figure 19: Otolith derived growth rates. Panel a represents Shinnecock Bay with dark grey diamonds representing 2007 and light grey squares representing 2008. Panel b represents Port Jefferson Harbor and symbols indicate the same years.

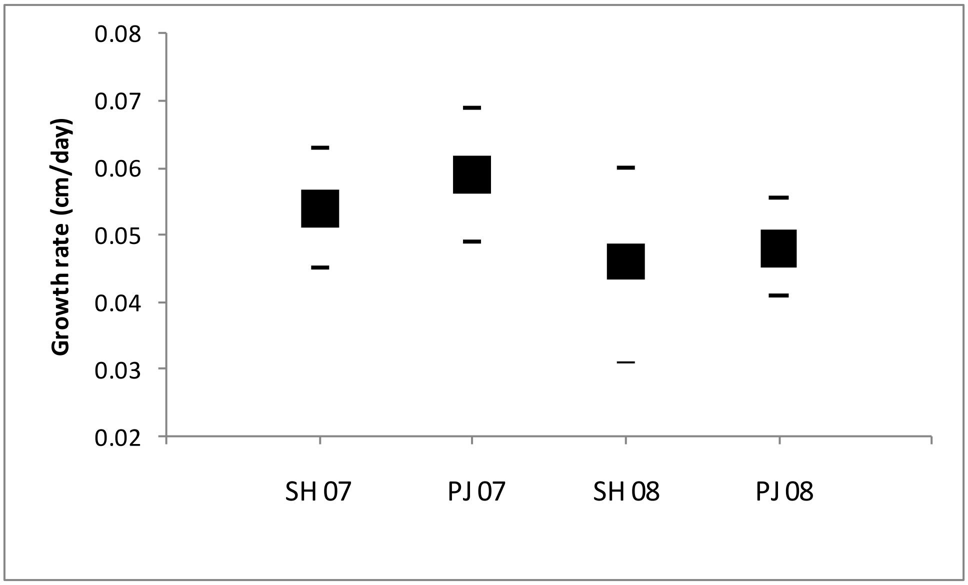


Figure 20: Confidence intervals for otolith derived growth estimates. The black square represents the slope (growth rate) and the dashes represent the 95% confidence interval. Shinnecock Bay is abbreviated SH. Port Jefferson Harbor is abbreviated PJ, and "07" and "08" corresponds with 2007 and 2008.

a.

b.

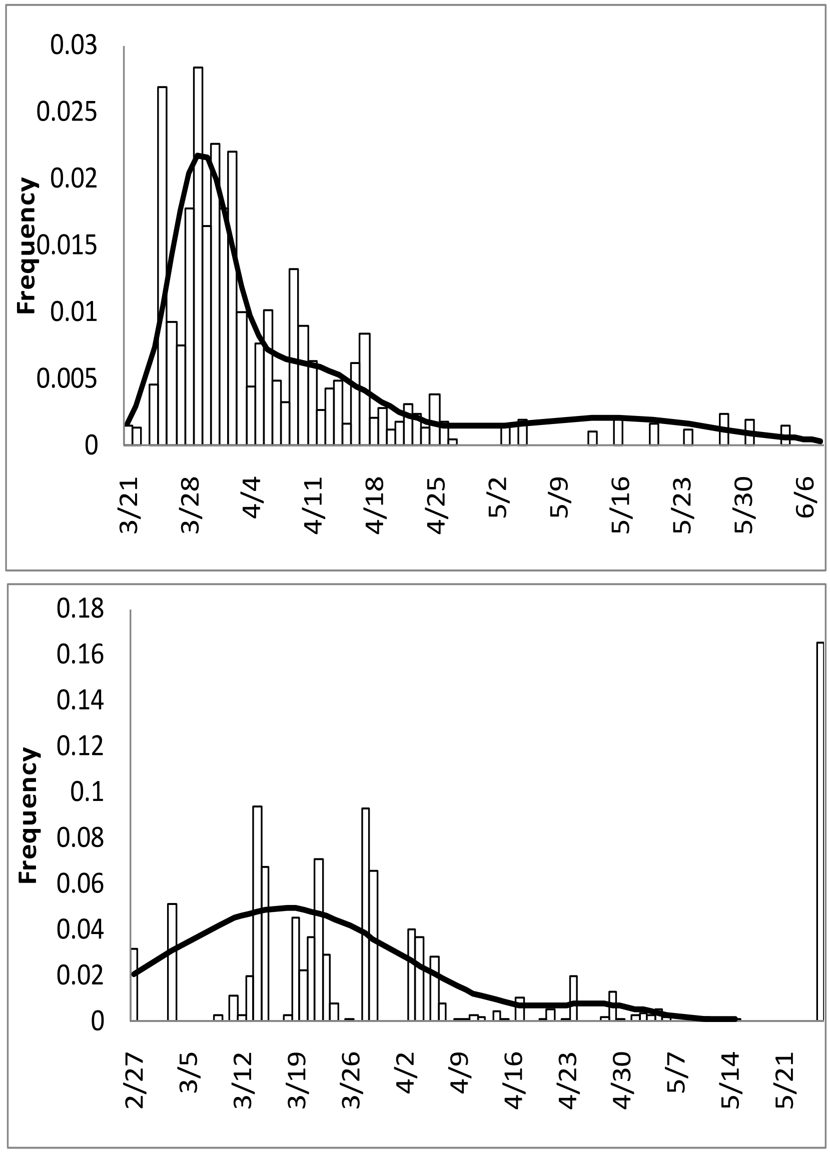


Figure 21: Settlement date frequency analysis for Shinnecock Bay. Panel a represents Shinnecock beach seine 2007 while panel b represents Beam Trawl 2008. Y-axis indicates the relative abundance of fish settling on a particular day. X-axis indicates the date over which settlement occurred. Bold line represents results of modal analysis.

a.

b.

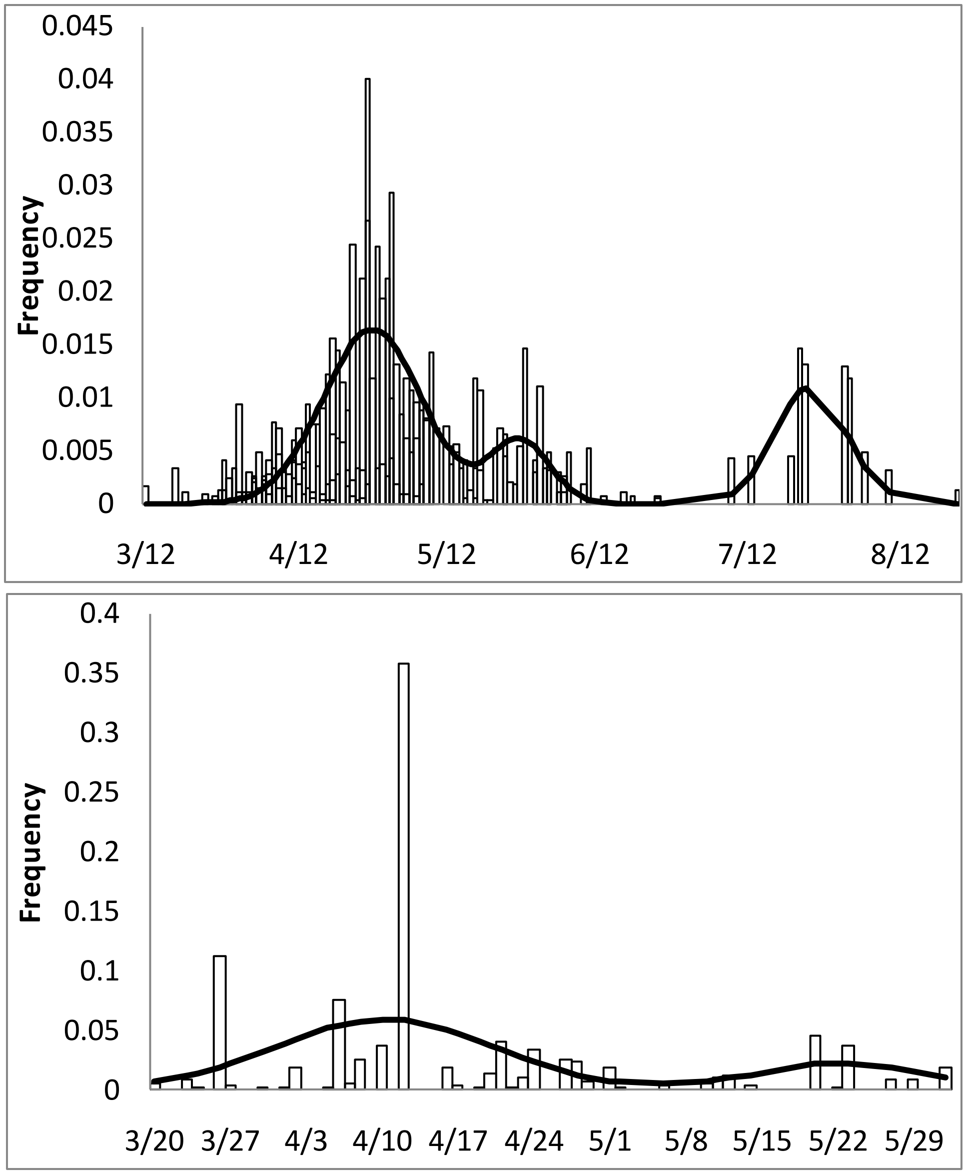


Figure 22: Settlement date frequency analysis for Port Jefferson Harbor. Panel a represents the results from Port Jefferson Harbor beach seine 2007 while panel b represents the results of Port Jefferson Harbor Beam Trawling 2008. Y-axis indicates the relative abundance of fish settling on a particular day. X-axis indicates the date over which settlement occurred. Bold line represents results of modal analysis.