ASSESSING THE LOCAL POPULATION OF WINTER FLOUNDER WITH A TWO-ERA BIOMASS DYNAMIC MODEL: A NARROWER VIEW OF SOUTHERN NEW ENGLAND

By

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INTRODUCTION

The winter flounder or blackback (*Pseudopleuronectes americanus)* is a New England flatfish inhabiting both inshore estuaries and offshore banks (Bigelow and Schroeder 1953). Its exploitation history is long but shorter than for some iconic New England species. The 1500 to 1800 account of northeast continental shelf fisheries by Bolster (2008) featuring whales, cod, herring, sea birds, and anadromous species does not mention flounder. The Claesson et al. (2010) reconstruction of Stellwagen Bank fisheries indicates that flounder of inshore Cape Cod Bay declined from 1855 to 1885 and the fishery moved offshore towards the marine sanctuary. Perlmutter (1947) described the early inshore fishery on winter flounder and the 1930's decline in southern New England. The fishery in the 1800's was prosecuted with fixed fyke and trap net gear. As the demand for fish protein increased, industry began to deploy beam trawls at the end of the 19th century. The beginning of the 20th century saw the introduction of otter trawl gear and combustion engines to fishing vessels increasing their range and fishing power. Fishery landings peaked in the 1920's and then declined. Both Perlmutter (1947) and Royce et al. (1959) note that fishing pressure shifted away from winter flounder to yellowtail flounder (*Limanda ferruginea*) in the 1930's and 1940's as blackbacks declined, demand for fish grew, and fishing vessels became larger. World War II caused a temporary decline in fleet size and fishing effort as capable trawlers were diverted to mine sweeping duties (Murawski 2005). Olsen and Stevenson (1975) documented the Rhode Island resurgence in both number and tonnage of otter trawl vessels following World War II. Saila (1961a) described a 1958 fleet of "about 40 small otter trawlers" that fished on winter flounder in Rhode Island Sound. Based on flounder tagged in Green Hill pond during their winter spawning migration that dispersed from the pond in the summer out to about 20 fathoms, he estimated the size of the Sound stock at 2,422 metric tons. The post war fisheries were significant enough so that by the 1950's mortality rate was 0.8-0.9 per year (Berry et al. 1965). Despite significant fishing, blackbacks dominated the fish community of Narragansett Bay in the early 1970's. The species was the most abundant finfish in trawl samples (Oviatt and Nixon 1973) and was a major component of bay ichthyoplankton in 1972 (Bourne and Govoni 1988). A long-term trawl survey conducted by the University of Rhode Island Gradate School of Oceanography (URIGSO) shows that winter flounder abundance in Rhode Island has fluctuated considerably over time (Jeffries and Terceiro 1985, Jeffries et al. 1989, Collie at al. 2008). The early 1970's were actually a period of medium abundance for winter flounder. Recent survey results show abundance well below the long-term average.

The first documented Rhode Island landings of winter flounder was 155 metric tons in 1887 (Perlmutter 1947). Intermittent reports indicate that landings reached 1,000 tons by 1930. They generally track long-term surveys and have exceeded 2,000 tons on several occasions. Landings are currently low with few fish coming from state waters. Tagging studies conducted in Rhode Island waters in the late 1930's indicate that exploitation rates ranged from 40-50% per year (RIDFW unpublished analysis of Perlmutter 1947 data) compared to the 20-22% needed to sustain maximum yield (NEFSC 2008, 2011). Although long-term over fishing has been a problem (NEFSC 2008, 2011), other anthropogenic sources of mortality can impact winter flounder production. Power plants kill fish through entrainment of eggs and larvae in condenser coolant flow or impingement of larger fish on intake screens (Vaughan 1988, Newbold and Iovanna 2007). Waste heat added to receiving waters by condenser coolant flows may have physiological impacts on individuals or ecological impacts on fishery production systems. Winter flounder are known to be a heat sensitive, estuarine dependent finfish (Buckley et. al. 1990, Keller and Klein-MacPhee 2000). Habitat degradation from low dissolved oxygen levels can impact juvenile growth and production (Meng et al. 2001, Stierhoff at al. 2006).

The decline of winter flounder is part of a larger ecological shift in Rhode Island fisheries (Oviatt 2004, Collie et al. 2008, Wood et al. 2009) as well as those of the northeast region (Nye et al. 2009). Climate change, habitat degradation, and over fishing may be interacting to produce impressive changes in the species composition in local waters A trawl survey conducted by the RI Division of Fish and Wildlife (RIDFW) since 1979 shows a shift from resident demersal species such as winter flounder, toadfish, and tautog toward a pelagic community dominated by seasonal migrants such as scup, squid, and butterfish (Figure 1). This shift has been coincident to a long-term increase in average water temperature in the area (Collie et al. 2008). A 2008 stock assessment for winter flounder in the southern New England (SNE) area found that the stock was overfished and subject to overfishing (NEFSC 2008). Fishing mortality rate was more than twice the overfishing threshold and spawning stock biomass (SSB) was only 9% of that needed for maximum sustainable yield (MSY). Recruitment was consistently low in association with depleted SSB. Projections indicated that although biomass increase was possible, the stock could not rebuild to B_{msy} in 10 years. SNE winter flounder stock status was recently updated for the 52nd stock assessment workshop (SAW). Using data through 2010, a new model, and a revised estimate of natural mortality rate, it was found that fishing mortality rate had declined dramatically so the stock was no longer subject to overfishing (NEFSC 2011). Stock biomass and recruitment remained very low and the probability of rebuilding remained near zero. Low recruitment has a temperature-predation component (Taylor and Collie 2003a, Taylor and Danilla 2005) and may be prolonged under climate change.

Pessimistic GARM III results and the lack of a timely New England Fisheries Management Council (NEFMC) rebuilding plan triggered implementation of an interim rule on May 1, 2009 by the National Marine Fisheries Service (NMFS). The rule was stringent, prohibiting possession of winter flounder and requiring 2:1 counting of groundfish days at sea. The prohibition on retention was continued in NEFMC Amendment 16 to the multispecies ground fish plan which took effect on May 1, 2010. Management in state waters is the responsibility of the Atlantic States Marine Fisheries Commission (ASMFC). They have responded with restrictive measures including a 50-pound commercial possession limit and a 2-fish recreational bag limit. The measures triggered concern by fishermen, congressional delegations, and state agencies over the reliability of the winter flounder science. Although the new federal assessment indicates that the stringent measures have reduced fishing mortality rate, the lack of recruitment and low biomass will continue to challenge management under catch limits. A recent action by the NEFMC to modestly allocate winter flounder in FW 48 may benefit industry by converting discarded fish to landed catch. This report summarizes winter flounder fishery independent and dependent data in the Rhode Island area and importantly examines the long-term dynamics of the local stock on multiple spatial scales. The value of examining long-term population dynamics was illustrated by Soutar and Isaacs (1969) in their seminal work on sardines and anchovies of the Santa Barbara basin. Historical stock analysis is gaining attention from scientists since Pauly (1995) identified the “changing baseline syndrome”. Researchers have been examining the impacts of fishing and climate change through the lens of historical stock analysis (Jennings et al. 1999, Jackson et al. 2001, Christensen et al. 2003, Rose 2004, Rosenberg et. al. 2005, Ainley and Blight 2008, Genner et al. 2009, Claesson 2010).

WINTER FLOUNDER STOCK STRUCTURE

The species exists along the US Atlantic Coast as a series of spawning units that exhibit fidelity to natal estuaries (Perlmutter 1947, Saila 1961, NUSCo.1984, Powell 1989, Phelan 1992, RIDFW 1999-2010 unpublished data). New evidence for divergent, offshore spawning by contingents may challenge that view at least for the Gulf of Maine (DeCelles and Cadrin 2010). Rhode Island fishermen have long maintained that at least two spawning contingents exist “bay fish” and “sound fish” and evidence for this is accumulating south of Cape Cod (Wuenschel et al. 2009, Sagarese and Frisk 2011). For management purposes, the ASMFC and NEFMC currently recognize three stock units; Gulf of Maine, Southern New England and south, and Georges Bank. The Shepherd et al. (1996) and NEFSC (1999) stock assessments had combined the southern New England with the mid-Atlantic areas upon review of existing biological data, reducing the number of recognized stocks from 3 to 4. A multidisciplinary review has generally affirmed the appropriateness of the 3-stock US management paradigm (DeCelles and Cadrin 2011) although the species varies on smaller spatial scales (Wirgin 2003, McCelland et al. 2005) so that SNE is more a complex of stocks that intermix (NEFSC 2011). The 3-stock assessment convention was retained in NEFSC (2011). Tagging studies in Narragansett Bay, the Rhode Island coastal salt ponds, eastern Connecticut, and south of Cape Cod show that post-spawning winter flounder make an offshore and easterly migration when estuarine water temperatures rise above preferred levels (Perlmutter 1947, Saila 1961, Howe and Coates 1975, NUSCo. 1984, Powell 1989). Rhode Island spawning populations are clearly a component of the southern New England stock. For this study, the Rhode Island substock region was defined as that covered by state territorial waters and National Marine Fisheries Service (NMFS) statistical area 539. Although tagging studies show that some Rhode Island fish move as far east as the Vineyard Sound and Nantucket, most are recovered in the Bay or coastal waters (Powell 1989, Gibson 1991, 2000). Under this substock definition, Narragansett Bay and the Rhode Island coastal salt ponds are combined.

Gibson (1993), reported results from an RIDFW tagging study which marked flounder in both upper Narragansett Bay and Mt. Hope Bay during the spawning season. His analysis found that 85% of tags returned the following spawning season were on the home grounds. Saila (1962) had come to the same result while researching potential impacts of constructing the Fox Point hurricane barrier on the Providence River. Recently, RIDFW has been tagging adult winter flounder in Pt. Judith Pond during the spawning period. Since 1999, a total of 1,516 fish have been tagged. Through 2011, a total of 194 tags have been returned excluding immediate recaptures by the sampling gear. No returns during subsequent spawning periods have come from other known spawning areas. In one case, a fish first captured in an RIDFW fyke-net and tagged in 1999, was recaptured in 2000 and 2001 at the same site. Crawford (1990) also found small scale fidelity to spawning location in Pt. Judith Pond. Complementing tagging studies, DNA microsatellite and micro-elemental analyses are advancing in their ability to discriminate adjacent populations of winter flounder. About 1 in 5 larvae entrained at Millstone Power Station are from the Niantic River, CT cooling water source while the rest are from other estuaries (DRS 2002, Crivello et al. 2004). Within estuaries, juvenile populations have been discriminated on small spatial scales (Buckley et al. 2008). Fidelity to local area in early life results in differences in otolith chemistry that may be useful as markers (Pruell et al. 2010). Considering the philopatry demonstrated by estuarine tagging studies and DNA evidence for distinct populations, there should be little doubt concerning the rich sympatric structure of SNE winter flounder nor the attendant management implications. When homing behavior and fidelity create distinct subunits, population dynamics of the subunits can be desynchronized by local impacts including concentrated fishing or habitat loss. Such impacts can lead to systematic loss of critical elements of the population structure (Thorrold 2001, Petitgas et al. 2010). Indeed, the discovery of homing behavior in Atlantic cod in relation to the depletion of subunits is viewed as an impediment to stock recovery since recolonization rates are reduced (Robichaud and Rose 2002, Reich and DeAlteris 2009). Review of winter flounder status at multiple spatial scales including the very small is warranted since it may be a means to advance understanding of regulatory processes (Shepherd et al. 1990).

METHODS AND DATA SOURCES

Fishery Independent Abundance Indices

The Rhode Island Division of Fish and Wildlife (RIDFW) conduct several surveys in and outside Narragansett Bay to monitor winter flounder abundance. A seasonal trawl survey is conducted in spring and fall at stratified random stations in the Bay as well as in adjacent Rhode Island and Block Island Sounds. Details of the survey may be found in Lynch (2000). A total of 42 stations are sampled per season and all winter flounder are weighed, enumerated, and measured for length. The survey has been conducted since 1979 and indices through spring 2011 are available. A monthly, fixed station cruise was added to the trawl survey program in 1990 to better assess seasonal abundance patterns of migratory species. A total of 13 stations are sampled each month in Narragansett Bay for a total of 156 tows. Biomass indices were computed for the seasonal and monthly cruises separately as an arithmetic mean weight per tow by cruise. Recruitment indices (age 1) were developed from the spring survey by application of Northeast Fisheries Science

Center (NEFSC) age-length keys (Mark Tercerio, NEFSC-pers. comm.). Fall survey indices (age 0 and age 1) were developed by inspection of the length frequencies informed by the Berry et al. (1965) and Hass and Recksiek (1995) growth studies. Fall age 0 and age 1 flounder were considered those fish less than or equal to 11 cm and fish ranging from 12 to 21 cm respectively. Beach seine surveys to monitor abundance of young of the year (YOY) flounder have been conducted by RIDFW in Narragansett Bay since 1986 and in the coastal salt ponds since 1992. Methodology for the seine surveys is given in Powell (1986). Briefly, beach seines are deployed once per month from May through October at fixed stations in the bay and ponds. Eighteen stations are located in Narragansett Bay and 17 are located in the salt pond complex. YOY generally recruit to the sampling gear in May and June with maximum abundance typically occurring in July. A few older flounder (>11 cm) are caught each year however generally 90% or more are YOY. Arithmetic mean YOY per haul was computed from the September and October sampling waves. In Pt Judith pond, fyke nets are set for spawning winter flounder each winter in addition to the YOY seining. The nets are set at the head of tide in known spawning areas in February and March. Commercial fyke gear was historically fished in the ponds when flounder were more abundant (Crawford 1990). In addition to providing fish for a tagging study, mean catch per set from the fykes can be used as an index of spawning stock biomass (SSB) to examine stock-recruitment dynamics on a small spatial scale.

The URIGSO trawl survey provides a long-term perspective for winter flounder abundance in Narragansett Bay. This weekly survey samples only two stations in the west passage but has been conducted since 1959. Details of the survey design and methods are given in Jeffries et al. (1989) and Collie et al. (2008). Briefly, a small otter trawl is deployed each week at the Fox Island and Whale Rock stations for a total of 104 tows per year. The survey does not include complete length composition and aggregate weight data so a consistent weight per tow computation was not possible. Examination of the RIDFW trawl data indicated that mean number per tow fluctuates with higher variance than mean weight per tow. This is likely due to the occurrence of numerically dominant year classes that recruit at low body weight. Trials with various power transformations indicated that a square root transform of number per tow would produce a series with similar long-term variance to untransformed weight per tow. It is important in fitting biomass dynamic models that the fishery independent abundance index be proportional to exploitable biomass. Therefore, the URIGSO number per tow index was so transformed and used as the primary abundance index to fit the biomass dynamic model. Data through December of 2011 were obtained (Jeremy Collie, URIGSO- pers. comm.). Age 1 indices from the survey were available from 1985 to 2010 from application of MADMF spring age-length keys (Mark Tercerio, NEFSC-pers. comm.). For years prior to 1985 when length samples were not available, the URIGSO aggregate catch per tow in number was subject to a deconvolution procedure using methods similar to that advocated by Walters and Hilborn (2005). Recruitment was estimated from the trawl series as:

$$R_t = N_t - N_{t-1}\exp(-Z) \qquad (1)$$

where: R= recruitment index at age 1

N= total survey catch
Z= mean mortality rate
t= year.

The value of Z was determined with SOLVER by comparing the predictions of eq. 1 to the available aged indices by least squares. The main difference between eq. 1 and that of Walters and Hilborn (2005) is that fishing (their catch) is included in Z. The reliability of this approach rests on assumptions 1) that natural mortality dominates Z for small fish 2) that it is relatively constant with respect to time, and 3) survey catchability is constant. There was good correspondence between deconvolved and aged indices for 1985 to 2010 (r=0.8) so eq.1 is believed to reliably hind cast estimates for years 1960-1984.

Normandeau Associates (NA) has conducted trawl surveys for the owners of Brayton Point Station (BPS) since 1972. BPS is located in Somerset MA at the head of Mt Hope Bay. Details of the company survey program may be found in DENE (2011). The trawl program has two components, a large mesh standard trawl and the Wilcox small mesh trawl. The large mesh trawl has been fished monthly at 6 fixed stations in upper Mt Hope Bay near BPS since 1972. The Wilcox trawl has been fished monthly at 10-12 random stations in Mt Hope and upper Narragansett Bay since 1996. As with the URIGSO series, a square root transformation was applied to the mean number per tow indices. An age 1 index was computed from the standard trawl as CPUE of fish between 90 and 160 mm in length. Indices through 2010 were obtained from NA staff (Mike Scherer- pers. comm.). A beach seine survey targeting YOY winter flounder has been conducted by NA in Mt Hope Bay as well since 1992. Ten fixed and 8-11 random stations are sampled each month from June to August.

The NMFS Northeast Fisheries Science Center (NEFSC) conducts a seasonal, random stratified trawl survey in federal waters from the Gulf of Maine south to Cape Hatteras, NC. Methodology is summarized in Grosslein (1974) and Azarowitz (1981). Winter flounder indices from this survey were a primary input to the GARM III stock assessment (NEFSC 2008). For this assessment, the spring 1968-2008 mean weight per tow index for the southern New England stock area was used as reported in NEFSC (2008). A change occurred in federal research vessels between 2008 and 2009 when the RV Henry Bigelow replaced RV Albatross IV. Recent indices from this survey utilizing the appropriate calibration coefficients were provided in NEFSC (2011).

The final trawl survey considered was that from the Northeast Area Monitoring and Assessment Program (NEAMAP). This survey is conducted by the Virginia Institute of Marine Science (VIMS) under contact from the ASMFC. The purpose of the survey is to fill the spatial gap between the NEFSC and state agency trawl surveys from Cape Hatteras, NC to Rhode Island Sound. Details of the survey design and methods can be found in Bonzek et al. (2009). Briefly, the survey is of random stratified design with stratification by depth and sampling 150 stations per year. For this assessment, only tows made in Rhode Island and Block Island Sounds were considered. Data were available for four fall cruises (2007-2010) and three spring cruises (2008-

2010). Between 18 and 22 stations were sampled in the Sounds each cruise. Arithmetic mean number and weight per tow of blackbacks were calculated for each cruise.

Ichthyoplankton sampling has been conducted by NA in Mt Hope Bay and the Providence River reach of upper Narragansett Bay since 1973 as a requirement of power plant monitoring at Brayton Point and Manchester Street stations. Methods were reported in Bourne and Govoni (1988). RIDFW also sampled ichthyoplankton throughout Narragansett Bay from 2001-2008 using similar methods. Mean number of winter flounder larvae per 100 m^3 of water sampled was computed as an index of larval abundance and potentially early recruitment.

Fishery Dependent Data

Recreational landings estimates for winter flounder in Rhode Island waters are made annually by the NMFS through the marine recreational information program (MRIP) survey. Estimates of fish landed (type A+B1) are available from 1981 to 2011 from the NMFS website. The 2004 to 2011 estimates are the revised MRIP series. Estimates for 1978-1980 were taken from a state survey (McConnel et al. 1981) and from early MRFSS estimates (USDOC 1984). Commercial landings for NMFS statistical area 539 were considered to be the most appropriate measure of commercial removals from the Rhode Island substock. Area 539 includes Narragansett Bay, Rhode Island Sound and federal waters south and east of Block Island. Total commercial landings of winter flounder for Rhode Island were available for 1950-2011 from NMFS databases. NMFS also provided landings specific to area 539 for the period 1964 to 2011. Prior to 1964, area 539 landings were estimated as 79% of total, the mean for 1964 to 1968. Estimates of recreational landings from 1950-1977 were made with a regression of recreational landings on area 539 commercial landings for years 1978-2010 ($r=0.62$, $df=31$, $P<0.01$). The reasonableness of these estimates was evaluated by reference to historical tagging studies that segregated returns into recreational and commercial components. Estimates of fishery discards were also included in this stock assessment. Discard proportions for the southern New England winter flounder stock, as recently assessed by NMFS (NEFSC 2011), were assumed to apply to the Rhode Island area. Discards were estimated as the discard proportion from SNE multiplied by area 539 landings by year. As noted above, stock mixing occurs in area 539. Since estimates of stock size and production from BDM models are sensitive to the magnitude of landings data analyzed, it is important to refine landings to include only flounder originating from Rhode Island waters to the extent possible. Although a complete disaggregation of landings into stock origin is not possible, the Gibson (1991) analysis of Perlmutter's extensive tagging experiment provides some insight. In that study, about 80% of the tagged fish recovered in area 539 had been previously tagged in Narragansett Bay or the coastal salt ponds. This suggest that area 539 commercial and Rhode Island recreational landings are an appropriate aggregation of the fishery removals from the stock indexed by the above indices.

A commercial fishery abundance index was calculated using fishing effort data for statistical area 539. The number of days fished in the area was provided by NMFS staff (Mark Terceiro- pers. comm.) and were previously used by Collie et al. (2008) in their study of factors influencing changes in the Narragansett Bay fish community. Area 539 landings were divided by effort to produce catch per day fished. Although fishery dependent indices are often regarded as unreliable if not dangerous for use in assessment modeling (Paloheimo and Dickie 1964, NRC 1998), area 539 CPUE was significantly correlated ($P<0.01$) with the long-term URIGSO and NMFS trawl indices. Further, the effort series displays multiple regions of both high and low effort. This is considered "informative" and "good contrast" data for BDM modeling (Hilborn and Walters 1992) and so was included in the assessment. Data for years 1964 to 2008 were available. With the federal closure of SNE waters in 2009 this series cannot be extended.

Tagging Studies and Mortality Rate

As noted above, winter flounder in the Rhode Island area have been subject to tagging experiments since the 1930's. These studies were reviewed by ASMFC and were the basis for estimating fishing mortality rates in the first management plan ASMFC (1992). A more recent RIDFW tagging effort began in 1999 in Pt. Judith Pond, a coastal salt pond on the south shore of Rhode Island. Fyke nets are used to capture spawning winter flounder in the upper reaches of the estuary during the winter. Adult flounder are tagged with individually numbered Peterson disc tags. A total of 1,556 fish have been tagged through the 2012 spawning season. This study was recently expanded to include Charlestown pond with 99 fish tagged from 1/20/12 to 3/28/12. For analysis of tag returns from multiple release experiments, models from the Brownie et al. (1985) framework were fit to the recapture data. Maximum likelihood methods, as implemented by the MARK 3.0 software, were used to estimate model parameters (White and Burnham 1999). AIC criteria and chi-square tests were used to rank alternative models. The MARK software estimates a survival rate (S) which is converted to total instantaneous mortality rate by $Z= -\ln(S)$. Fishing mortality rate is obtained by subtraction ($F=Z-M$) where the natural mortality rate M is set at 0.20 per year. For single release year studies, catch-curve analysis was used to estimate Z as the slope of the regression of log transformed tag recaptures on time. A tag loss correction was not applied since tag loss is generally low for Peterson discs. In a recent tagging study of yellowtail flounder on the Grand Bank, the tag shedding rate was estimated at only 0.024 per year (Cowen et al. 2009). Estimates of F internal to the BDM model were compared to the time series of tag based F in calibration mode. The calibration assumed that tag based and BDM F were equivalent i.e. the catchability parameter was set to 1.0. This was deemed a reasonable assumption since 1) the tagging studies are extensive and use well established methods (mostly Peterson discs), 2) the GARM III catch at age modeling shows little difference between fully recruited mean F and biomass weighted F, and 3) a free q parameter produced early (1919) biomass estimates above K that were unrealistic in view of the exploitation history. The convention of tag $q=1.0$ is a strong one since the internal estimates of F through fishery landings and the catch equation, limit the feasible range of biomass solutions. The consequences of this convention are discussed further under model diagnostics.

Survey Based Estimates of Mortality Rate

As noted above, the RIDFW and URIGSO trawl survey catches have been disaggregated into age components using NEFSC and MADMF age-length keys. The age specific indices have been used to calibrate the SNE age-structured stock assessment (NEFSC 2008, 2011). Survey age composition from 1981 to 2010 was examined for trends in total mortality rate. Examination of the age frequencies in log scale indicated that age 2 (URIGSO) and age 3 (RIDFW) should be designated the recruitment age for the calculation. Total mortality rate was estimated as the log ratio of 3+ to 2+ and 4+ to 3+ catch in successive survey years. An estimate of M was made using a similar approach but with age groups not recruited to the fishery. For the RIDFW survey, this was age 2-3 and for URIGSO it was age 1-2. The difference in ages between surveys relates to the timing of the survey. RIDFW is a spring survey whereas the URIGSO is an annual survey so that the fish in the later are actually older for an anniversary age.

Production Model Estimates of Stock Size and Fishing Mortality Rate

A biomass dynamic model for the Rhode Island stock was fit to landings and biomass indices and calibrated with auxiliary estimates of F from tagging. Biomass dynamic models are a mass balance approach in which stock biomass each year is biomass the year before plus new production minus the catch removed (Hilborn and Walters 1992). New production is the net difference between additions from growth and recruitment and mortality losses. If stock growth is assumed to follow the familiar logistic curve, a Schaeffer biomass model in finite difference form from Walters and Hilborn (1976) is:

$$B_t= (B_{t-1}+r_m B_{t-1}(1-(B_{t-1}/k))-C_{t-1}) \exp(e_p) \qquad (2)$$

where: B= population biomass
C= catch biomass
r_m= intrinsic rate of increase
k= unfished population biomass.
t= year
e_p= lognormal process error term.

The r_m parameter is a measure of population growth rate at very low abundance when density dependent factors are inoperative. The term in parenthesis in eq. 2 is the density dependent feedback mechanism that reduces stock growth when abundance is high. The discrete time step form of the production model is a simplification over the differential equation that forms the basis of continuous production models. Hilborn and Walters (1992) note that the discrete and differential forms of the model are essentially equivalent except for extreme values of r_m and fishing mortality (F). Useful management quantities for sustainable fisheries can be derived from the logistic model parameters as follows:

$$MSY= r_m k/4$$
$$F_{msy}= r_m/2$$
$$B_{msy}= k/2.$$
$$F_{coll}=r_m.$$

Maximum sustainable yield (MSY) is the maximum yield that a stock can deliver year after year over the long term. It is a function of both carrying capacity and stock productivity. In order to produce MSY, a stock needs to be at a biomass level equal to one-half carrying capacity (B_{msy}) and be subject to a fishery removal rate no greater than F_{msy}. The latter is equal to one-half the maximum rate of stock growth. A fishing mortality rate that approaches the maximum rate of stock growth will lead to stock collapse (F_{coll}).

Since the actual biomass levels in eq.2 are not known, an observation model is needed in the form of research survey catch per unit effort:

$$U_t = q(B_t)\exp(e_m) \qquad (3)$$

where:
B= biomass
U= survey relative abundance
q= catchability coefficient
t= year
e_m= lognormal measurement error.

The q parameter is a scaler that relates survey relative abundance to absolute stock abundance. Substitution of eq.3 into eq.2 and combining error terms gives the final biomass dynamic model for the Rhode Island stock:

$$U_t = (U_{t-1} + r_m U_{t-1}(1 - U_{t-1}/kq) - q(C_{t-1}))\exp(e) \qquad (4)$$

Parameters in eq. 4 (r,k,q) were estimated by minimizing the sum of squared deviations between observed and predicted log catches per unit effort or:

$$\text{minimize } SSQ = \sum_{j=1}^{n} \sum_{t=1}^{n} (\ln U_t - \ln \hat{U}_t)^2 \qquad (5)$$

where j and t denote survey and year respectively. The double summation indicates that multiple abundance indices are used. A separate q parameter is estimated for each index. A mixed error model was assumed so that the residual sum of squares (RSSQ) is composed of process error in the population dynamics model and measurement error in the CPUE indices (Polachek et al. 1993). This procedure involves estimation of additional parameters in the form of process errors and a starting biomass level (U_0). It is accomplished in EXCEL by comparing, in a least squares sense, the observed indices to their parameter estimated values as well as to the step-ahead forecasts from the population dynamics model. The procedure cannot resolve measurement from process error without external information. Therefore, weighting in the minimization was adjusted until process error accounted for 10-20% of the RSSQ (Conser and Idoine 1992). This allows for some deviation from the logistic population model but allocates most of the error to the input indices. Solutions were found using the EXCEL problem solver configured with quadratic approximation, forward differentiation, and quasi-Newton search method. The model was adapted from an EXCEL catch-survey application provided by J. Collie from the University of Rhode Island Graduate School of Oceanography (Collie and Sissenwine 1983). As suggested by Hilborn and Walters (1992) and Prager (1994), the objective function (eq. 5) was expanded to consider the auxiliary F data.

$$\text{minimize } SSQ=\sum_{j=1}^{n} \alpha_j \sum_{t=1}^{n} (\ln U_t - \ln \hat{U}_t)^2 + \alpha \sum_{t=1}^{n} (\ln F_t - \ln \hat{F}_t)^2 \qquad (6)$$

Estimates of F from tagging studies were used to aid in estimation of model parameters. Auxiliary data can be given various weights (α) depending on the level of confidence in the data. In this study, all α weights were set equal to 1.0 as there was no objective basis to emphasize one data set over another. Eq. 4 was fit to the landings-abundance index data for years 1959 to 2012. Tags based estimates of F from studies in Narragansett Bay and nearby state waters were included in BDM tuning. Model F was calculated by solving exploitation rate (catch/biomass) for F assuming M=0.20.

Uncertainty in model estimated and derived quantities were evaluated with bootstrapping (Efron 1982). Residuals from the original model fit were re-sampled and added to the estimated survey abundance indices and auxiliary F estimates. The model was then successively refit to the alternate input data series and output quantities accumulated over 1,000 replications. Confidence intervals for parameters and calculated quantities were estimated directly from the bootstrap results. Ten-year projections of stock size relative to carrying capacity were made by propagating each terminal year bootstrap realization of stock biomass forward in time under several assumed rates of fishing mortality and stock productivity using eq. 2. Five and ten year periods are typical planning horizons for assessing rebuilding opportunities in depleted fish stocks under the national standards imposed by the Magnuson and Sustainable Fisheries Acts.

Model Development and Configuration

Surplus production modeling has been used to assess local winter flounder for some time (Gibson 1987, 2000, 2003). Age-structured assessments were attempted in the 1990's but could not be sustained absent a long-term age sampling programs. The BDM has undergone a number of modifications and configuration changes. Initial efforts used Schnute's (1977) regression estimation of the dynamic Schaeffer model (Gibson 1987). That approach formulated biomass change as a regression function of mean abundance and effort. It was applied to 1964-1987 area 539 commercial landings and effort data. No fishery independent abundance indices or auxiliary

F estimates were included. The Gibson (2000) work used “time series” fitting methods with both process and observation error with user specified ratio. A single, long-term trawl index replaced the commercial CPUE index. Auxiliary estimates of F from tagging were used in model calibration. To support power plant impact assessment, this model was expanded to include all available fishery independent abundance indices including trawl surveys, impingement and entrainment monitoring, YOY seining, and larval sampling (Gibson 2003). No fishery CPUE was used but auxiliary tag based F was. A nested stratum for Mt Hope Bay was configured within the overall model. Power plant losses from Brayton Point Station were included in the stratum population dynamics equation and indexed by condenser coolant flow. In the current study, the larval, YOY, and impingement/entrainment indices were dropped as was the separate Mt Hope Bay stratum. The historical era component was added as was time varying productivity as a function of water temperature.

The Gibson (2003) study indicated that productivity of the stock had declined. Several aspects of winter flounder biology are known to be sensitive to temperature with abundance generally reduced during periods of high water temperatures (Jeffries 1994, Oviatt 2004, Collie et al. 2008). The first winter flounder decline documented by Perlmutter (1947) was coincident to a warming period evident in long-term data for the northeast shelf area (NMFS 2009). Monitoring data in Rhode Island show that average water temperature has increased about 2 degrees C since 1960 (Oviatt 2004). Other data sets in southern New England have been inter-calibrated to produce a series over 100 years long (Nixon et al. 2004). Higher water temperatures may have lowered stock resilience to fishing pressure by increasing mortality (Keller and Klein-MacPhee 2000 and DeLong et al. 2001) and reducing egg viability (Buckley et al. 1990). Since the r_m parameter in eq.2 represents a balance between birth-growth accruals and mortality losses, an increase in the mortality component and reduction in hatching would reduce stock productivity. Conventional production modeling assumes a stationary process where the model parameters are constant. Non-stationarity occurs when environmental and ecological factors change with respect to time (Walters 1987). A dangerous outcome can be the overestimation of contemporary stock resilience based on analysis of a full time series of data (Hilborn and Walters 1992, Caddy and Agnew 2004). For example, estimates of F_{msy} for North Sea plaice and sole were significantly reduced when the impact of rising sea temperature was accounted for (Cook and Heath 2005). The condition can sometimes be detected through the examination of residual patterns in the model. One remedy is to fit the model with time varying parameters (Freon 1988, Maunder and Watters 2003, Carson et al. 2009). Initial model runs with constant productivity produced non-random process errors and a strong correlation of stock biomass to temperature. Further, STARS testing of biomass estimates (Rodionov and Overland 2005) consistently indicated a regime shift in 1987. Consequently, the final model run allowed for time-varying r_m parameter as a function of annual water temperature:

$$r_{mt} = r_0 * \exp(\beta * D_t) \qquad (7)$$

where: r_0 = base intrinsic rate
β= temperature effect parameter

D= annual temperature deviation from series mean
t= year.

The implications of reduced stock productivity are discussed in the context of vulnerability to anthropogenic sources of mortality and appropriate management responses.

Historical Stock Productivity

The above data and model describe the “modern” 1959-2010 era for the assessment. In order to evaluate stock dynamics over a longer term, historical landings, abundance, and mortality rate data were developed from information reported in Perlmutter (1947) and Olsen and Stevenson (1975). These data were used to parameterize a second biomass dynamic model for the “historical” 1919 to 1958 era. The early era was handled as an additional sum of squares component in the main minimization (eq.6). This format is useful as the α-weight can be set to zero and the era “switched off” for sensitivity evaluation. Dynamic consistency at the splice point (1958-1959) was assured by constraining the r_0 and k of the logistic population dynamics model to be the same in both eras and by using tag based estimates of F in the both the modern and historical calibration. The temperature parameter was also constrained to be the same in both eras. Utilizing historical, albeit more uncertain, data to inform the model about long-term stock dynamics follows the “Robin Hood” approach of Punt et al. (2011). They showed that assessing multiple stocks simultaneously with sharing of key parameters allowed data-poor stocks to be better assessed without impacting the quality of data-rich assessments.

Perlmutter (1947) provided several indices of abundance from commercial logbooks and fyke nets used to capture broodstock for hatchery operations. The data span the region from Booth Bay, ME to Peconic Bay, NY. I assumed that these data were generally representative of the early conditions operating in the Rhode Island fishery. Fyke net data covered the period 1919 to 1941. Logbook data covered the period 1930 to 1941. Effort data from Olsen and Stevenson (1975) covered the period 1930 to 1958 and, along with landings data, allowed for calculation of a CPUE series. All of the individual indices were transformed to Z-scores, averaged, and back transformed into a single index in Woods Hole fyke net units that spanned the period 1919 to 1958. Perlmutter (1947) provided sporadic landings data from 1880 to 1935 for Rhode Island. The 16 years of tallied landings closely followed an exponential curve (r^2=0.95) with a rate of increase of 5.2% per year. This allowed for interpolation of the missing years. No adjustment was made for “other” flounders that Perlmutter indicated were present in the blackback tallies as he did not consider recreational harvests and the biases are offsetting. Landings from 1936 to 1949 were taken from Stevenson and Olsen (1975) and no adjustments were made for similar rational. Landings from 1950 and later were described above. Tag based estimates of mortality for the historical era are summarized in Table 4.

Spatial Scale Patterns

This Rhode Island substock assessment covers Narragansett Bay and the coastal salt ponds, a production area of about 400 km^2. The NEFSC (2008) southern New England and Georges Bank assessments by comparison are stock areas on the order of 10^4 km^2. Given the sympatric population structure in the SNE complex, smaller scale dynamics should be examined. Pt Judith pond, a 6.2 km^2 salt pond on the Rhode Island south shore, has supported commercial and recreational winter flounder fisheries (Crawford 1990). As discussed above, it is likely to support a distinct population segment because of reproductive isolation arising from natal homing. It might be considered an evolutionary significant unit (ESU) under the US Endangered Species Act. NOAA guidance for the Act defines an ESU as "a population that 1) is substantially reproductively isolated from conspecific populations and 2) represents an important component in the evolutionary legacy of the species" (Waples 1991). RIDFW pond surveys of both adults and juveniles allow an examination of population dynamics at a small spatial scale. A stock-recruitment analysis was conducted for Pt Judith pond using the fyke survey index as a measure of SSB and the seine index as a measure of recruitment. Mt Hope Bay is a 35 km^2 upper arm of Narragansett Bay that supports a winter flounder population likely to be distinct from other areas in the Bay (Saila 1962, Wirgin 2003). In addition to overfishing and climate change, it has suffered from power plant impact and declined more than other areas (Gibson 2003). Impact assessment is not the objective of this study but significant monitoring data for this stock component exists allowing for comparative analysis at a medium spatial scale. As with Pt Judith Pond, stock-recruitment properties were examined using the Normandeau trawl data. The final population examined was that from Niantic Bay, CT the attributes of which are reported in DRS (2010).

RESULTS

Survey Abundance and Length Composition

Indices of winter flounder biomass and recruitment in the Rhode Island stock area are summarized in Tables 1 and 2. The long-term trawl surveys were significantly ($P<0.01$) correlated with one another. Biomass indices, standardized for the mean, generally show high abundance in the late 1960's and again in the early 1980's (Figure 2). Abundance declined to a low point in 1975-1976 and again in 1992-1993. There was a brief increase in abundance in 1995-1997 that was not maintained. Surveys begun after the 1980's period of abundance are hard to interpret for lack of contrast particularly the short NEAMAP series. Standardized recruitment indices are plotted in Figure 3. The 1966, 1967, 1978 and 1982 year classes were strong. It has generally been low since with the exception of moderate recruitment events in 1992 and 1996 which were also noted on a region-wide basis (NEFSC 1998). The long-term recruitment problem is well shown by the deconvolution of the URIGSO trawl survey (Figure 4). It has been three decades since a heavy recruitment pulse has occurred. This along with fishing mortality, has greatly reduced the abundance of older fish (Figure 4, Table 6b).

Size composition from the RIDFW spring survey is plotted in Figure 5. The modes for the first three age groups are evident at 12, 20, and 27 cm. The size composition has changed dramatically over the 32 years of the survey (Figure 6). In addition to an order of magnitude decline in abundance (note the differing scale of the y-axes) the population has shifted from one dominated by recruitment to one dominated by intermediate size fish. A similar pattern occurs in the fall survey, the main difference being that the first recruiting mode is YOY (Figures 7 and 8). Size composition of winter flounder in the Narragansett Bay monthly survey is plotted in Figure 9. Data for the past two decades are pooled by quarter. The data show several noteworthy features. First, quarter 1 data show similar abundance of juvenile and adult fish. This may reflect the winter, estuarine spawning of adult fish and incomplete recruitment of the age 1 fish to the deeper waters. In the second and third quarters, age 1 fish become progressively more dominant as they recruit to the deeper water and post-spawned adults leave estuarine areas. Quarter 4 shows the return of adults to inshore areas in preparation for spawning. The second major pattern is the evolution of new year classes. YOY flounder first appear in the second quarter and average 40 mm in length. Recruitment to the trawl gear continues and by the 4th quarter they average 95 mm. Age 1 fish are plainly evident in the surveys and progress from 115 to 180 mm during the season. Finally, the length composition attenuates sharply after the 305 mm minimum size is reached.

The NEAMAP survey is new so that meaningful trend analysis is not possible but sampling intensity is high so that size structure is well characterized. Since the fall of 2007, NEAMAP cruises in Rhode Island and Block Island Sounds have measured 4,956 flounder compared to 1,520 and 3,692 measured on monthly and seasonal RIDFW cruises. The NEAMAP survey in Rhode Island is confined to Sound waters deeper than 18 m (Bonzek et al. 2009) and so likely samples a sub-stock mixture. Length frequency data for the survey is plotted in Figure 10. For historical comparison, the size composition of blackback flounder tagged in Rhode Island waters in 1937-1941 by Perlmutter (1947) is plotted in Figure 11. Fish in that study were captured using commercial fyke and trawl gear and were representative of an industry that discouraged product smaller than 25 cm. A KS test indicated a significant difference at P=0.01. For fish larger than 25 cm, Perlmutter's lengths averaged 2 cm. less. Fishing effects on the length composition were likely before 1937 as a well developed fishery existed by the late 1920's (Perlmutter 1947) and high mortality rates were operative (see tagging results below). It also suggests that recent mortality rates have moderated allowing for some expansion of the size structure. Truncation of size structure increases variability in fish stocks (Hseih et al. 2006), reduces reproductive rate (Venturelli et al. 2009), and in winter flounder could deprive a population of its most competent spawners (Buckley et al. 1991). Berry et al. (1965) provided evidence for differential mortality and size truncation for winter flounder between Narragansett Bay and Charlestown Pond.

Fishery Landings

Landings data are summarized in Table 3. The hind cast estimates of recreational catches are reasonable relative to independent tagging data. Historical tagging studies in southern New England including Narragansett Bay indicate that on average, the recreational fishery accounted for about 20% of tags recovered (Perlmutter 1947, Saila 1962, Howe and Coates 1975). Hind cast estimates of recreational landings for years 1950 to 1970 averaged 17% of total landings, close to the estimate from tagging studies. Large total landings from the stock were made from 1964 to 1968 and again from 1980 to 1986 (Figure 12). These likely reflect recruitment of strong year classes to the fishable stock. High landings were not maintained as weaker cohorts rotated through the age structure. The modest increase in landings that occurred from 1994 to 2000 likely reflects recruitment of the 1992 and 1996 year classes to the fishable stock. These were the last recruitment events in the seine and larval surveys. Recreational landings have declined more precipitously than commercial and currently account for only about 0-3% of total. During the 1980's period of abundance, recreational catch averaged 21% of total. Commercial landings in 2011 were 24.0 mt while recreational landings were 0 mt. Discards added another 16 mt for a total of 40.0 mt. Low landings reflect the closure of federal waters in SNE. State logbooks indicate that state waters commercial landings are only 5-13 mt in recent years. Current discard estimates comprise about 40% of total stock removals.

Tagging Studies

Results from analyzing historical tagging studies are found in Table 4. A total of 17 estimates were made with years of inference ranging from 1931 to present. The average total mortality rate was Z=0.85 and ranged from 0.44 to 1.51. No obvious trend over time was apparent. If M≈0.20, these studies indicate that fishing mortality rate on winter flounder has been consistently high for some time. The first tagging study in 1931 south of Woods Hole, Massachusetts may be the most compelling. A total 4,171 fish were tagged and 251 were recovered over the next six years. The slope of the catch curve regression was 0.84 with a standard error of 0.06. In 1937, 698 fish were tagged in Narragansett Bay and 105 were recovered over four years. The slope of that catch-curve was 0.94 (SE=0.25). Seven out of eight estimates from that era exceed 0.7. This suggests that fishing mortality rate in the 1930's was at least twice the current F=0.25 overfishing definition.

The tag recovery matrix for the current RIDFW tagging effort in Pt Judith Pond is found in Table 5. Of the 1,516 tags released in 1999-2011, a total of 194 have been returned so far. Recovery rate has clearly declined in later releases. Using the constant survival rate and variable recovery rate MARK formulation, survival rate in 1999-2010 was estimated at S=0.45 per year with a standard error of 0.04 (Table 4). This corresponds to a fishing mortality rate of F=0.61 for M equal to 0.2. The fishing mortality rate in the new study compares to F=0.30 and F=1.31 for the 1996-1998 and 1986-1990 RIDFW tagging studies in Narragansett and Mt. Hope Bays. Overall, the tag results suggest that F is higher now than in 1996-1998 but not as high as in the 1980's. The most recent tag based F=0.61 also compares favorably to the 1999-2007 mean F=0.50 estimated with ASAP for the SNE stock area (NEFSC 2011). Of the 99 tags released in Charlestown pond in February and March 2012, 9 (9.1%) have been recovered as of June 28, 2012. Recoveries occurred initially on Nebraska shoals (7) in Block Island Sound and then east of Block Island and Pt Judith (2). This 3 month rate of raw exploitation is significant and unexpected. If expanded to a full year, it could result in an F rate of 0.3-0.4. It is unknown what the tag reporting rate is or how mortality rate will change as fish migrate from state to federal waters. This study should continue as two full years of tag recoveries are needed to fit the base

MARK model 1 formulation.

Survey Mortality Rate

Age-disaggregated indices from the RIDFW spring and URIGSO trawl surveys are found in Tables 6a and 6b. The RIDFW pattern corroborates the interpretation of changes in the length composition from above. There has been a major decline in the abundance of juvenile flounder and not nearly as much in older flounder. Abundance of age 1 fish declined by an order of magnitude from 1981 to 2010 while the trajectory of fish 4 and older was relatively flat. Total mortality rate (Z) was above 1.0 for many years but seems to have declined recently. A smoothing function indicates that current Z is about 0.5 per year. The URIGSO aged data do not show the same decline in age 1 fish although the time series is shorter, missing the 1982 event. They do corroborate some reduction in Z but at a higher scale. The last smoothed value is 1.4 compared to values around 2.0 at the beginning of the series. The differences may be the result of application of different age-length keys. Natural mortality rate for fish age 2/3 in the RIDFW survey was estimated at 0.32 per year (SE=0.16). The URIGSO survey estimate for fish age 1+/2+ was 0.24 (SE=0.18). Although imprecise because of year to year survey variability, they do suggest that an $M \approx 0.2$ assumption for larger fish recruited to the fishery is reasonable. They also correspond well with the 27% reported by Howe and Coates (1975).

Historical Landings and Abundance

Landings of winter flounder and abundance indices derived from the Perlmutter (1947) and Olsen and Stevenson (1975) sources are found in Table 7. Landings of winter flounder in Rhode Island were around 500 tons at the turn of the 20th century. They more than doubled to over 2,500 tons from 1910 to 1931 as the fishery expanded. Landings then declined sharply, reaching a low point during WW II at just over 300 tons. A modest increase occurred after the war with landings returning to the 500 ton level. All of the early CPUE indices declined during their period of record substantiating the pre-war concerns of fishermen and scientists. Perlmutter (1947) concluded from these data that a decline of 31% to 63% in blackback abundance had occurred. Accordingly, the long-term Z-score index declined at about 5% per year for the period 1919 to 1958 (Table 7). If the oldest Boothbay fykenet data is representative of the region, it suggests that the winter flounder population was rapidly fished down during early industrialization of the fishery. This interpretation would be consistent with the high fishing mortality rates estimated from early tagging studies.

Environmental Conditions

Average annual sea temperature in the Rhode Island area has exhibited significant variability on decadal scales during the past century (Figure 13). Two cool periods followed by warming have occurred. Cool periods occurred from 1900 to 1912 and again from 1959 to 1968. Warm periods occurred from 1944 to 1952 and since 1998 with 2012 being the highest on record. Temperature differential between warm and cold years is on the order of 2 degrees C. Variation within season is greater than for annual means (DRS 2010) and the observed level of variation is capable of influencing key life history stages (Buckley et al. 1990, Keller and Klein-MacPhee 2000, Taylor and Danilla 2005). Local sea temperature is correlated with other large scale indicators of climate such as the North Atlantic Oscillation Index (NAO). The best correlation of sea temperature was with winter NAO one year before ($r= 0.52$, $P<0.01$). The NAO is the dominant mode of climate variability in the North Atlantic influencing temperature, precipitation, and wind (Hurrell 1995). A 1980's ecological regime shift in both the North and Baltic seas was linked to a shift from negative to positive NAO conditions (Alheit et al. 2005). The transformation of Narragansett Bay from a demersal to pelagic community also occurred in the 1980's in association with an NAO shift from negative to positive (Collie et al. 2008).

Estimates of Stock Size and Fishing Mortality Rate

Table 8 summarizes the parameter estimates and derived quantities for the BDM run with time varying productivity. Precision was good with bootstrap CV's generally less than 0.15 although precision is overstated by fixing the tag catchability parameter at 1.0. Only the temperature parameter was less precise (0.16). Estimated biomass of winter flounder in the Rhode Island area has fluctuated considerably over time (Figure 14). Recent levels are low relative to the series mean. Biomass in 2012 was estimated at 957 mt with a 95% confidence interval of 738-1,177 mt. This is compared to biomass needed for MSY equal to 5,951 tons (5,062-6,839). Relative biomass, expressed as current biomass divided by B_{msy}, was estimated at 0.16 (0.11-0.21). Bootstrap distributions for current biomass and B_{msy} are found in Figures 15 and 16. There is no overlap indicating that stock biomass is well below that needed for MSY, i.e. the stock is overfished.

Fishing mortality rate estimates for the Rhode Island stock are plotted in Figure 17. Except for a period in the 1970's and most recently, fishing mortality rate has exceeded F_{msy}. F in 2011 was estimated at 0.10 with a 95% confidence interval of 0.09 to 0.11. F_{msy} in 2011 was estimated at 0.18 with a 95% confidence interval of 0.16 to 0.20. Bootstrap distributions for current F and F_{msy} are shown in Figure 18 and 19. Over fishing is not occurring as the distributions do not overlap. Base intrinsic rate was estimated at 0.46 (0.42-0.49) with a temperature effect parameter estimated at -0.38. The bootstrap distribution for temperature did not include zero and the 95% confidence bound was -0.51 to -0.25 (Figure 20). The warming trend in the modern era has resulted in a 50% reduction in sustainable F rate because of declining stock productivity (Figure 17). Accordingly, MSY dropped from 1,700 tons in 1959 to just under 1,000 tons by 2011. Estimates of stock biomass and fishing mortality rate during the historical era are plotted in Figures 21 and 22 relative to MSY counterparts. The carrying capacity parameter was estimated at 11,901 mt with a 95% confidence interval of 10,123-13,679. The starting biomass level in 1919 was 8,891 tons. This is equivalent to 75% of carrying capacity. Biomass remained above B_{msy} until 1931 after which it declined sharply. Fishing mortality rate rose steadily from 1919 to 1931 exceeding F_{msy} by about twice. These results confirm the findings of Perlmutter (1947) that the stock was in decline following industrialization of the fishery. The BDM results and the early tagging studies summarized above strongly suggest that over fishing occurred early on the inshore stock in association with the advent and use of otter trawl gear.

The surplus production (SP) vs. biomass plot is found in Figure 23. The overall pattern is parabolic in keeping with standard production theory but the time deviations are noteworthy. The stock history of SP traces a series of clockwise loops in which SP is higher for a given biomass during stock increases than during stock declines. This was the most common pattern observed in the Walters et al. (2008) review of 110 fish stocks. It is likely caused by periodic recruitment bursts that increase production temporarily. The insert graph is for the last period of high abundance in 1983 and the decline to present. The tight spiral since 1994 around the 400/1,000 ton level suggests that the stock has become stuck in a low productivity-low biomass phase. A regime shift test on the biomass series using the “STARS” procedure of Rodinov and Overland (2005) indicated that 1986-1987 was a shift point. The transition to low productivity may be related to the increase in water temperature.

Stock Rebuilding Projections

Rebuilding of depleted fish stocks may require significant reductions in fishing mortality rate (Rosenberg et al 2006). Rebuilding F rates are generally less than those associated with F_{msy}. Both the ASMFC and NEFMC have specified conservative rates for this purpose, $F_{40\%}$=0.21 and $F_{0.1}$=0.25 respectively. On an annual basis, these correspond with removals of 17%-20% of standing stock. Projection results from this study show that under status quo levels of fishing (F=0.10) and reduced stock productivity, there was only a 21% chance that the Rhode Island stock could rebuild to the B_{msy} level in ten years (Figure 24). Further, there was no chance that the stock could reach B_{msy} by 2014, the NEFMC deadline under Magnuson-Stevens Act requirements. These findings are similar to those of NEFSC (2008, 2011) for the entire SNE area. The SARC 52 work found that recent recruitment was weak and correlated with increased water temperatures. The SNE stock was at 16% of B_{msy} and projections under weak recruitment indicated no ability to rebuild by 2014 despite very low F (NMFS 2011). B_{msy} notwithstanding, some biomass recovery is possible. The RI projections show a doubling time of about 3.5 years at current stock size and low F. Managers should consider the value of limited stock rebuilding.

Model Diagnostics

As described above, the BDM has gone through a number of iterations involving choice of abundance indices, use of auxiliary F estimates, nested spatial strata, and parameter format (constant, blocked, function of environment). Process errors from the final configuration selected maintained a shift from negative to positive in the late 1970’s despite use of a temperature varying r_m parameter (Figure 25). Alternate model configurations indicated that an abrupt change in the r_m parameter (split model) would be needed to remove this pattern. The pattern likely results from the emergence of several strong year classes (Figure 3). Another notable diagnostic is the residual pattern for the long-term trawl survey in Mt. Hope Bay (Figure 26). Residuals for the MRI standard trawl index trend strongly from positive to negative. This indicates that the Mt. Hope Bay population in the vicinity of BPS has declined more than the rest of the area assessed.

Resolution of this pattern required splitting the series and estimating two catchability parameters. The magnitude of the change (3.5X decline in catchability) however is unrealistic for a research trawl. It is more likely that this population component is subject to an additional mortality source. Several other indices display blocks of positive or negative residuals. This is an outcome of assessing a stock over a long period of time under climate change and where none of the indices encompass the entire region inhabited.

Inclusion of the historical era had little influence on terminal year estimates of management interest. Biomass, fishing mortality, and sustainable F in 2011 changed by less than 5% when this model component was turned off. Quantities relating to unfished stock size (K, B_{msy}, MSY) approximately doubled without information from the early era. These results were deemed unrealistic since they would mean that the biomass peaks of the 1960's and 1980's reached less than 20% of carrying capacity. High uncertainty in unfished stock size is a common problem in BDM analyses (Hilborn and Walters 1992) and stems from lack of contrast in stock size and fishing pressure. Inclusion of the historical era provides that contrast with a period of high index abundance under low F rate that escalates quickly followed by depletion. The finding that starting biomass in 1919 was 75% of unfished is realistic given the exploitation history described. It is concluded that a modern assessment informed about unfished stock size from historical data is a useful advance.

Spatial Scale Considerations

The YOY and age 1 recruitment indices, standardized for their respective means, are plotted against BDM stock biomass for the year of cohort formation in Figure 27. The indices were not used in model fitting and so are not smoothed for measurement errors. A general pattern is evident for indices that span a wide range of biomass levels (6X). Linear or 2^{nd} order models with negative y-intercepts were better fits than curves through the origin. A depensatory relationship such that recruitment approaches zero at positive stock biomass is suggested. The cluster of points at approximately 1,000 tons may be a critical biomass level to avoid from a resource persistence standpoint. Production of YOY flounder in Pt Judith Pond has declined to low levels (Table 2, Figure 3). The 2012 index of 5.9 per seine haul is among the lowest of the time series. The relationship between YOY and adult spawners was linear (Figure 28). The negative y-intercept suggests the possibility of critical depensation or recruitment rate declining to zero at low spawner abundance (Quinn and Deriso 1999). If so, extinction of this small population segment is likely if spawners decline further. The Pt Judith subpopulation relationship recapitulates that from the larger Rhode Island stock. A similar but more time-advanced pattern is evident for the Mt Hope Bay S-R data (Figure 29). When adult abundance declined to a critical level, recruitment collapsed to near zero. The pattern is repeated in the Niantic River, CT population as evidenced by monitoring data collected near Millstone Power Station (DRS 2010). Figure 30 shows the progression of SSB and recruitment since 1977 for the population produced in this 15 km^2 CT estuary. Stock and recruitment data for the entire SNE stock area from the NEFSC (2011) results are plotted in Figure 31. As with the smaller stock components, SNE recruitment and SSB are at very low levels. Recent data points do not fall on a curve through the origin but rather a curve displaced to the right with negative y-intercept. The evidence for depensatory recruitment at low stock sizes over a spatial scale ranging from 10^1 to 10^4 km^2 is remarkable but portends peril for the stocks. Solution of best fitting regression equations for the x-axis intercept, that is the SSB level where recruitment is zero, gave estimates that were between 1 and 16% of the maximum SSB indices observed. In contrast to the inshore populations, the GARM III results for the Georges Bank stock show no evident parametric relationship between stock and recruitment and recent year classes are not perilously close to zero (Figure 32).

DISCUSSION

Winter flounder in the Rhode Island area are currently at low abundance with biomass only about 16% of that needed for MSY. Past abundance surges are associated with recruitment pulses, the last strong one occurring in 1982. Fishing mortality rate has only recently dropped below the temperature-eroded F_{msy} level. Fishery development and stock dynamics in the past century (Figure 33) are remarkably similar to that reconstructed for North Sea plaice, another pleuronectid flounder, by Rijnsdorp and Millner (1996). Under current criteria, the stock is overfished but not subject to overfishing. Abundance has exhibited long-term fluctuations in association with chronic overfishing and climate change. For the period 1919 to 2011, fishing mortality rate (F) exceeded the overfishing limit (F_{msy}) in 85 of 93 years. During that period, average annual sea temperature has cycled twice between cool (≈ 10.5 C) and warm (≈ 12 C) temperature periods. Stock productivity and resilience to fishing were inversely related to sea temperature in keeping with laboratory demonstration of life history impacts (Buckley et al. 1990, Keller and MacPhee 2000, Taylor and Collie 2003b), correlative studies of abundance and environmental time series (Jeffries and Terceiro 1985, Collie et al. 2008), and fundamental ecological theory (Brown et al. 2004). Overfishing has persisted long enough so that the attributes of a lightly fished stock are unknown. The period is long enough to cover several generations of flounder, allowing for the possibility of an evolutionary response to selective fishing (Conover et al. 2009). The stock's vulnerability to climate change has probably increased (Hseih et al. 2008). While projections indicate that some stock rebuilding is possible, potential MSY under the current climate regime has been reduced by about 40%.

Sustainable fishing mortality rate (F_{msy}) has declined by about 50% since the 1960's in association with increasing water temperature. Cook and Heath (2005) estimated comparable erosions of F_{msy} for North Sea plaice (*Pleuronectes platessa*) and sole (*Solea solea*). Bering Sea flatfish showed decadal reductions in stock productivity in association with climate variation (Wilderbuer et al. 2002). Flatfish with northern distributions declined while those with southern distributions increased in the Bay of Biscay during a period of increasing sea temperature due to reduced recruitment (Hermant et al. 2010). Both yellowtail flounder off the US Atlantic coast and plaice in the North Sea have showed strong recruitment during cold periods (Sullivan et al. 2005, Van der Veer and Witte 1999). Pauly (1994) observed that flatfish biomass was higher in northern latitudes and hypothesized that an over-adaption to benthic feeding limited their abundance in benthos poor tropics by food limitation. If so and if increasing water temperature limits phytoplankton production (Boyce et al. 2010) and its contribution to the detrital food chain (Oviatt 2004), flatfish at the southern end of their range may continue to decline. There is now global evidence for changes in abundance and re-distribution by fish stocks in response to climate change (Perry et al. 2005, Levin et al. 2006, Nye et al. 2009, Rijnsdorp et al. 2009, Conversi et al. 2010, Last et al. 2011). Climate change models indicate that warming of the oceans is likely to continue (Salomon et al. 2009, Overland et al. 2010). The consequence to fisheries could be a major catch re-distribution with the continental US projected to experience a large loss (Cheung et al. 2009).

Both the BDM and stock-recruit analyses suggest reductions in productivity and operation of depensatory mortality at low abundance. A likely mechanism is a predator-prey relationship forced by overfishing and climatic variation (Steele and Henderson 1984, Collie and Spencer 1993). Taylor and Collie (2003a,b) and Taylor and Danilla (2005) showed that a density dependent predator-prey relationship between the sand shrimp, *Crangon septemspinosa,* and juvenile winter flounder was destabilized by increasing water temperature so that predation mortality was increased. A parallel relationship may exist between European plaice and the congener shrimp *Crangon crangon* (Van der Veer 1986, Van der Veer and Witte 1999). The key element of the mechanism is increasing water temperature which elevates *Crangon* metabolic activity and increases the spatio-temporal overlap of predator with prey. A type III, prey switching response completes the mechanism allowing for formation of a "predator pit" (Kempf et al. 2008). Winter flounder become trapped at a low abundance level. The fine scale S-R data provided above resembles the progression of this process. Spawning biomass is depressed by fishing and environmentally enhanced predation traps recruitment at low levels. The argument for overfishing capped with environmental forcing is supported by GARM III and SARC 52 results of F around 1.0 from 1985 to 1993 and findings that the range of recruitment synchrony increased during the same period (Manderson 2008). If depensation is critical, there is an SSB level which when reached will drive the stock to extinction (Quinn and Deriso 1999). Loss of stock components is occurring; the Point Judith pond study provides an observational opportunity. Since there is evidence that the magnitude of flatfish recruitment and ultimately stock size is related to the size of the nursery areas (Van der Veer at al. 2000), loss of nursery production will prevent full rebuilding of the winter flounder stock complex.

Collie et al. (2008) found evidence of an abrupt change from demersal to pelagic fisheries in Narragansett Bay in the 1980's and considered a regime shift likely. That shift followed a significant increase in mean sea temperature (Figure 12). This assessment lends support to the regime shift hypothesis. Winter flounder productivity declined with increasing water temperature and recruitment appears depensatory at low spawner abundance. STARS abundance testing indicates a significant shift in 1986-1987. Management under regime shift is difficult since the phenomenon invalidates a fundamental assumption of an optimum harvest strategy that is stable save for random noise (deYoung et al. 2008). A constant harvest rate policy can be a management approach under regime shift if the rate is precautionary with regard to stock productivity (Caddy and Agnew 2004, Polovina 2005). They have recommended a harvest rate of no more than 10% and additional measures to protect remaining spawning stock. Current Rhode Island regulations prohibit possession of the species in certain areas, primarily upper Narragansett Bay and coastal salt ponds. Open areas are subject to low limits (50 pound commercial, 2 fish recreational). Monitoring of the stock, including surveys on small spatial scales should continue. Additional area closures and caps on fishing may be needed. Petigas et al. (2010) distinguished between depleted and collapsed stocks in that the later, in addition to abundance decline, have incurred structural damage from loss of intraspecific contingents. This is happening to winter flounder and it may inhibit stock recovery. Fishing in non-linear synergy with environmental forcing make return to dominance of species like winter flounder unlikely (Lucey and Nye 2010).

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Table 1- Winter Flounder Biomass Indices Considered in Rhode Island Biomass Dynamic Model Stock Assessment

Year	/1 URIGSO Trawl	/2 RIDFW Spring	/2 RIDFW Fall	/3 NMFS Spring	/4 Dominion STD Trawl	/5 Dominion Wilcox Trawl	/6 RIDFW Monthly	/7 Area 539 CPUE	/8 NEAMAP Spring	/8 NEAMAP Fall
1959	7.72									
1960	7.47									
1961	8.22									
1962	8.56									
1963	8.37									
1964	7.73							1565		
1965	9.79							1125		
1966	10.75							1562		
1967	13.62							1136		
1968	14.26			0.62				1338		
1969	12.78			2.08				1256		
1970	10.46			0.99				1126		
1971	8.47			0.63				932		
1972	7.78			0.57	6.61			741		
1973	7.84			1.37	7.77			848		
1974	7.38			0.82	6.02			544		
1975	6.15			0.35	4.35			404		
1976	5.54			0.44	3.26			471		
1977	6.42			0.60	4.06			671		
1978	9.90			0.95	6.97			878		
1979	12.91	7.72	4.88	0.53	8.83			825		
1980	11.91	6.17	2.17	2.07	3.97			1150		
1981	10.73	12.13	1.99	2.68	4.40			1150		
1982	9.40	5.25	1.30	1.37	7.07			1248		
1983	13.65	9.52	2.28	1.95	6.56			1011		
1984	8.58	8.43	3.38	1.38	4.23			1058		
1985	5.92	5.93	3.01	1.63	3.87			909		
1986	5.09	6.61	2.91	0.74	2.41			635		
1987	8.07	8.14	2.25	0.52	1.45			534		
1988	7.43	6.02	1.45	0.71	0.85			517		
1989	6.04	3.09	0.79	0.51	0.60			570		
1990	4.49	3.07	0.67	0.51	0.98		2.47	513		
1991	4.10	7.34	0.18	0.65	0.75		2.59	863		
1992	3.45	0.95	0.42	0.42	0.70		1.23	368		
1993	4.37	0.22	0.50	0.20	1.00		1.16	257		
1994	3.53	1.67	0.33	0.34	0.66		1.26	211		
1995	7.59	6.04	0.89	0.59	0.95		2.42	263		
1996	6.42	4.45	0.91	0.44	0.78	2.69	1.77	254		
1997	6.56	4.57	0.64	0.41	0.95	2.74	1.11	303		
1998	5.19	5.00	0.32	0.77	0.73	3.00	0.70	287		
1999	3.64	3.66	0.57	1.23	0.50	1.47	0.72	251		
2000	3.83	4.52	0.56	1.17	0.33	1.30	0.70	373		

2001	4.09	3.56	0.28	0.60	0.45	1.26	0.69	379		
2002	3.16	3.29	0.28	0.69	0.34	1.00	0.67	314		
2003	4.44	1.56	0.68	0.26	0.59	2.14	1.07	220		
2004	5.08	1.85	0.53	0.42	0.59	2.29	1.26	239		
2005	5.55	2.02	1.09	0.34	0.95	2.33	1.62	335		
2006	3.29	3.45	0.44	0.47	0.74	1.52	1.50	586		
2007	2.92	1.96	0.70	0.32	0.47	0.67	1.07	501		5.50
2008	5.20	1.63	1.00	0.41	0.43	1.18	1.76	369	16.60	6.60
2009	3.40	1.11	0.96	0.46	0.46	0.89	1.55	494	13.70	4.40
2010	3.51	3.24	0.39	0.30	0.75	1.53	1.45		14.90	3.00
2011	2.26	2.21	0.49		0.83	1.47	0.95			
2012	1.98	3.94	0.55				0.56			
Mean	7.07	4.44	1.17	0.80	2.46	1.72	1.35	686.57	15.07	4.88
STD	3.12	2.78	1.08	0.57	2.55	0.72	0.58	387.67	1.46	1.54

/1
Mean number per tow in URIGSO Trawl survey at Fox Island and Whale Rock stations, square root transformed.
/2
Mean weight (kgs) per tow in RIDFW seasonal trawl surveys in Narragansett Bay, Rhode Island Sound, and Block Island Sound
/3
Mean weight (kgs) per tow in NMFS spring trawl surveys, SNE stock area
/4
Mean number per tow in Dominion Power fixed station standard trawl survey in Mt Hope Bay, square root transformed
/5
Mean number per tow in fixed Dominion Power random Wilcox trawl survey in Narragansett and Mt Hope Bays
/6
Mean weight (kgs) per tow in RIDFW monthly trawl survey in Narragansett Bay
/7
NMFS statistical reporting area 539 commercial kilograms per day fished.
/8
Mean weight per tow in NEAMAP survey Rhode Island stations

Table 2- Winter Flounder Recruitment Indices Considered in Rhode Island Biomass Dynamic Model Stock Assessment

Year Class	/1 URIGSO Trawl Age 1	/2 RIDFW Spring Age 1	/2 RIDFW Fall Age 1	/3 Dominion Trawl Age 1	/4 RIDFW NB Seine	/5 RIDFW CP Seine	/6 Dominion WFL Seine	/7 Dominion Larval Survey	/8 RIDFW Larval Survey
1959	38.37								
1960	51.29								
1961	53.44								
1962	48.71								
1963	39.23								
1964	78.43								
1965	87.47								
1966	151.80								
1967	149.14								
1968	103.75								
1969	61.63								
1970	39.75								
1971	39.59								
1972	43.70			20.94					
1973	36.45			11.26				27.50	
1974	21.96			3.05				22.10	
1975	19.65			3.04				29.50	
1976	32.21			3.35				31.40	
1977	85.95			20.61				8.80	
1978	138.07	53.14	54.40	46.91				40.40	
1979	93.17	26.04	9.92	7.77				15.90	
1980	73.56	45.67	11.18	6.18				21.00	
1981	54.67	13.42	5.98	19.17				16.80	
1982	160.62	29.49	9.84	26.28				43.70	
1983	19.08	6.67	9.66	7.62				20.30	
1984	13.53	6.01	8.59	5.59				74.90	
1985	15.63	11.94	18.04	1.68				49.40	
1986	57.48	15.30	12.74	0.19	29.03			15.60	
1987	36.20	8.93	2.68	0.11	11.55			22.10	
1988	20.30	4.79	4.28	0.05	8.90			15.00	
1989	9.47	6.46	5.98	0.44	21.43			39.90	
1990	10.91	11.21	0.49	0.37	13.90			18.50	
1991	6.98	1.30	2.41	0.24	12.35			17.50	
1992	15.59	2.32	6.17	0.66	27.45		25.71	74.90	
1993	6.87	2.84	1.41	0.23	5.73	8.26	1.60	16.60	
1994	53.99	9.36	4.74	0.39	2.59	8.86	1.83	15.00	
1995	24.35	3.11	3.82	0.09	3.47	13.29	4.82	45.10	
1996	31.01	4.90	3.95	0.40	3.02	20.85	4.13	8.30	
1997	14.38	2.11	1.41	0.25	3.87	27.09	3.48	28.40	
1998	5.36	1.71	1.37	0.10	1.81	22.07	1.92	7.80	
1999	10.77	2.88	1.45	0.04	12.99	27.96	5.74	15.10	
2000	12.42	2.46	1.71	0.10	17.24	28.52	2.52	6.20	

2001	5.08	1.60	0.95		11.50	9.03	6.89	13.00	9.00
2002	16.79	1.72	4.21		9.60	22.27	10.01	14.50	7.00
2003	20.05	5.47	3.83		23.34	28.53	11.86	6.00	14.51
2004	23.21	8.86	8.67		14.28	15.74	5.46	8.70	13.08
2005	1.83	2.07	1.21		4.24	10.61	5.11	5.90	8.03
2006	5.38	1.19	1.71		4.04	13.14	15.72	11.10	11.10
2007	24.53	3.29	3.81		11.50	23.52	14.96	10.60	7.94
2008	3.64	0.37	1.64		4.76	10.25	12.28	8.20	7.74
2009	8.93	3.24	1.38		9.26	17.95	8.64	5.40	
2010	1.52	1.19	0.84		4.54	13.30	1.41	2.50	
2011	2.41	2.00	0.95		4.50	19.55	11.20	3.50	
2012					4.32	7.18			
Mean	41.14	8.91	6.22	6.45	10.65	17.93	7.76	21.46	9.80

/1
Mean number per tow Age 1 in URIGSO Trawl survey at Fox Island and Whale Rock stations

/2
Mean number Age 1 per tow in RIDFW seasonal trawl surveys in Narragansett Bay, Rhode Island Sound, and Block Island Sound

/3
Nean number Age 1 per tow in Dominion standard trawl survey in upper Mt Hope Bay

/4
Mean number young of the year per haul in the RIDFW seine survey in Narragansett Bay

/5
Mean number young of the year per haul in the RIDFW seine survey in coastal salt ponds

/6
Mean number young of the year per haul in the Dominion Power seine survey in Mt Hope Bay

/7
Mean number larvae per 100 m3l in the Dominion Power larval surveys in Providence River and Mt Hope Bay

/8
Mean number larvae per 100 m3l in the RIDFW larval survey in Narragansett Bay

Table 3- Winter Flounder Landings and Discards Used in the Biomass Dynamic Model
Rhode Island Waters Stock Assessment.

Year	/1 RI Commercial Landings kgs	/2 Area 539 Landings kgs	/3 RI MRFSS A+B1 kg	/4 Discards Kg	Stock Total MTs
1950	673300	532311	105806	0	638.1
1951	620600	490646	95360	0	586.0
1952	627100	495785	96649	0	592.4
1953	524600	414749	76332	0	491.1
1954	593300	469063	89949	0	559.0
1955	669100	528990	104973	0	634.0
1956	1307100	1033393	231431	0	1264.8
1957	1225300	968722	215217	0	1183.9
1958	886000	700472	147965	0	848.4
1959	1026900	811867	175893	0	987.8
1960	1097400	867604	189866	0	1057.5
1961	923700	730277	155437	0	885.7
1962	924200	730673	155537	0	886.2
1963	1326600	1048810	235296	0	1284.1
1964	1857500	1591485	371349	0	1962.8
1965	1659500	1117807	252594	0	1370.4
1966	1954500	1617020	377751	0	1994.8
1967	1751600	1320319	303366	0	1623.7
1968	1558900	1274661	291919	0	1566.6
1969	2002600	998908	222785	0	1221.7
1970	2555200	859954	187948	0	1047.9
1971	2506400	671200	140626	0	811.8
1972	2258900	438472	82280	504	521.3
1973	2143900	523084	103492	6948	633.5
1974	1555300	390693	70301	9873	470.9
1975	1284500	360750	62794	13535	437.1
1976	1184100	379504	67496	19094	466.1
1977	1932400	483473	93562	30989	608.0
1978	2980200	660385	388438	68095	1116.9
1979	2788000	820815	209300	78688	1108.8
1980	3971100	1276341	88700	120260	1485.3
1981	4178200	1101607	69835	117226	1288.7
1982	3480000	1324041	262370	148692	1735.1
1983	3087500	1231135	195589	168942	1595.7
1984	3295200	1292491	201866	117746	1612.1
1985	2888800	1161610	533839	246621	1942.1
1986	1948200	853005	600000	246963	1700.0
1987	1751300	621629	223827	102476	947.9
1988	1180700	505158	196689	87305	789.2
1989	1089200	444070	128944	152433	725.4
1990	804900	347024	111106	60911	519.0

1991	831000	660751	64428	100803	826.0
1992	840400	358704	4618	45469	408.8
1993	575100	246820	6737	32366	285.9
1994	426900	191520	18204	28508	238.2
1995	459400	355241	12221	21642	389.1
1996	505700	314479	36917	20599	372.0
1997	560200	400924	36648	32281	469.9
1998	560800	445596	26130	25595	497.3
1999	525000	328202	48687	7807	384.7
2000	813100	488928	21482	20086	530.5
2001	658500	437376	56263	4061	497.7
2002	602000	329988	20069	11115	361.2
2003	470600	260804	4137	19737	284.7
2004	394500	238856	3840	12069	254.8
2005	306400	196680	26	16211	212.9
2006	585800	361200	48	32505	393.8
2007	529700	341880	287	23347	365.5
2008	289100	204792	371	19375	224.5
2009	149900	74254	2371	37347	114.0
2010	34749	21576	744	17734	40.1
2011	38582	23956	0	15971	39.9

/1
Total Rhode Island commercial winter flounder landings
/2
Winter flounder landings from NMFS statistical area 539
/3
Rhode Island winter flounder recreational landings from MRFSS/MRIP survey
/4

Table 4- Summary of Winter Flounder Tagging Studies in the Rhode Island and Southern New England Stock Area

Study	Area of Release	Years of Release	Years of Recovery	Number Tagged	Number Returned	Percent Returned	Estimation Method [1/]	Z Rate	SE (Z)	Percent Recreational
Perlmutter (1947)	Waquoit Bay, MA	1931	6	4171	251	6.0%	Catch curve	0.836	0.055	8.4%
	Point Judith Pond, RI	1937	6	279	87	31.2%	Catch curve	0.728	0.134	76.2%
	Narragansett Bay, RI	1937	4	698	105	15.0%	Catch curve	0.938	0.254	10.7%
	Mystic River, CT	1938	5	632	117	18.5%	Catch curve	1.128	0.060	35.1%
	Block Island Sound	1940-1942	4	1053	66	6.3%	Model 2	0.443	0.143	11.5%
	Watch Hill, RI	1940	3	307	59	19.2%	Catch curve	0.923	0.004	3.4%
	Narragansett Bay, RI	1940	3	282	30	10.6%	Catch curve	1.099	0.295	22.9%
Saila (1961)	Green Hill Pond, RI	1956	3	952	309	32.5%	Catch curve	0.640	0.062	21.7%
Saila (1962)	Narragansett Bay, RI	1958	2	880	309	35.1%	Catch curve	0.882	0.125	12.0%
Howe and Coates (1975)	South of Cape Cod, MA	1964-1968	5	2454	1054	43.0%	Catch curve	0.610	0.043	21.0%
Howe et al. (1976)	Waquoit Bay, MA	1970	5	NA	241		Catch curve	0.461	0.198	NA
Black et al. (1988)	Narraganset Bay	1980	3	997	185	18.6%	Catch curve	1.222	0.139	NA
NUSCo (1987)	Niantic River, CT	1980-1983	3	4978	1227	24.6%	Catch curve	0.893	0.098	62.7%
Dominion Power (2009)	Niantic River, CT	1983-2009	26	42694	2203	5.2%	Model 1	0.891	0.147	NA
RIDFW, Powell (1989)	Narragansett Bay, RI	1986-1990	6	6766	901	13.3%	Model 2	1.506	0.300	39.7%
RIDFW, unpublished	Narragansett Bay, RI	1996-1998	3	840	58	6.9%	Model 2	0.495	0.138	16.0%
RIDFW, unpublished	Pt Judith Pond, RI	1999-2009	9	1486	194	13.1%	Model 2	0.810	0.083	93.1%
RIDFW, unpublished	Charlestown Pond, RI	2012	1	99	9	9.1%	Expl Rate	0.540		0.0%

/1
Catch curve is a linear regression of the logarithm of number of tags returned on time, Models 1-3 are from the Brownie et al. (1985) framework.

Table 5- Mark and Recapture Data for RIDFW Winter Flounder Tagging Study in Pt Judith Pond

		Recaptures												
	Tagged	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1999	332	31	8	10	1	0	1	0	0	0	0	0	0	0
2000	208		23	17	5	1	0	0	0	0	0	0	0	0
2001	358			43	11	1	2	0	0	0	0	0	0	0
2002	182				1	3	1	0	0	0	0	0	0	0
2003	87					1	1	2	0	0	0	0	0	0
2004	64						9	1	2	0	0	0	0	0
2005	115							4	4	2	1	0	0	0
2006	91								3	2	0	0	0	0
2007	35									2	1	0	0	0
2008	14										0	0	0	0
2009	0											0	0	0
2010	19												0	0
2011	11													0
Total	1231	31	31	70	18	6	14	7	9	6	2	0	0	

Table 6a- Catch per Tow at Age of Winter Flounder in the RIDFW Spring Trawl Survey In Narragansett Bay and Rhode Island Coastal Waters, 1981-2010. Ages Determined Using NEFSC Age-Length Keys

	Age												
Year	1	2	3	4	5	6	7	8	9	10+	3+	4+	Z Rate
1981	45.7	27.9	12.9	1.3	0.2	0.0	0.0	0.0	0.0	0.0	14.4	1.6	
1982	13.4	9.7	5.0	2.3	0.3	0.1	0.0	0.0	0.0	0.0	7.8	2.8	1.7
1983	29.5	9.8	11.0	6.0	2.1	0.6	0.0	0.0	0.0	0.0	19.7	8.7	-0.1
1984	6.7	16.8	13.9	3.0	0.8	0.4	0.0	0.0	0.0	0.0	18.2	4.2	1.5
1985	6.0	15.7	10.3	2.2	0.6	0.1	0.0	0.0	0.0	0.0	13.3	2.9	1.8
1986	11.9	15.6	9.6	2.6	1.1	0.1	0.0	0.0	0.0	0.0	13.4	3.9	1.2
1987	15.3	24.6	13.1	2.7	0.4	0.1	0.0	0.0	0.0	0.0	16.3	3.2	1.4
1988	8.9	12.4	9.5	2.9	0.7	0.0	0.0	0.0	0.0	0.0	13.1	3.6	1.5
1989	4.8	8.2	4.9	2.3	0.5	0.1	0.0	0.0	0.0	0.0	7.9	2.9	1.5
1990	6.5	6.4	4.9	2.2	0.5	0.0	0.1	0.0	0.0	0.0	7.6	2.7	1.1
1991	11.2	14.4	12.0	2.8	0.4	0.1	0.1	0.0	0.0	0.0	15.4	3.4	0.8
1992	1.3	0.9	1.2	0.8	0.2	0.0	0.0	0.0	0.0	0.0	2.2	1.0	2.7
1993	2.3	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	3.3
1994	2.8	4.6	2.0	0.6	0.2	0.0	0.0	0.0	0.0	0.0	2.9	0.9	-1.2
1995	9.4	11.4	9.9	1.5	0.1	0.0	0.0	0.0	0.0	0.0	11.5	1.6	0.6
1996	3.1	8.4	7.5	1.6	0.1	0.0	0.0	0.0	0.0	0.0	9.2	1.7	1.9
1997	4.9	8.8	6.9	1.5	0.3	0.0	0.0	0.0	0.0	0.0	8.6	1.7	1.7
1998	2.1	9.5	5.9	1.6	0.1	0.0	0.0	0.0	0.0	0.0	7.6	1.7	1.6
1999	1.7	6.5	4.3	0.8	0.1	0.1	0.0	0.0	0.0	0.0	5.2	1.0	2.1
2000	2.9	5.0	5.5	2.2	0.7	0.1	0.0	0.0	0.0	0.0	8.5	2.9	0.6
2001	2.5	3.5	3.7	2.2	0.6	0.0	0.0	0.0	0.0	0.0	6.6	2.9	1.1
2002	1.6	4.8	3.2	1.2	0.5	0.1	0.1	0.0	0.0	0.0	5.2	2.0	1.2
2003	1.7	0.9	1.8	0.5	0.3	0.3	0.1	0.0	0.0	0.0	3.0	1.2	1.4
2004	5.5	4.0	1.0	0.4	0.1	0.1	0.0	0.0	0.0	0.0	1.7	0.7	1.5
2005	8.9	2.4	1.7	1.4	0.8	0.4	0.1	0.0	0.0	0.0	4.5	2.7	-0.5
2006	2.1	4.7	5.2	2.2	0.7	0.3	0.0	0.0	0.0	0.0	8.6	3.3	0.3
2007	1.2	1.1	2.0	1.6	0.9	0.4	0.1	0.0	0.0	0.0	5.0	3.0	1.1
2008	3.3	1.0	1.0	1.1	0.7	0.2	0.1	0.0	0.0	0.0	3.1	2.1	0.9
2009	0.4	1.2	0.8	0.7	0.5	0.1	0.0	0.0	0.0	0.0	2.1	1.3	0.8
2010	3.2	2.7	3.1	1.2	1.1	0.2	0.0	0.0	0.0	0.0	5.6	2.5	-0.2
Mean	7.36	8.10	5.80	1.78	0.52	0.13	0.03	0.01	0.00	0.00	8.28	2.48	1.15

Table 6b- Catch per Tow at Age of Winter Flounder in the URIGSO Trawl Survey In Narragansett Bay and Rhode Island Coastal Waters, 1985-2010. Ages Determined Using MADMF Age-Length Keys

	Age											
Year	1	2	3	4	5	6	7	8	9	10+	3+	4+	Z Rate
1985	2.1	18.3	12.1	1.9	0.6	0.0	0.0	0.0	0.0	0.0	14.6	2.5	
1986	6.9	13.8	4.2	0.8	0.1	0.0	0.0	0.0	0.0	0.0	5.2	0.9	2.75
1987	16.7	35.9	10.7	1.5	0.2	0.0	0.0	0.0	0.0	0.0	12.5	1.7	1.08
1988	22.3	24.0	7.8	1.0	0.0	0.0	0.1	0.0	0.0	0.0	8.9	1.0	2.48
1989	19.7	24.2	2.4	0.9	0.1	0.0	0.0	0.0	0.0	0.0	3.5	1.1	2.09
1990	6.2	10.3	2.2	0.7	0.1	0.0	0.0	0.0	0.0	0.0	3.1	0.9	1.36
1991	7.8	5.8	2.5	0.5	0.1	0.1	0.0	0.0	0.0	0.0	3.1	0.6	1.65
1992	5.8	4.2	1.4	0.5	0.1	0.0	0.0	0.0	0.0	0.0	1.9	0.6	1.74
1993	9.0	8.8	0.9	0.3	0.1	0.0	0.0	0.0	0.0	0.0	1.3	0.4	1.62
1994	4.5	6.2	1.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.2	1.87
1995	34.7	13.6	7.3	1.4	0.2	0.3	0.1	0.0	0.0	0.0	9.3	2.0	-0.17
1996	14.2	19.7	5.4	1.1	0.4	0.2	0.1	0.0	0.0	0.0	7.3	1.9	1.59
1997	18.1	15.6	7.0	1.6	0.4	0.2	0.1	0.1	0.0	0.1	9.5	2.6	1.04
1998	7.5	13.7	3.9	1.3	0.3	0.2	0.0	0.0	0.0	0.0	5.7	1.8	1.65
1999	7.1	3.1	2.1	0.7	0.1	0.1	0.1	0.0	0.0	0.0	3.1	1.0	1.73
2000	7.5	3.8	2.3	0.8	0.1	0.1	0.1	0.0	0.0	0.0	3.4	1.1	1.01
2001	4.1	0.9	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.2	3.02
2002	5.4	3.2	1.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	1.4	0.4	0.07
2003	14.2	4.3	0.8	0.3	0.1	0.0	0.0	0.0	0.0	0.0	1.2	0.4	1.19
2004	18.4	6.5	0.5	0.3	0.1	0.0	0.0	0.0	0.0	0.0	1.0	0.5	0.97
2005	23.6	6.3	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.2	1.64
2006	5.2	4.0	1.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.4	0.82
2007	4.4	2.9	1.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	1.3	0.3	1.66
2008	18.7	7.4	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.2	2.07
2009	3.6	5.9	1.7	0.2	0.1	0.0	0.0	0.0	0.0	0.0	2.0	0.3	0.99
2010	7.7	3.2	1.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.3	1.83
Mean	11.36	10.21	3.18	0.67	0.13	0.06	0.02	0.01	0.00	0.00	4.08	0.90	1.51

Table 7- Abundance Indices and Landings Data Used in the Historical Era of the Rhode Island Biomass Dynamic Model

				/4	/5	/6	/7	/8	/9	/10
	/1	/2	/3	Boothbay	Woods Hole	CT Spring	CT Winter	NY Spring	NY Winter	Combined
Year	Landings MT	OT Effort	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE Index
1910	808.9			550						551.4
1911	851.0			342						345.2
1912	895.3			286						289.6
1913	941.8			223						227.2
1914	990.8			270						273.8
1915	1042.3			183						187.5
1916	1096.5			227						231.1
1917	1153.6			288						291.6
1918	1213.6			272						275.8
1919	1114.5	19	59.6	230	157					176.6
1920	1343.1	20	68.1	120	82					121.5
1921	1412.9	21	68.0	114	109					128.4
1922	1486.4	22	67.9	123	58					114.3
1923	1563.7	23	67.8	83	59					101.3
1924	1408.6	24	57.9	77	133					116.8
1925	1730.6	26	67.5	105	118					128.1
1926	1820.6	27	67.4	66	76					101.1
1927	1915.3	28	67.3	93	108					120.6
1928	2000.5	30	66.7	96	118					124.5
1929	2176.8	32	68.9	94	142					133.4
1930	2136.8	33	64.1	133	119	1023	552			136.2
1931	2765.5	35	78.8	131	143	875	536	639	259	145.8
1932	1710.0	37	46.2	133	106	592	464	318	288	108.1
1933	1168.1	39	30.0	128	46	610	588	208	115	78.1
1934	1086.3	31	35.0	43	15		387	195	112	48.4
1935	843.9	25	33.8	49	38	704	407	176	150	63.2
1936	593.0	27	22.0	59	74	514	225	291	176	60.2
1937	494.1	29	17.0	44	141	304	217	260	170	58.0
1938	296.5	23	12.9	28	60			231		47.8
1939	222.4	18	12.4	31	128	450	312			57.7
1940	296.5	20	14.8	25	22		478			46.4
1941	326.1	21	15.5		50	304	660			66.2
1942	370.6	21	17.6							47.6
1943	444.7	28	15.9							43.7
1944	543.5	32	17.0							46.1
1945	464.5	35	13.3							38.1
1946	469.4	50	9.4							29.6
1947	444.7	55	8.1							26.8
1948	691.8	50	13.8							39.3
1949	593.0	62	9.6							30.0
1950	636.4	55	11.6							34.4

1951	584.0	103	5.7	21.5
1952	590.5	109	5.4	21.0
1953	488.7	109	4.5	19.0
1954	556.9	135	4.1	18.2
1955	632.2	125	5.1	20.2
1956	1266.0	141	9.0	28.7
1957	1184.8	128	9.3	29.3
1958	847.7	100	8.5	27.6
1959	987.7	75	13.2	37.8

/1
Landings estimates 1910-1949 from Perlmutter (1947) and Olsen and Stevenson (1975), 1950-1959 from NMFS sources
/2
Number of otter trawl vessels ported in Rhode Island from Olsen and Stevenson (1975)
/3
CPUE as metric tons per vessel from column two divided by column three
/4
Catch per fyke net at Boothbay Hatchery from Perlmutter (1947)
/5
Catch per fyke net at Woods Hole Hatchery from Perlmutter (1947)
/6
Pounds per day spring season from CT dragger from Perlmutter (1947)
/7
Pounds per day spring season from CT dragger from Perlmutter (1947)
/8
Pounds per day spring season from NY dragger from Perlmutter (1947)
/9
Pounds per day spring season from NY dragger from Perlmutter (1947)
/10
Mean index using Z-score method, back transformed to Woods Hole units. Values from 1919 on used in assessment

Table 8- Parameter Estimates and Derived Quantities for the Rhode Island Winter Flounder Biomass Dynamic Model with Time Varying Productivity

Parameter or Quantity	SOLVER Estimate	Bootstrap Mean	Bootstrap SE	Coefficient Variation	Lower 95%	Upper 95%
Biomass in 2012 mt	957	956	110	0.115	738	1177
Bmsy mt	5951	5446	444	0.082	5062	6839
Relative Biomass 2012	0.161	0.177	0.024	0.139	0.112	0.210
MSY mt	966	893	97	0.109	772	1161
Carrying Capacity mt	11901	10893	889	0.082	10123	13679
Base Intrinsic Rate	0.456	0.471	0.019	0.039	0.418	0.493
Temperature Effect	-0.379	-0.407	0.065	-0.160	-0.509	-0.249
Fishing Mortality in 2011	0.095	0.095	0.002	0.017	0.091	0.098
Fmsy 2011	0.177	0.179	0.009	0.050	0.159	0.195
URIGSO Trawl q	0.00353	0.00354	0.00023	0.064	0.00308	0.00398
Commercial CPUE q	0.33032	0.33110	0.02126	0.064	0.28781	0.37284
NMFS Trawl q	0.00069	0.00069	0.00004	0.065	0.00060	0.00078
RIDFW Spring Trawl q	0.00238	0.00237	0.00016	0.066	0.00207	0.00269
Normandeau Trawl q1	0.00216	0.00217	0.00022	0.101	0.00172	0.00260
Normandeau Trawl q2	0.00063	0.00063	0.00005	0.084	0.00052	0.00073
RIDFW Monthly Trawl q	0.00117	0.00117	0.00010	0.085	0.00097	0.00137
Normandeau Wilcox Trawl q	0.00152	0.00152	0.00015	0.100	0.00121	0.00182
RIDFW Fall Trawl q	0.00060	0.00061	0.00004	0.071	0.00052	0.00069
Historical Era Index q	0.01768	0.01766	0.00052	0.029	0.01664	0.01872
Tag F catchability	Fixed at 1.0					

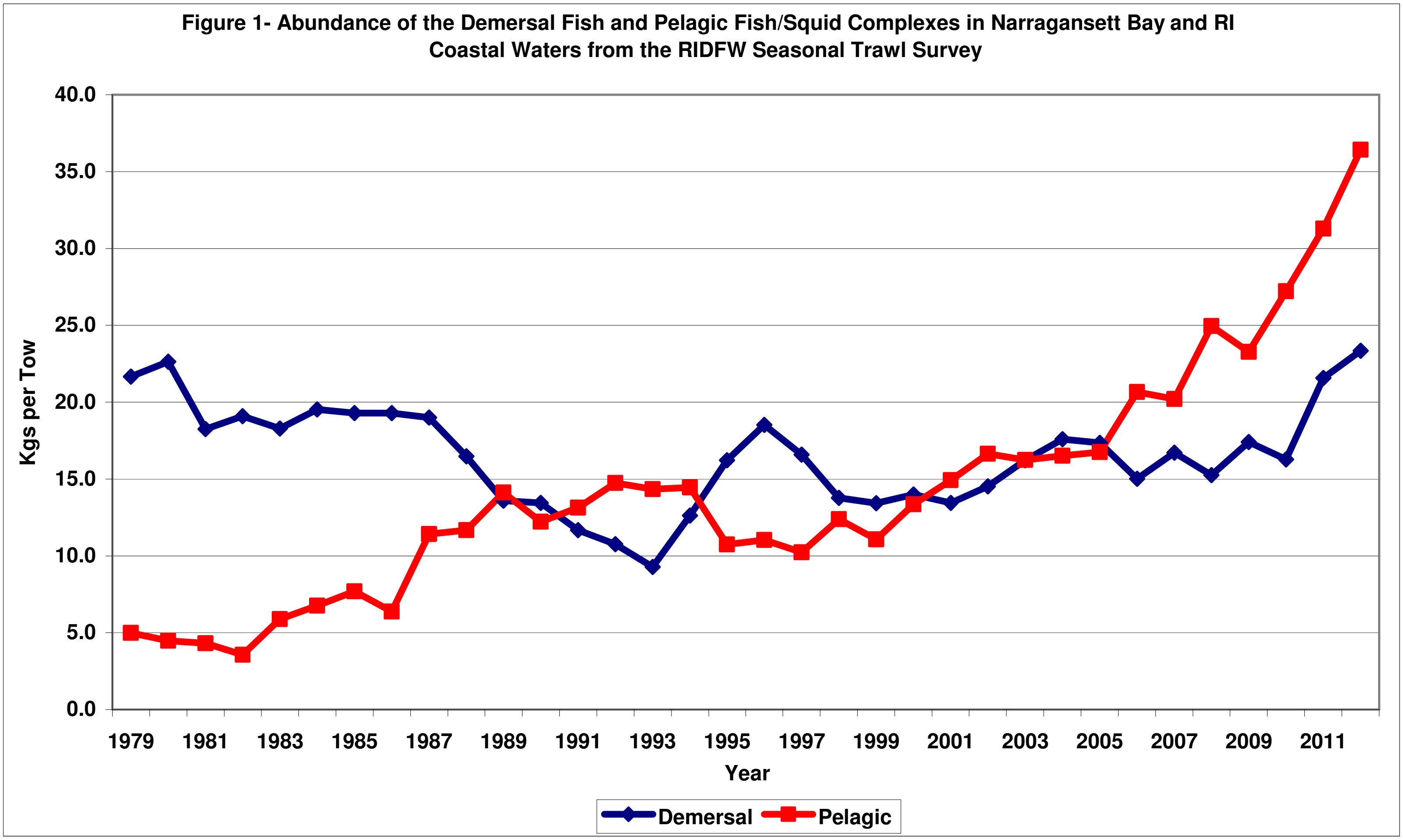


Figure 1- Abundance of the Demersal Fish and Pelagic Fish/Squid Complexes in Narragansett Bay and RI Coastal Waters from the RIDFW Seasonal Trawl Survey
Kgs per Tow
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Year
Demersal
Pelagic

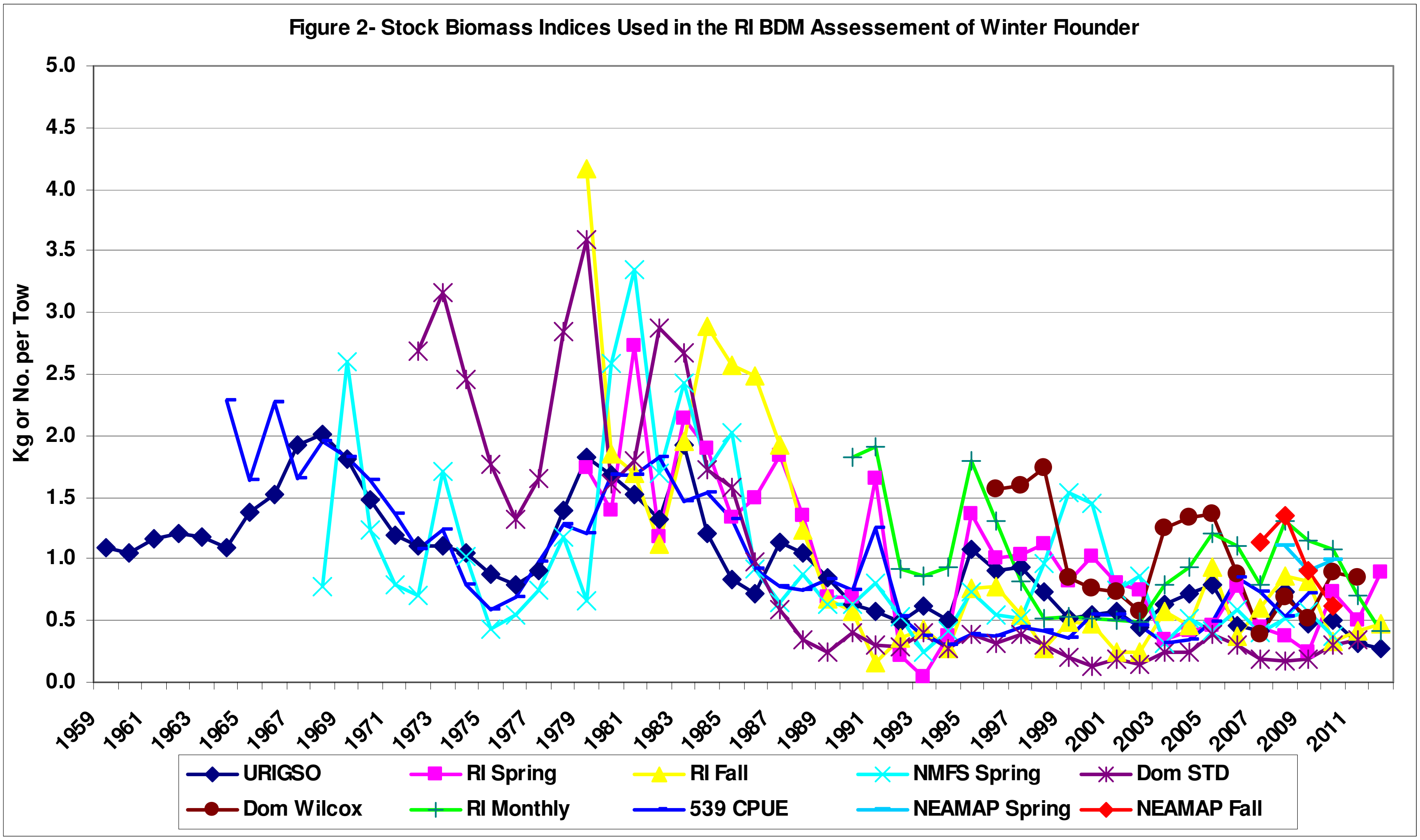


Figure 2- Stock Biomass Indices Used in the RI BDM Assessement of Winter Flounder
Kg or No. per Tow
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
URIGSO
RI Spring
RI Fall
NMFS Spring
Dom STD
Dom Wilcox
RI Monthly
539 CPUE
NEAMAP Spring
NEAMAP Fall

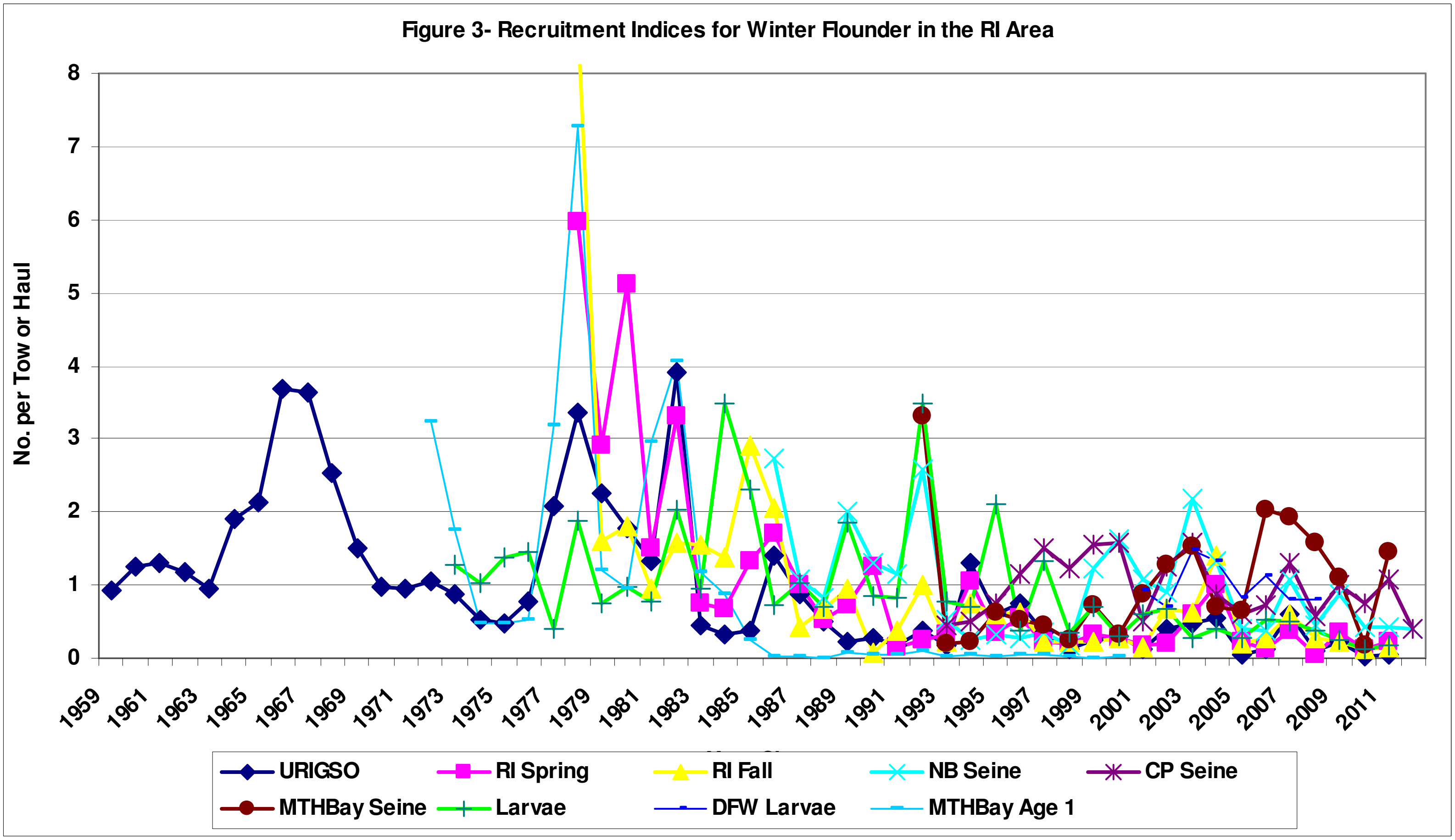


Figure 3- Recruitment Indices for Winter Flounder in the RI Area
No. per Tow or Haul
8
7
6
5
4
3
2
1
0
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
URIGSO
RI Spring
RI Fall
NB Seine
CP Seine
MTHBay Seine
Larvae
DFW Larvae
MTHBay Age 1

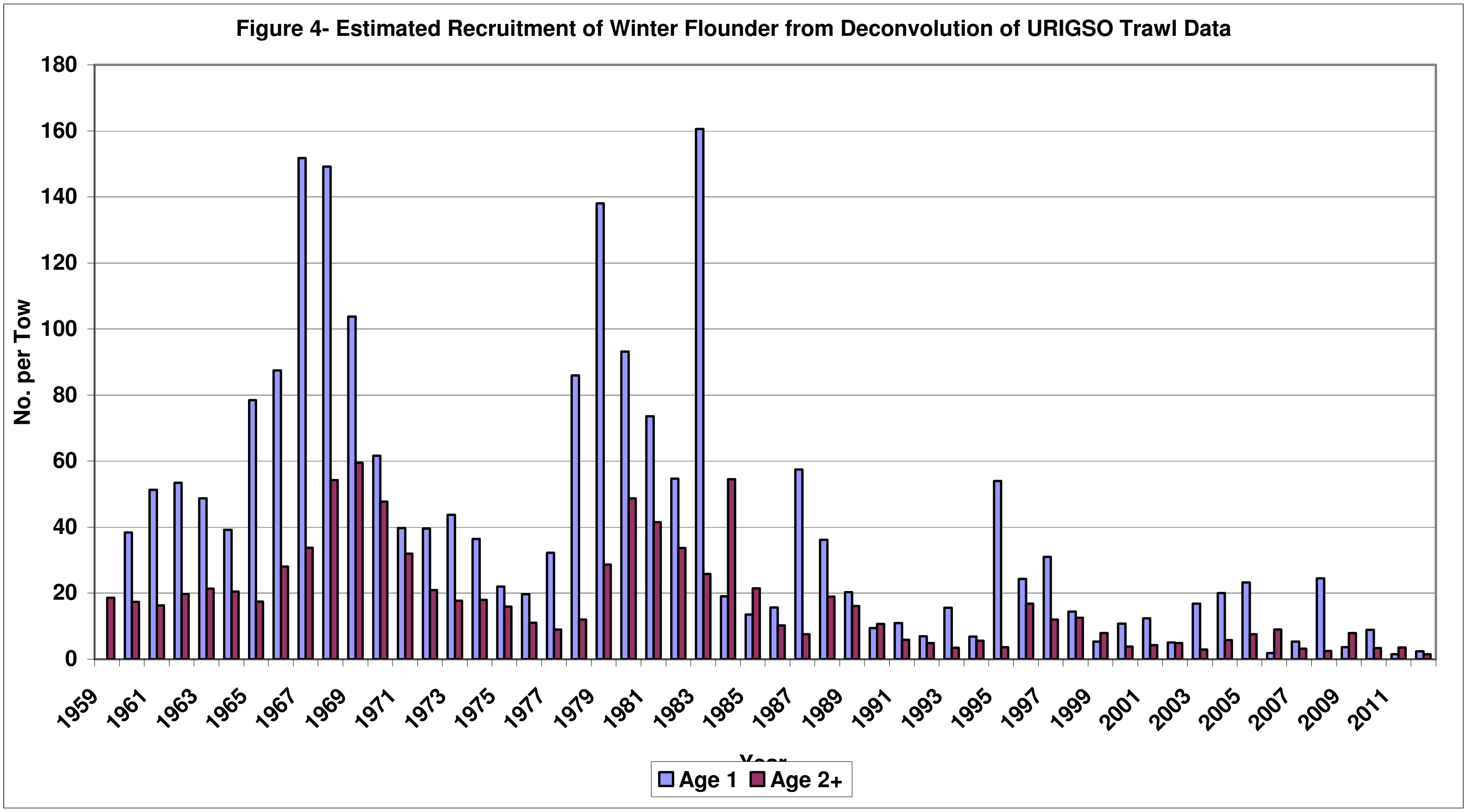


Figure 4- Estimated Recruitment of Winter Flounder from Deconvolution of URIGSO Trawl Data
No. per Tow
Year
Age 1
Age 2+

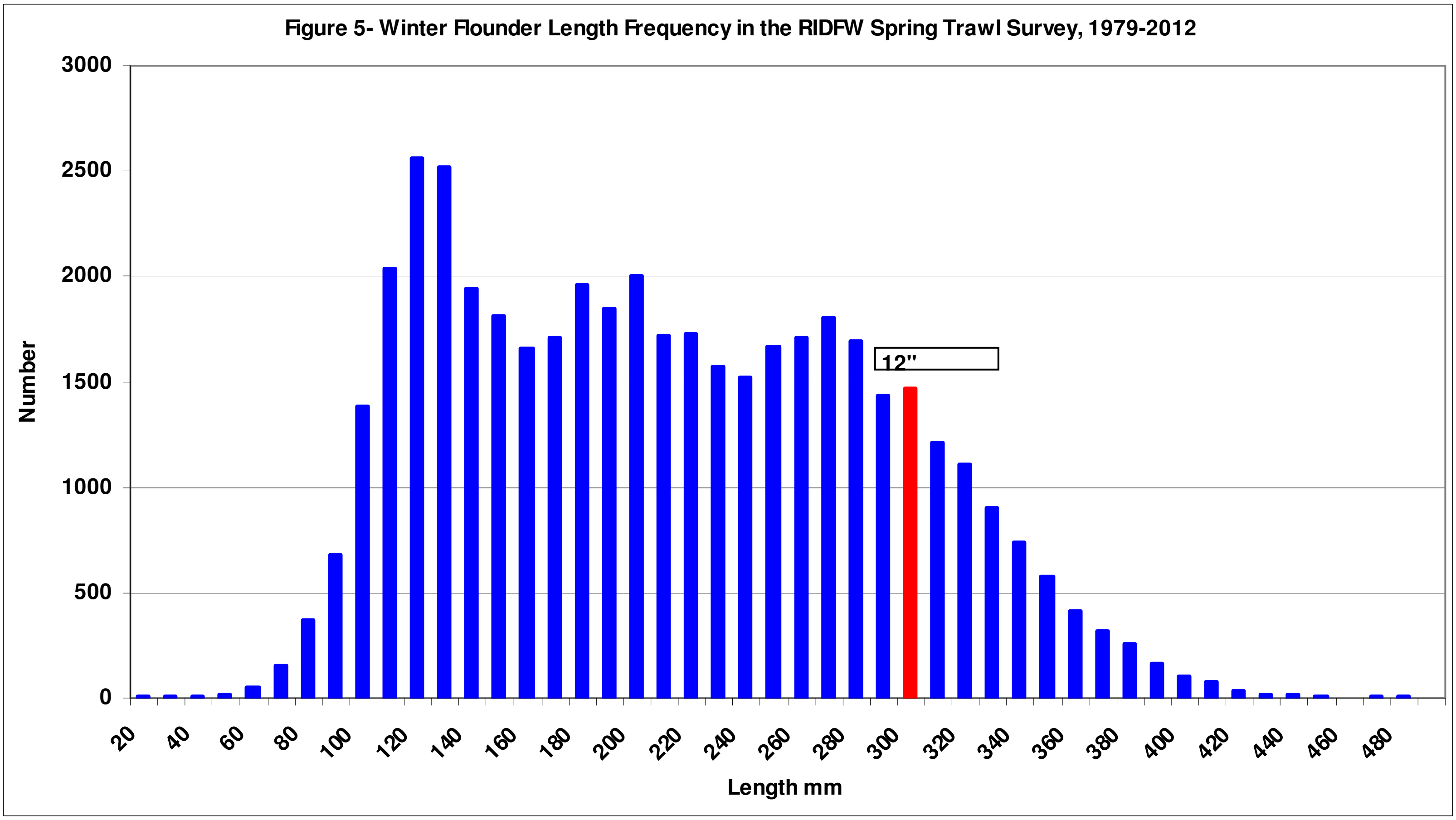


Figure 5- Winter Flounder Length Frequency in the RIDFW Spring Trawl Survey, 1979-2012
Number
3000
2500
2000
1500
1000
500
0
12"
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
Length mm

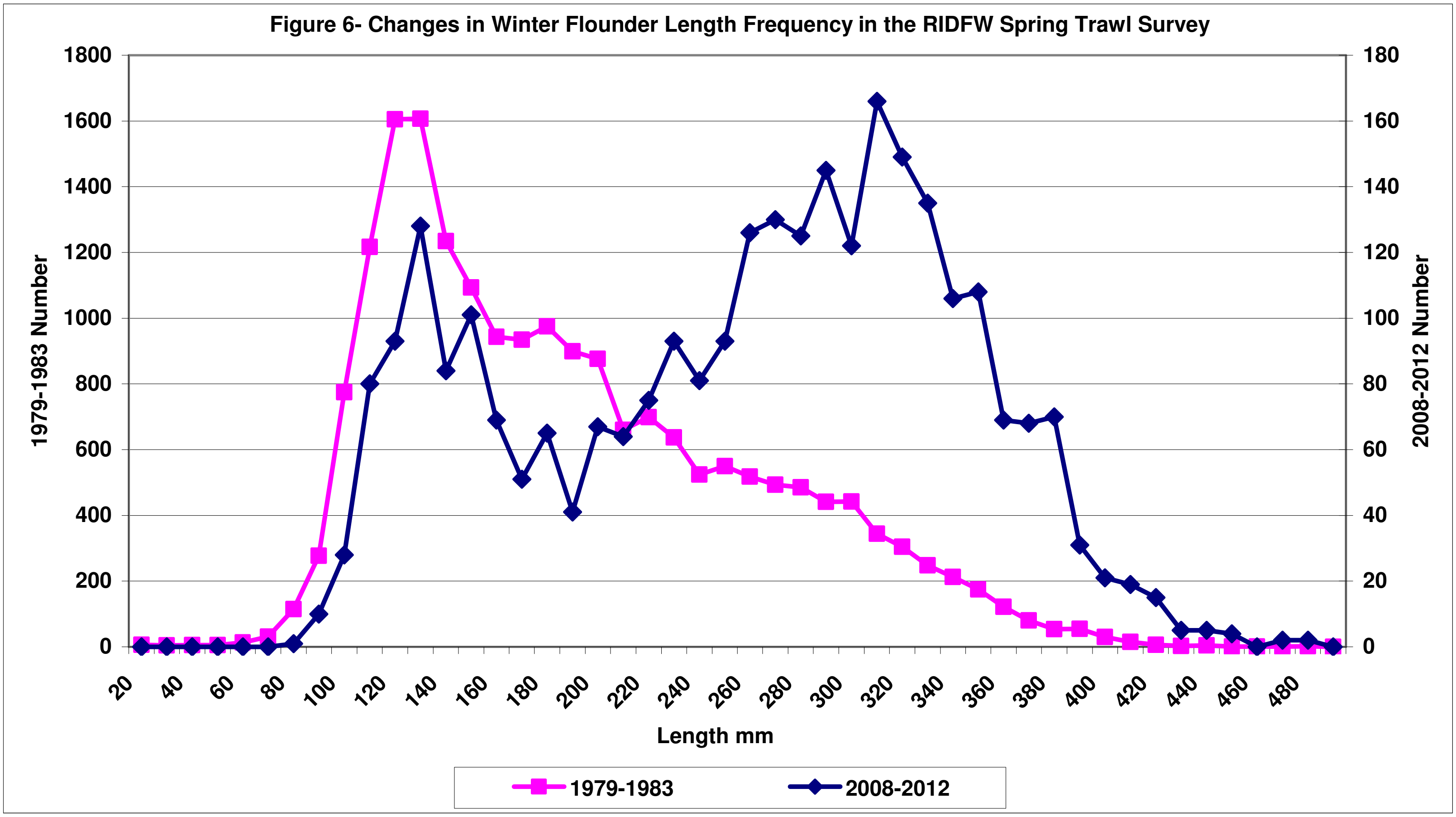


Figure 6- Changes in Winter Flounder Length Frequency in the RIDFW Spring Trawl Survey
1979-1983 Number
2008-2012 Number
Length mm
1979-1983
2008-2012
0
200
400
600
800
1000
1200
1400
1600
1800
20
40
60
80
100
120
140
160
180
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480

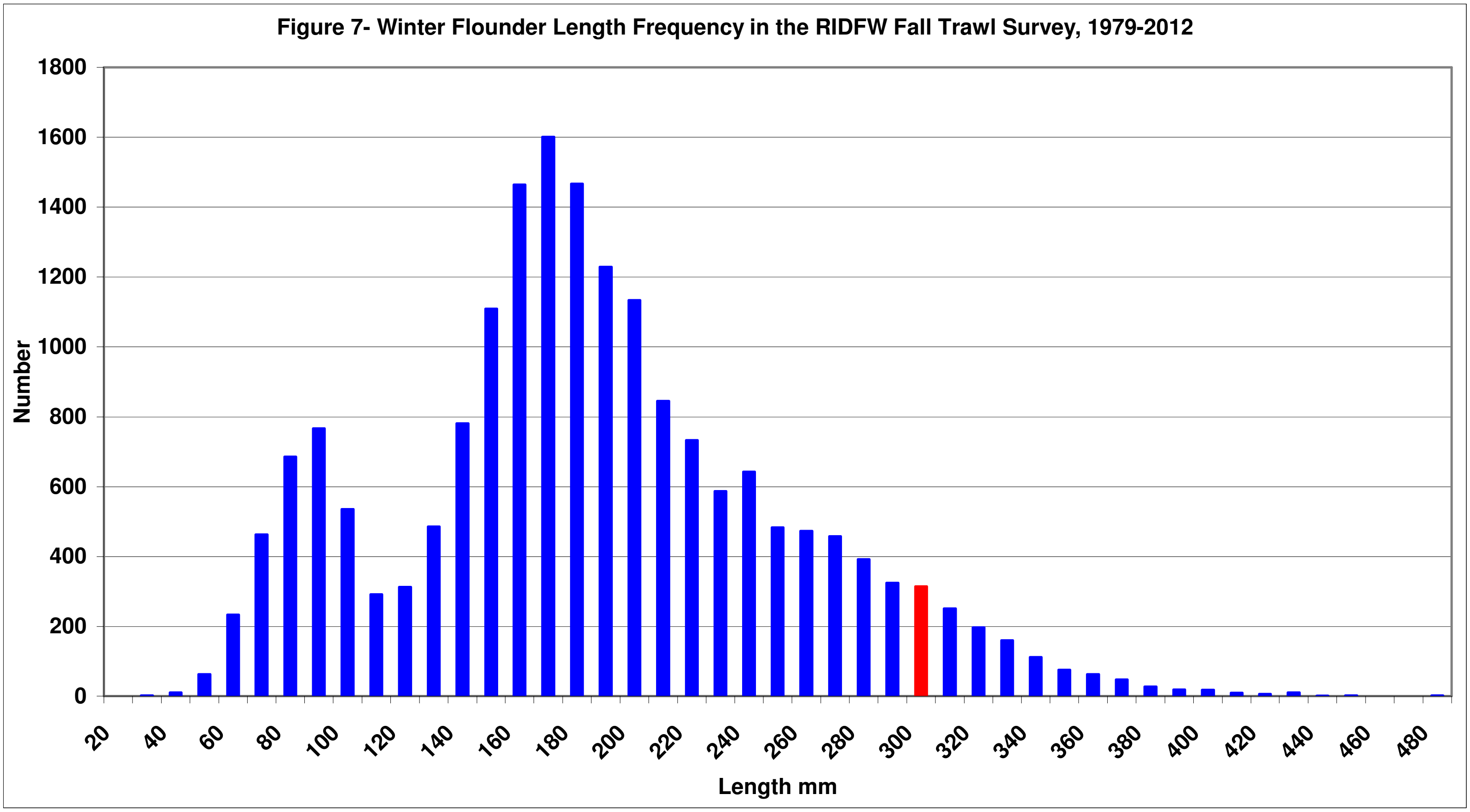


Figure 7- Winter Flounder Length Frequency in the RIDFW Fall Trawl Survey, 1979-2012
Number
1800
1600
1400
1200
1000
800
600
400
200
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
Length mm

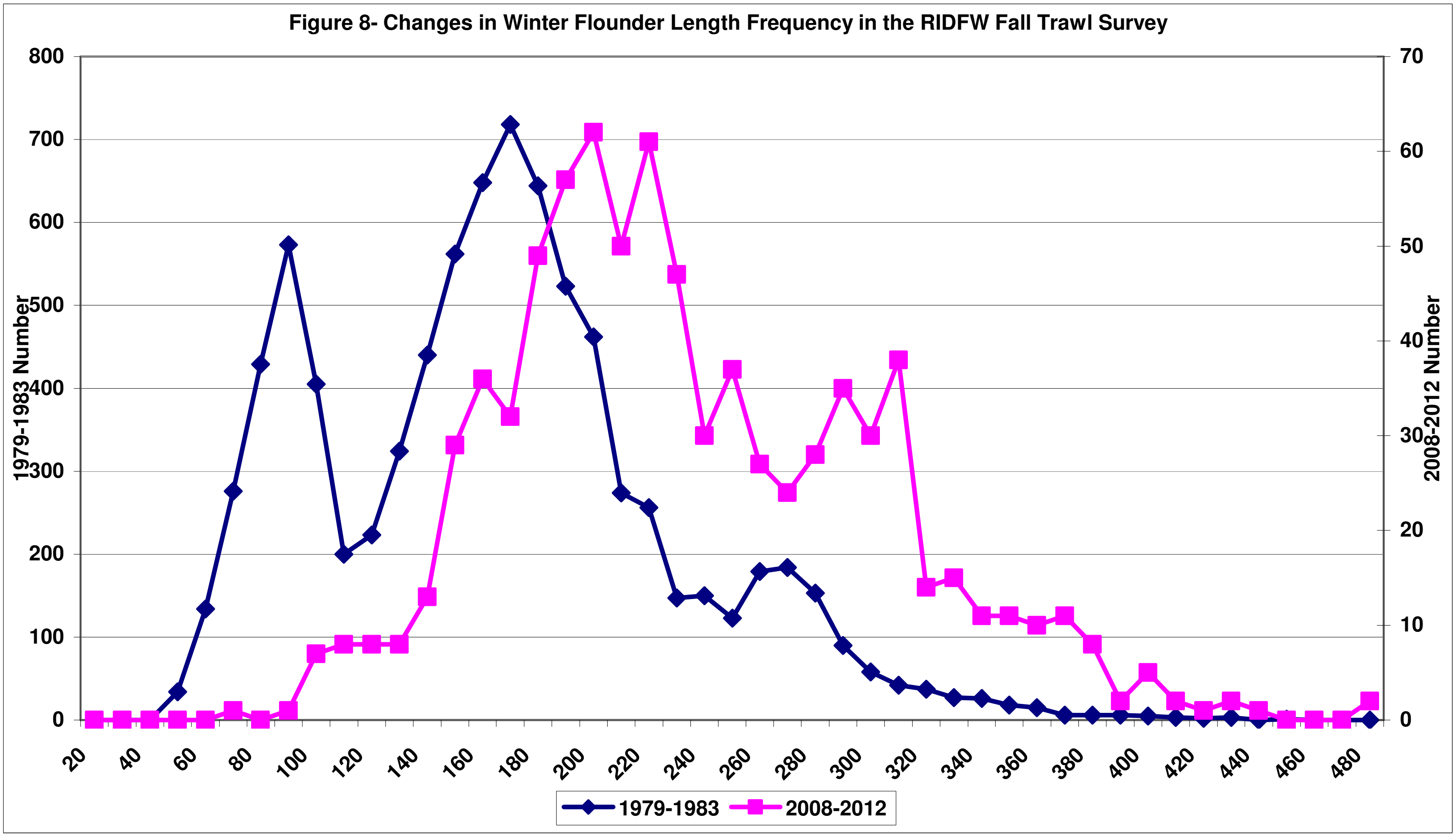


Figure 8- Changes in Winter Flounder Length Frequency in the RIDFW Fall Trawl Survey
1979-1983 Number
2008-2012 Number
0
100
200
300
400
500
600
700
800
0
10
20
30
40
50
60
70
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
1979-1983
2008-2012

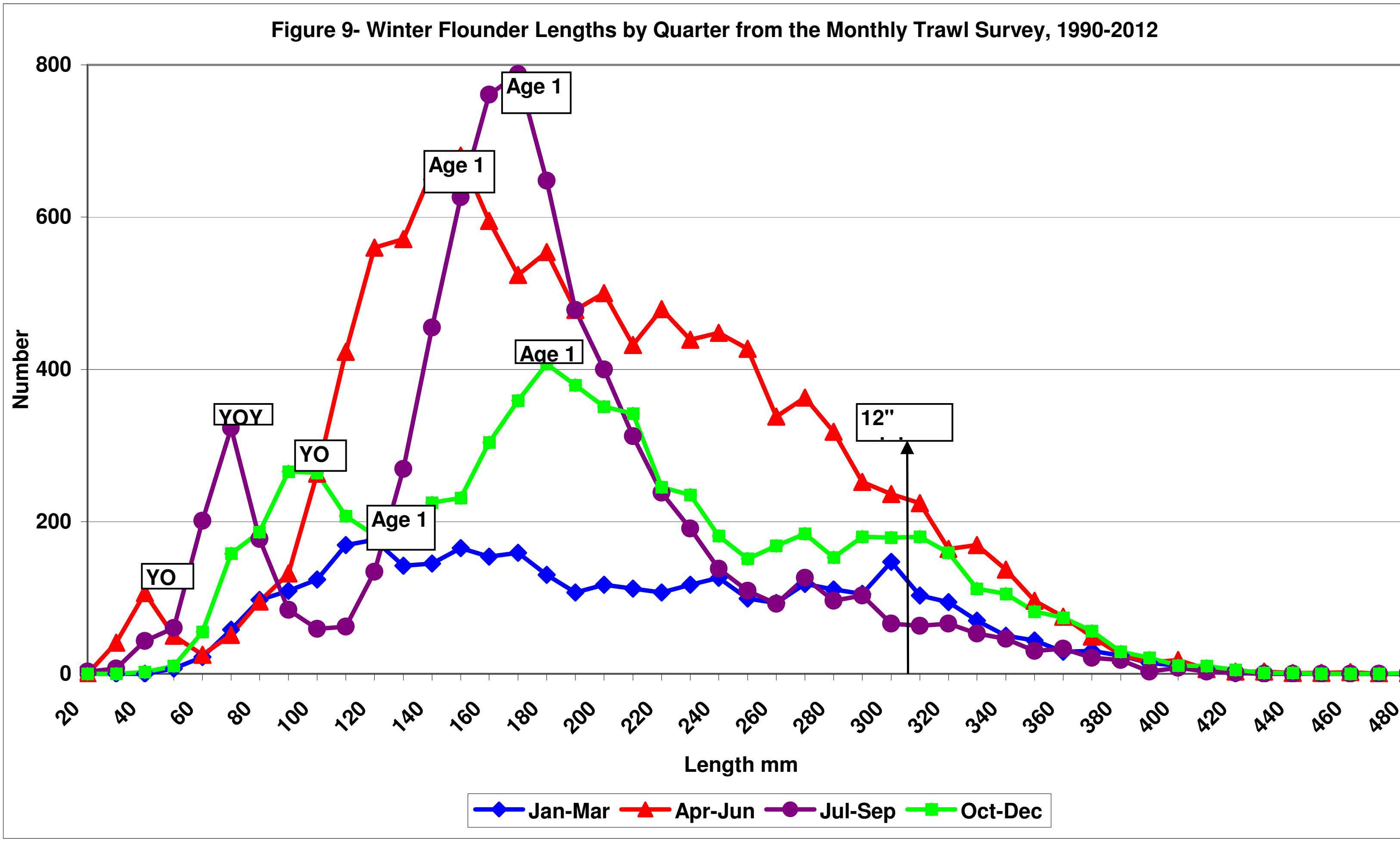


Figure 9- Winter Flounder Lengths by Quarter from the Monthly Trawl Survey, 1990-2012
Number
Length mm
800
600
400
200
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
YO
YOY
YO
Age 1
Age 1
Age 1
Age 1
12"
Jan-Mar
Apr-Jun
Jul-Sep
Oct-Dec

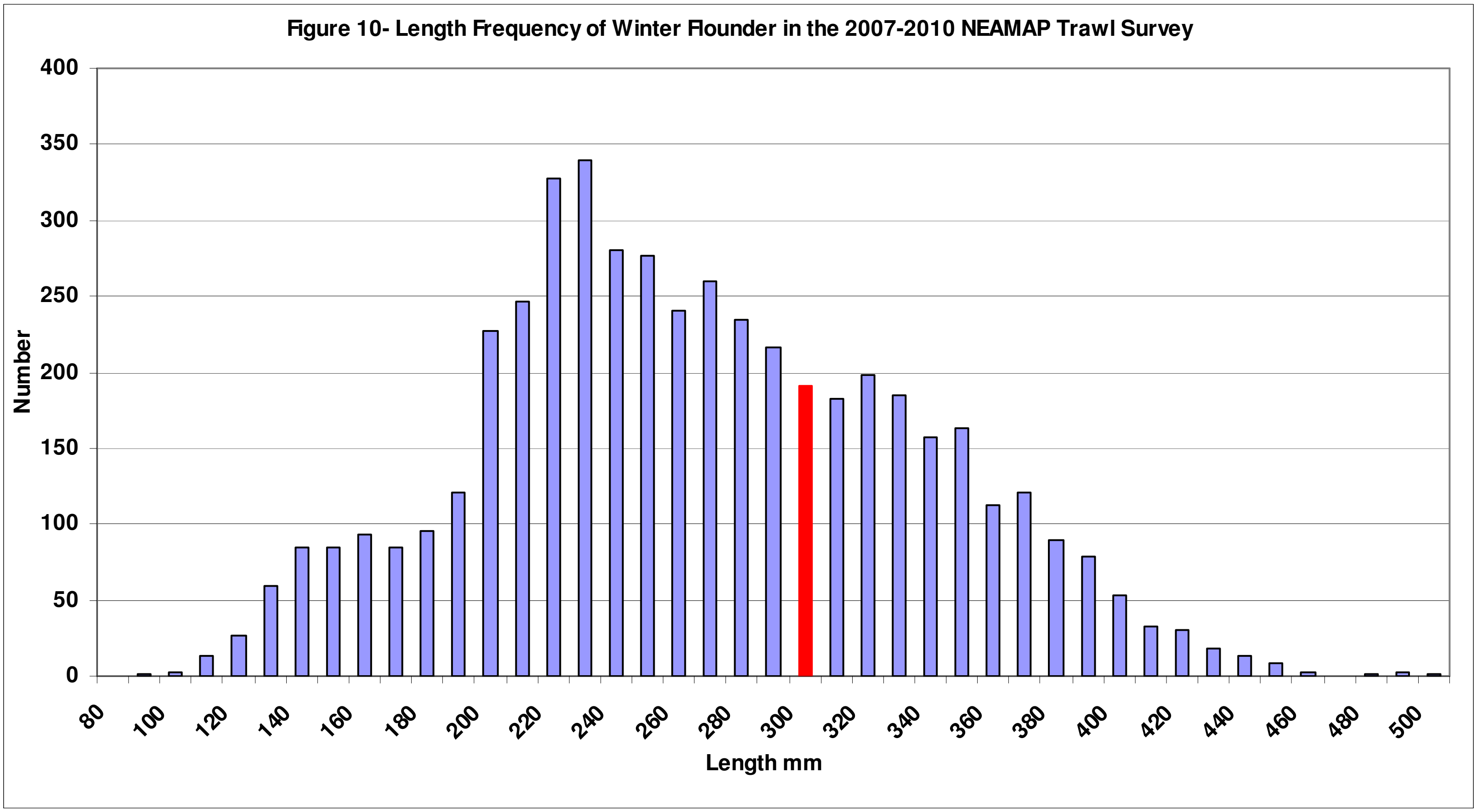


Figure 10- Length Frequency of Winter Flounder in the 2007-2010 NEAMAP Trawl Survey
Number
0
50
100
150
200
250
300
350
400
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
Length mm

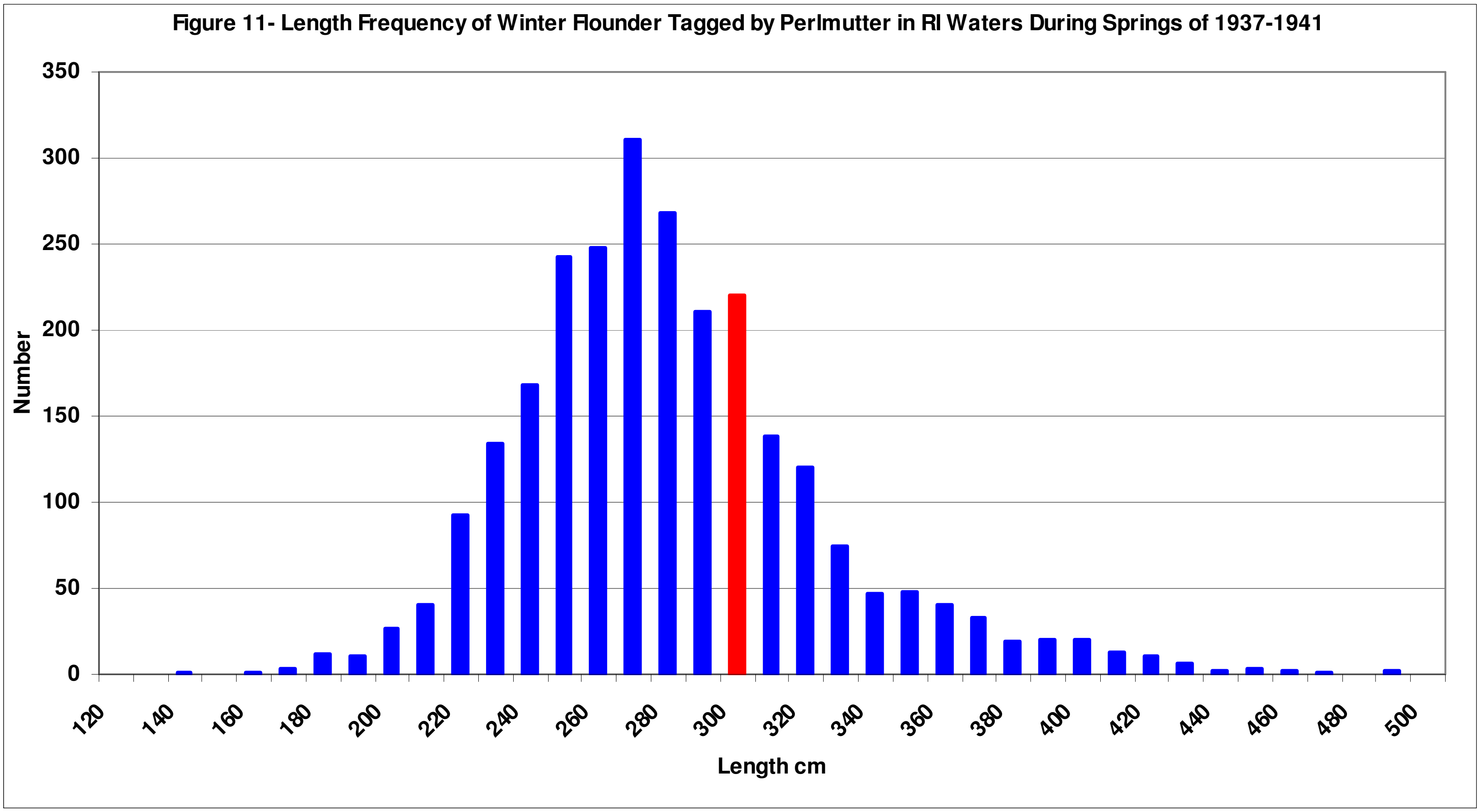


Figure 11- Length Frequency of Winter Flounder Tagged by Perlmutter in RI Waters During Springs of 1937-1941
Number
0
50
100
150
200
250
300
350
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
Length cm

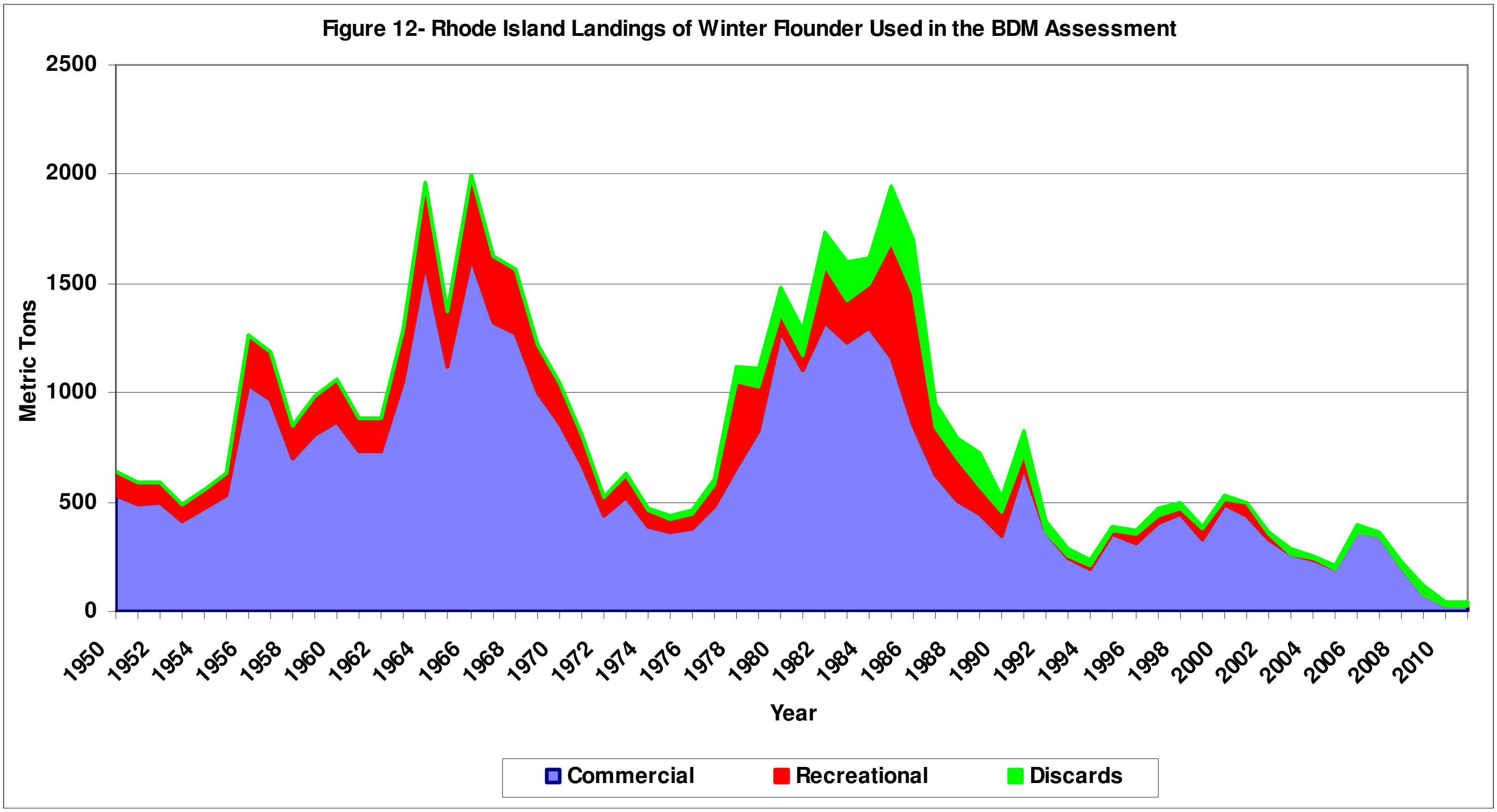
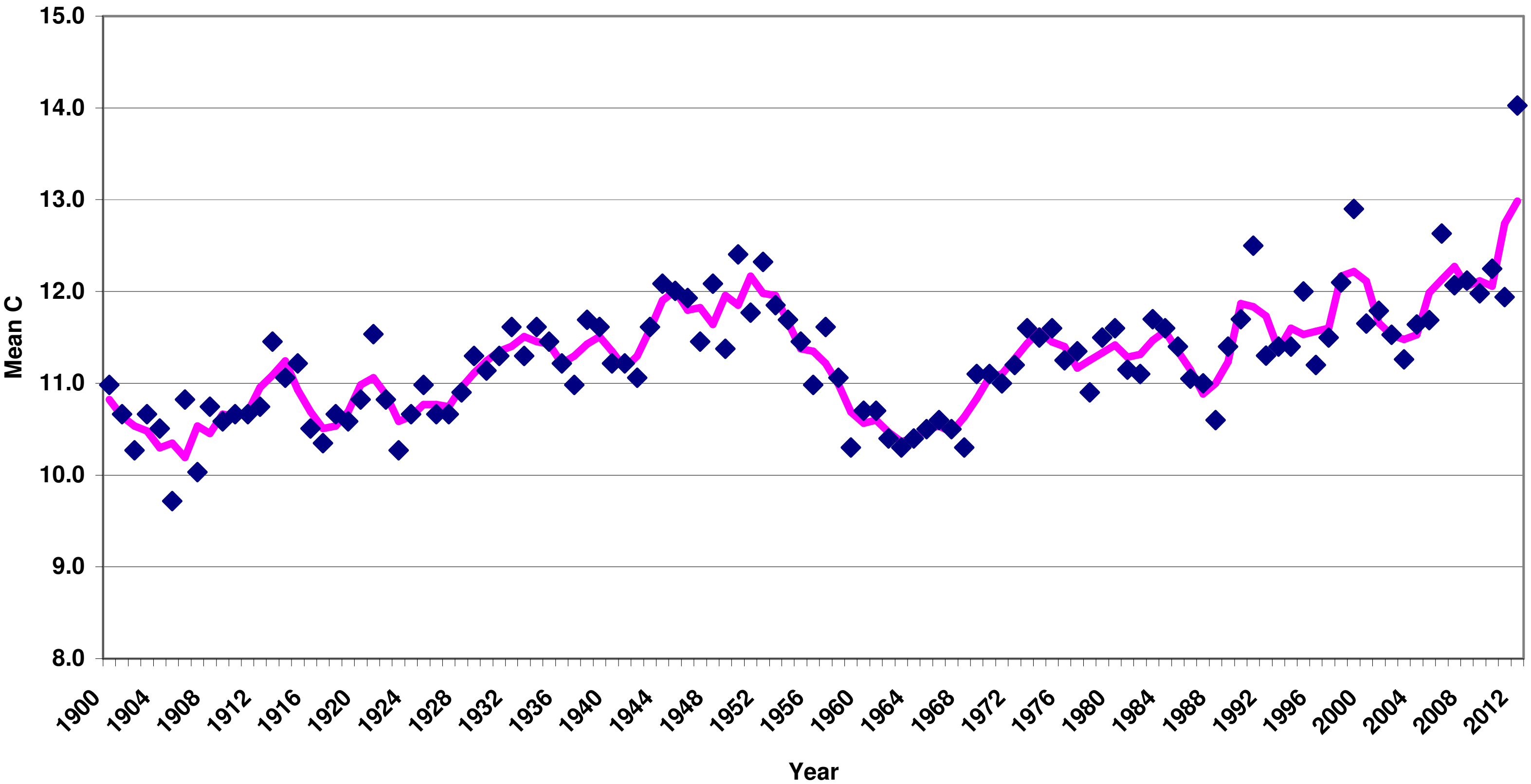


Figure 12- Rhode Island Landings of Winter Flounder Used in the BDM Assessment
Metric Tons
2500
2000
1500
1000
500
0
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
Year
Commercial
Recreational
Discards

Figure 13- Long-Term Sea Surface Temperatures in the RI Area



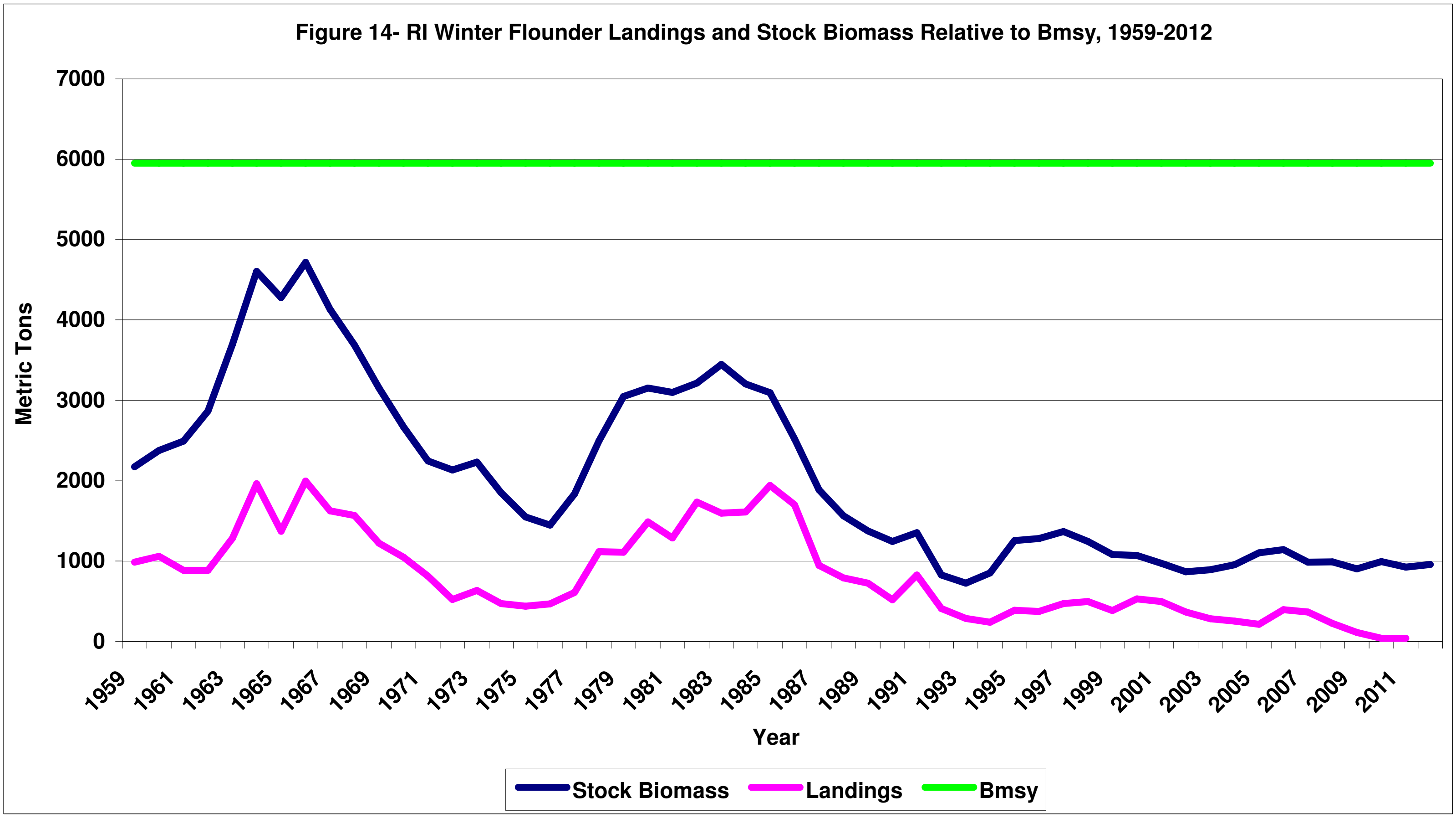


Figure 14- RI Winter Flounder Landings and Stock Biomass Relative to Bmsy, 1959-2012
Metric Tons
7000
6000
5000
4000
3000
2000
1000
0
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Year
Stock Biomass
Landings
Bmsy

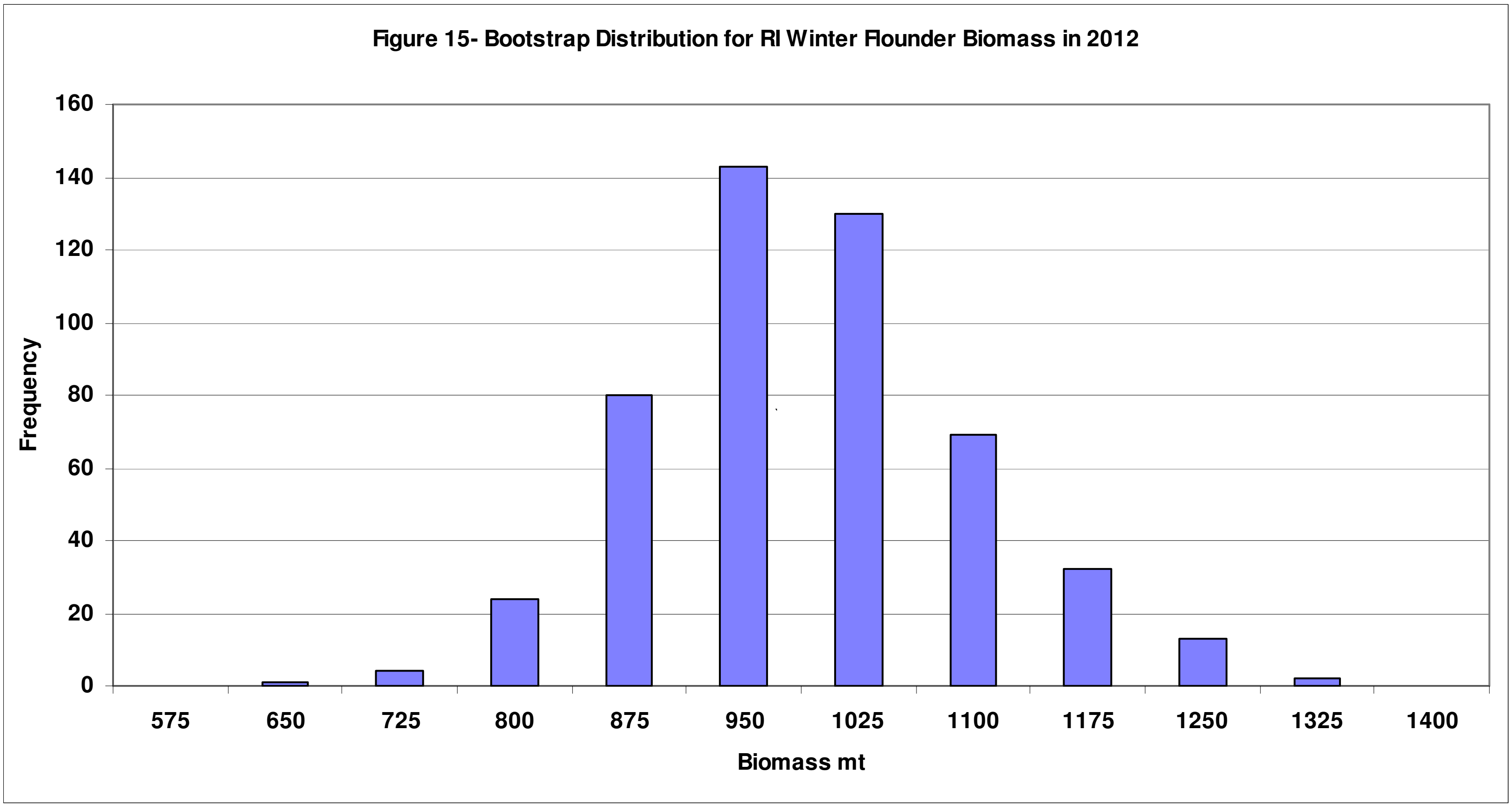


Figure 15- Bootstrap Distribution for RI Winter Flounder Biomass in 2012
160
140
120
100
80
60
40
20
0
Frequency
575
650
725
800
875
950
1025
1100
1175
1250
1325
1400
Biomass mt

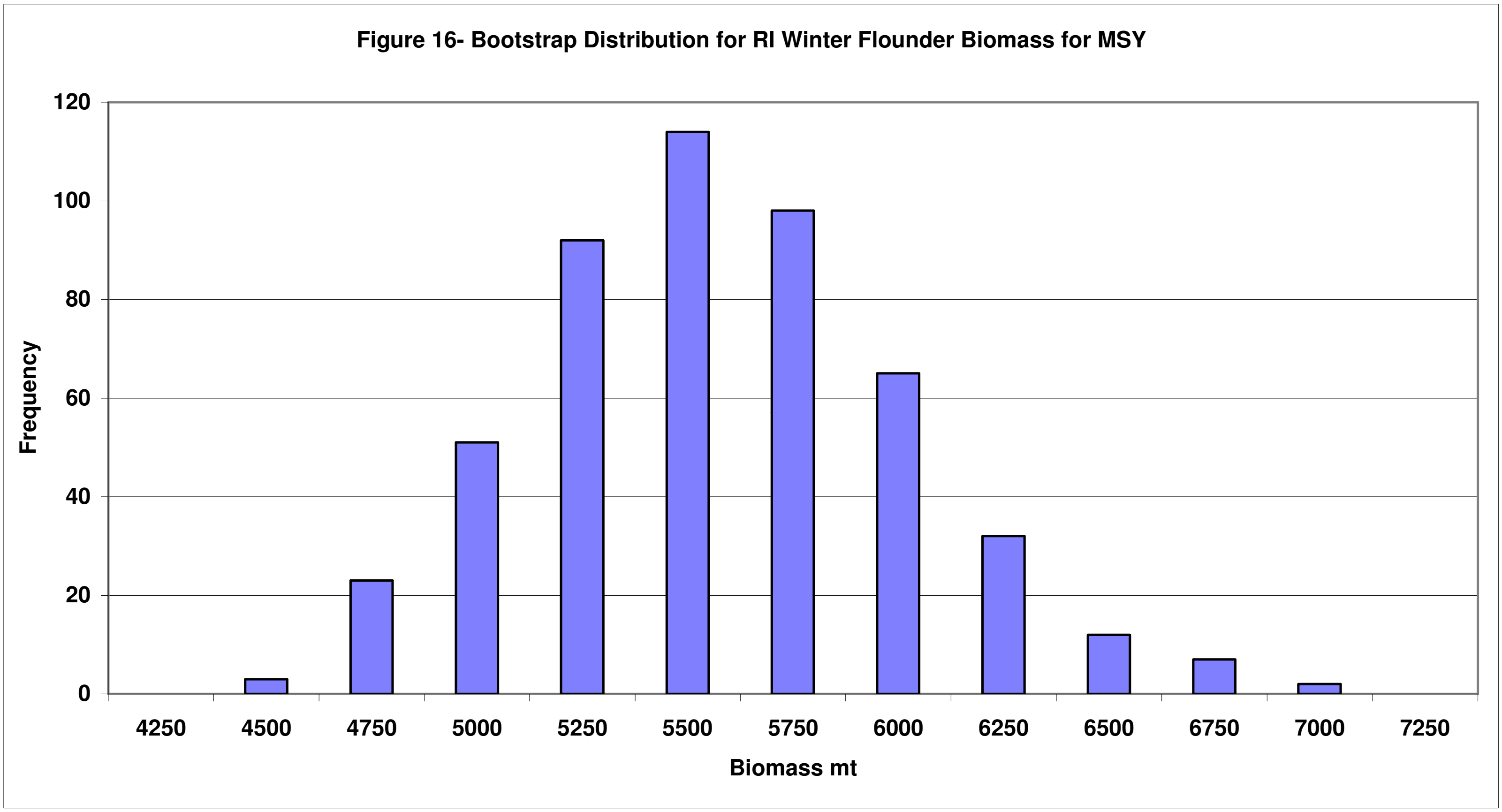


Figure 16- Bootstrap Distribution for RI Winter Flounder Biomass for MSY
Frequency
120
100
80
60
40
20
0
4250
4500
4750
5000
5250
5500
5750
6000
6250
6500
6750
7000
7250
Biomass mt

Figure 17- RI Winter Flounder Fishing Mortality Relative to Time Varying Fmsy, 1959-2011

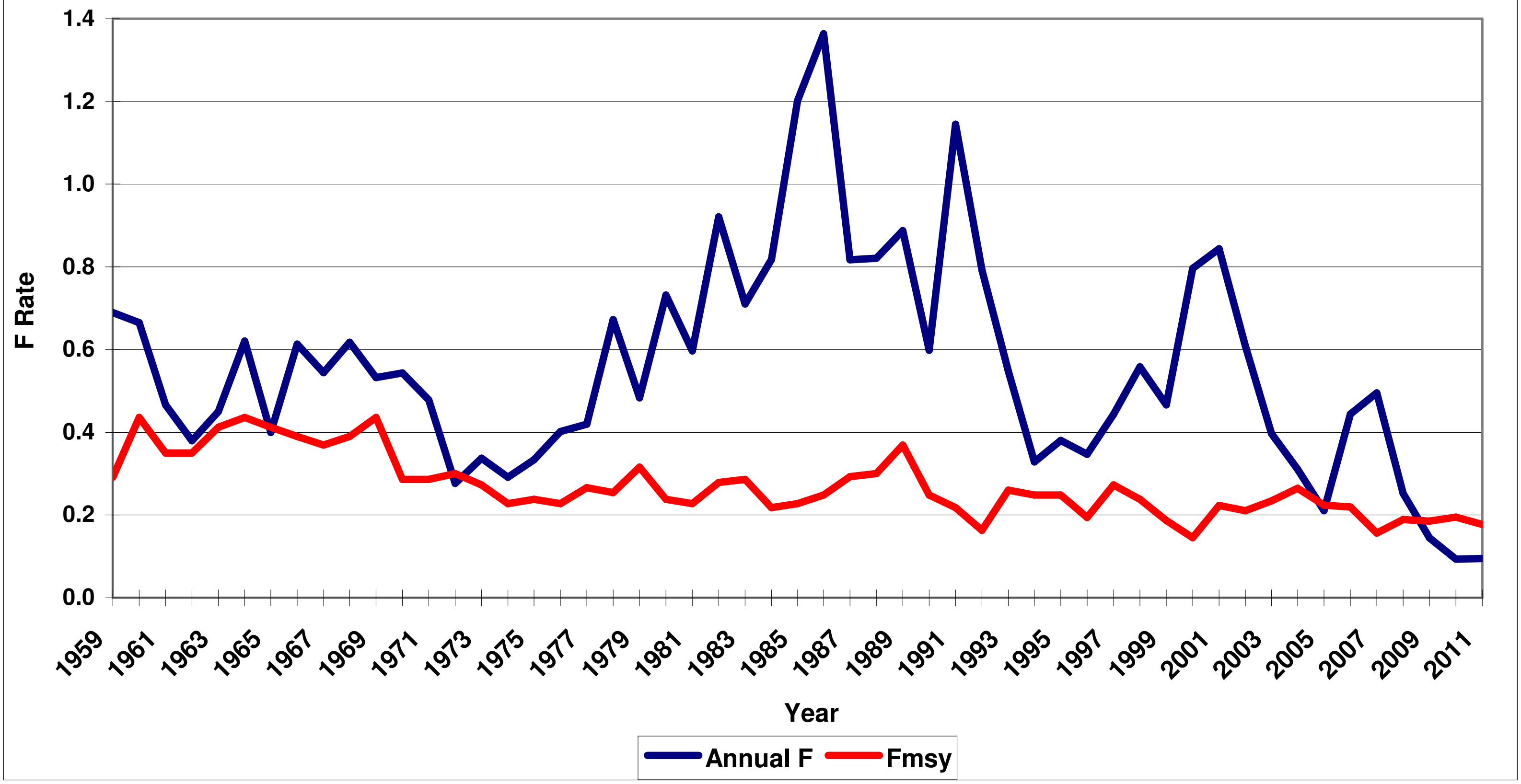
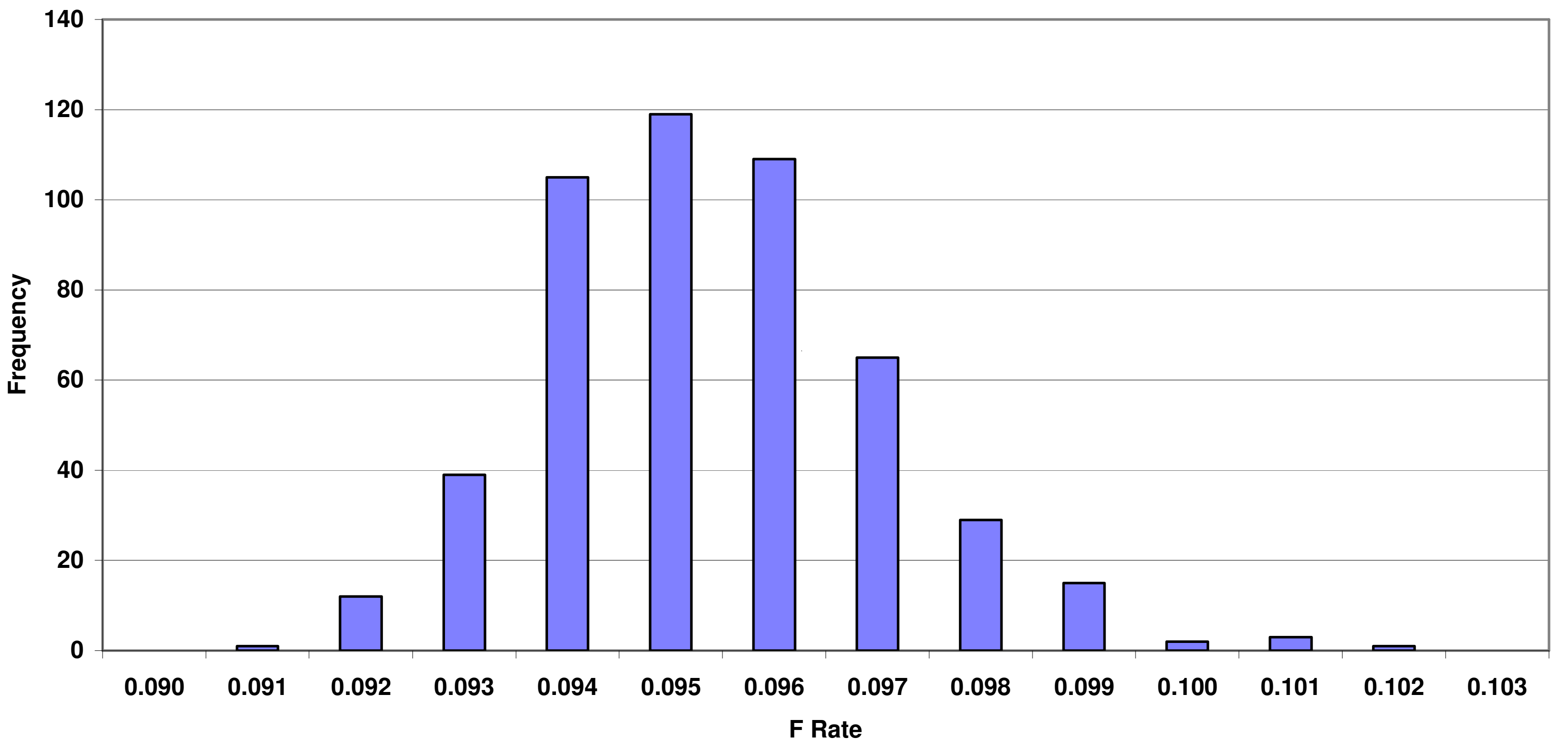


Figure 18- Bootstrap Distribution for RI Winter Flounder Fishing Mortality in 2011



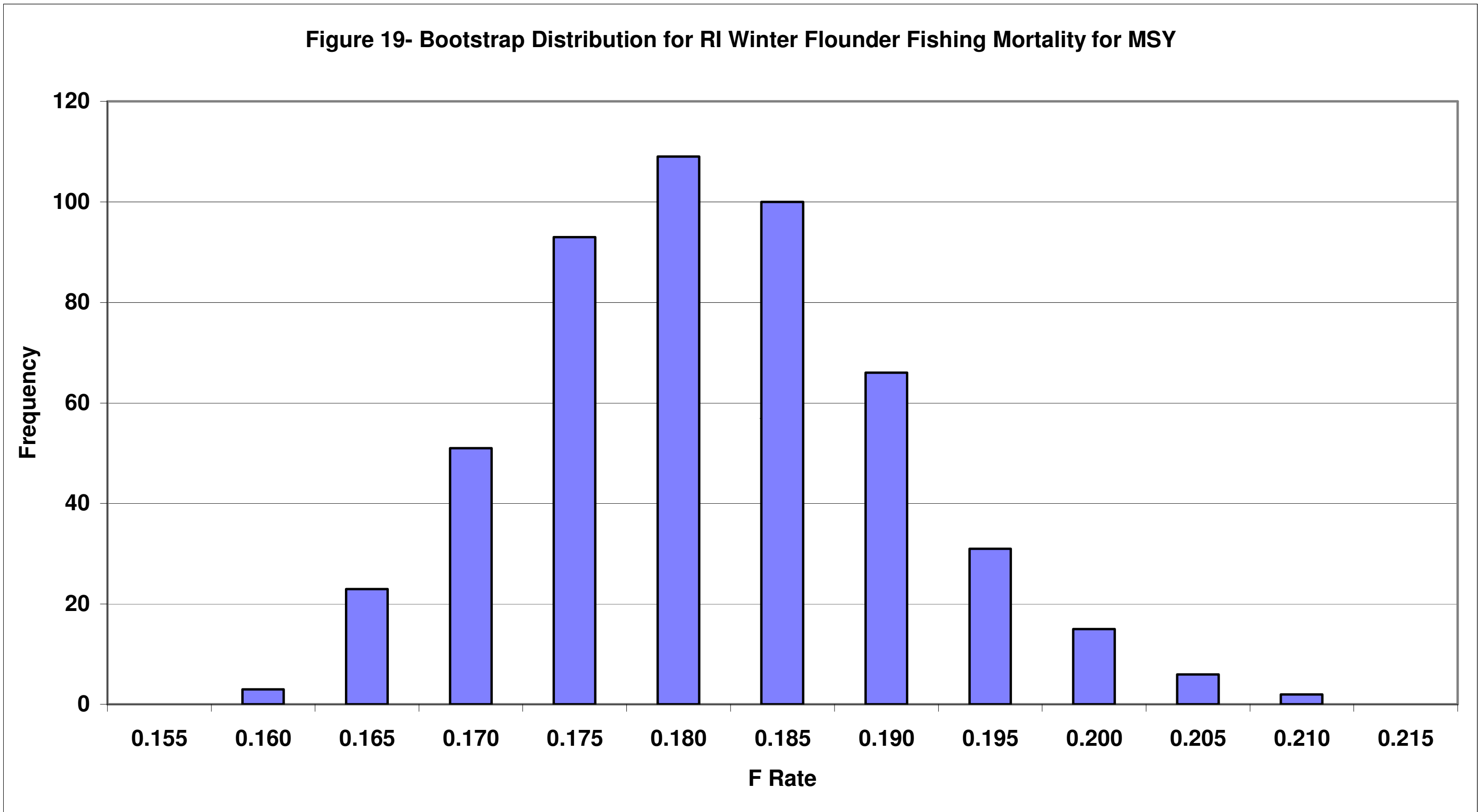


Figure 19- Bootstrap Distribution for RI Winter Flounder Fishing Mortality for MSY
Frequency
120
100
80
60
40
20
0
0.155
0.160
0.165
0.170
0.175
0.180
0.185
0.190
0.195
0.200
0.205
0.210
0.215
F Rate

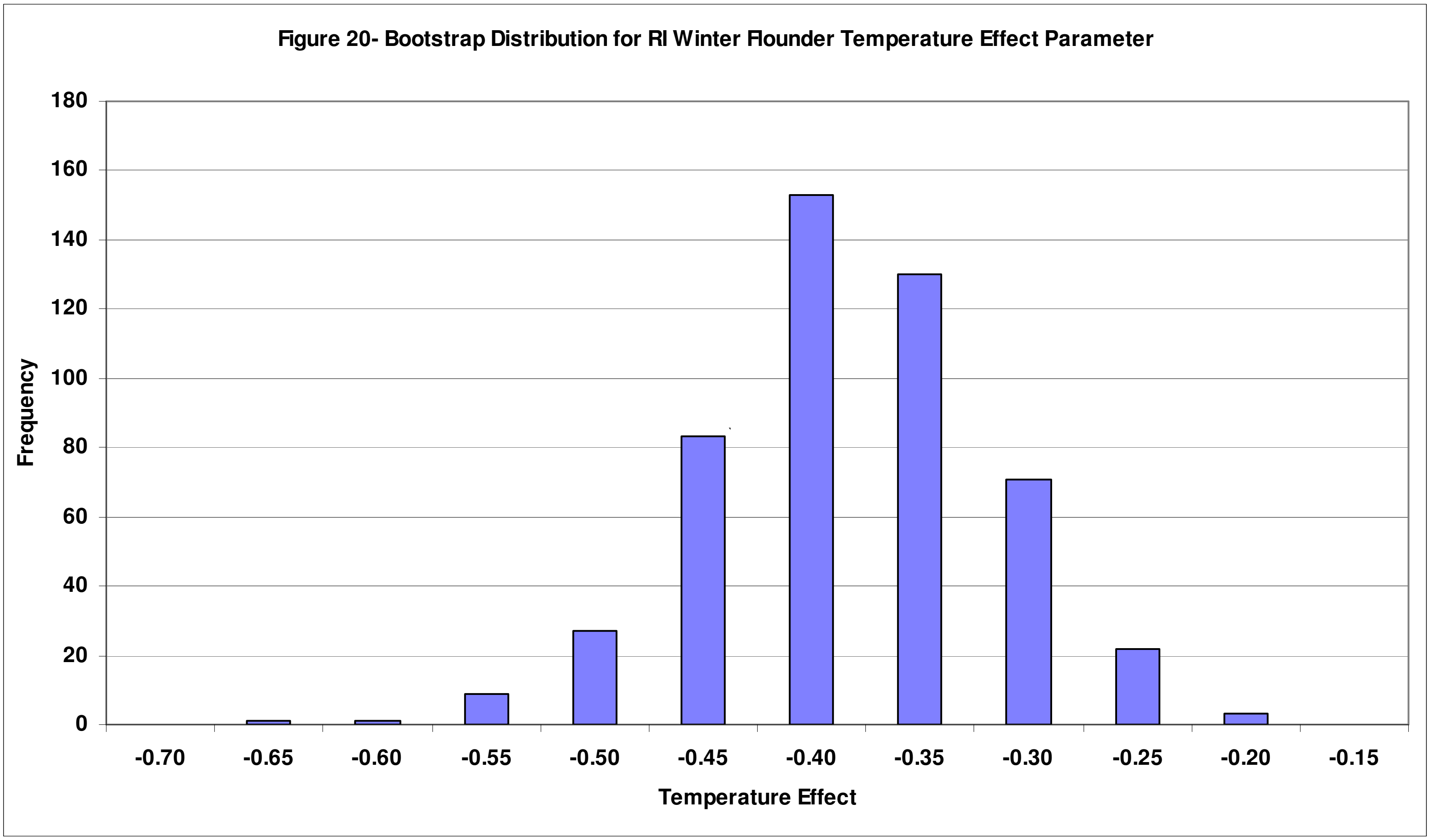


Figure 20- Bootstrap Distribution for RI Winter Flounder Temperature Effect Parameter
180
160
140
120
100
80
60
40
20
0
Frequency
-0.70
-0.65
-0.60
-0.55
-0.50
-0.45
-0.40
-0.35
-0.30
-0.25
-0.20
-0.15
Temperature Effect

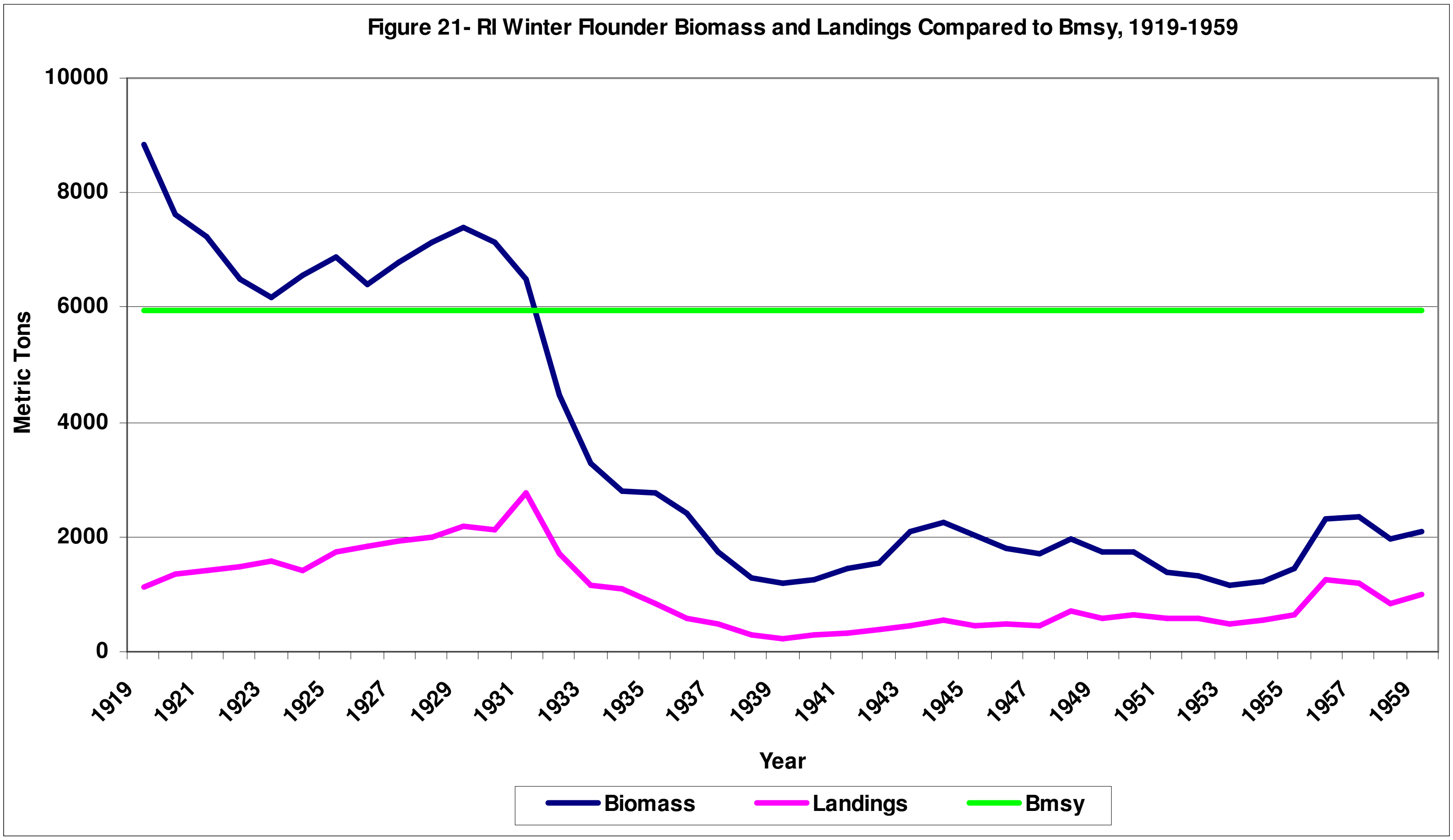


Figure 21- RI Winter Flounder Biomass and Landings Compared to Bmsy, 1919-1959
10000
8000
6000
4000
2000
0
Metric Tons
1919
1921
1923
1925
1927
1929
1931
1933
1935
1937
1939
1941
1943
1945
1947
1949
1951
1953
1955
1957
1959
Year
Biomass
Landings
Bmsy

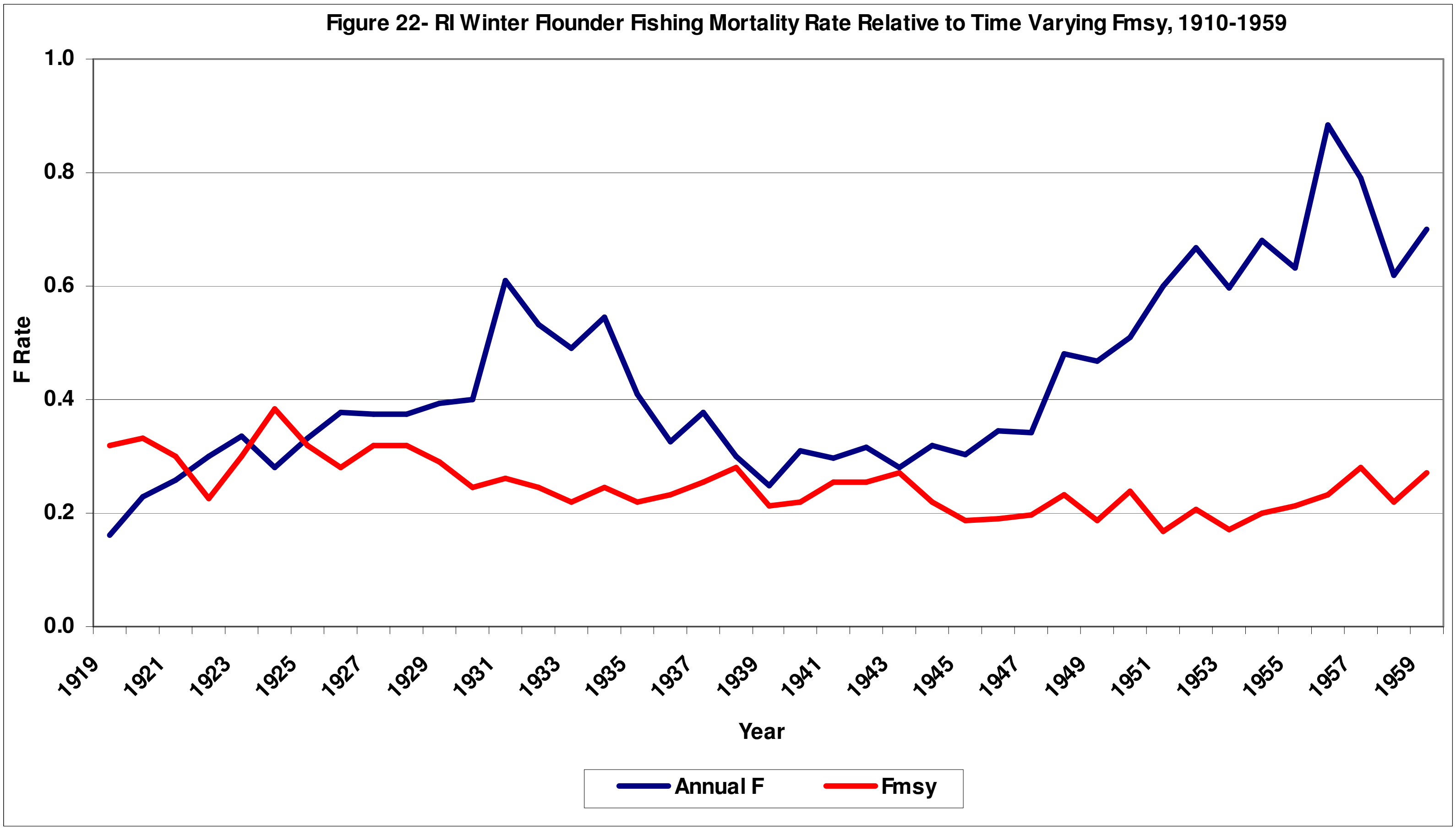


Figure 22- RI Winter Flounder Fishing Mortality Rate Relative to Time Varying Fmsy, 1910-1959
F Rate
1.0
0.8
0.6
0.4
0.2
0.0
1919
1921
1923
1925
1927
1929
1931
1933
1935
1937
1939
1941
1943
1945
1947
1949
1951
1953
1955
1957
1959
Year
Annual F
Fmsy

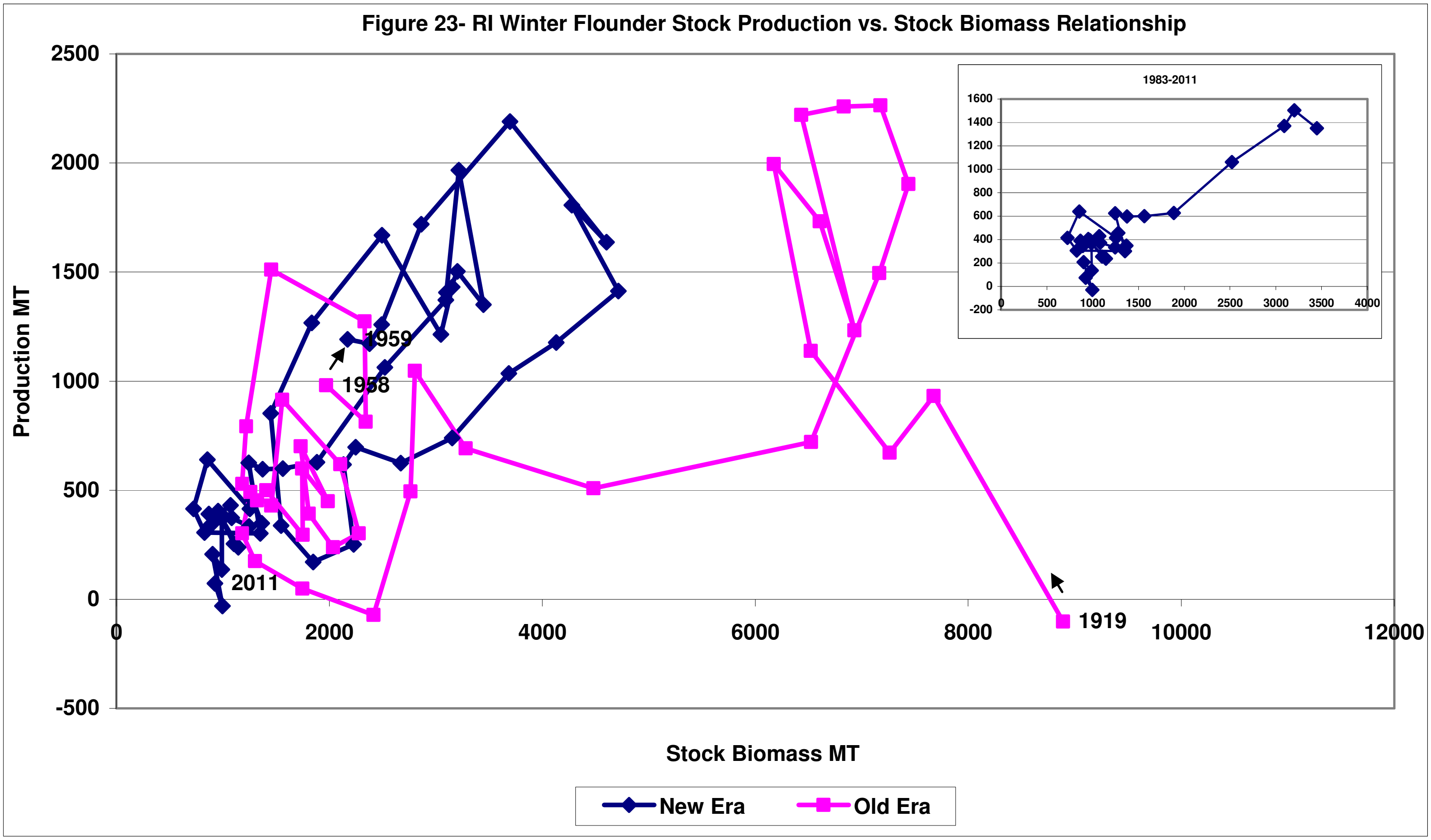


Figure 23- RI Winter Flounder Stock Production vs. Stock Biomass Relationship
Production MT
Stock Biomass MT
2500
2000
1500
1000
500
0
-500
0
2000
4000
6000
8000
10000
12000
1959
1958
2011
1919
1983-2011
New Era
Old Era

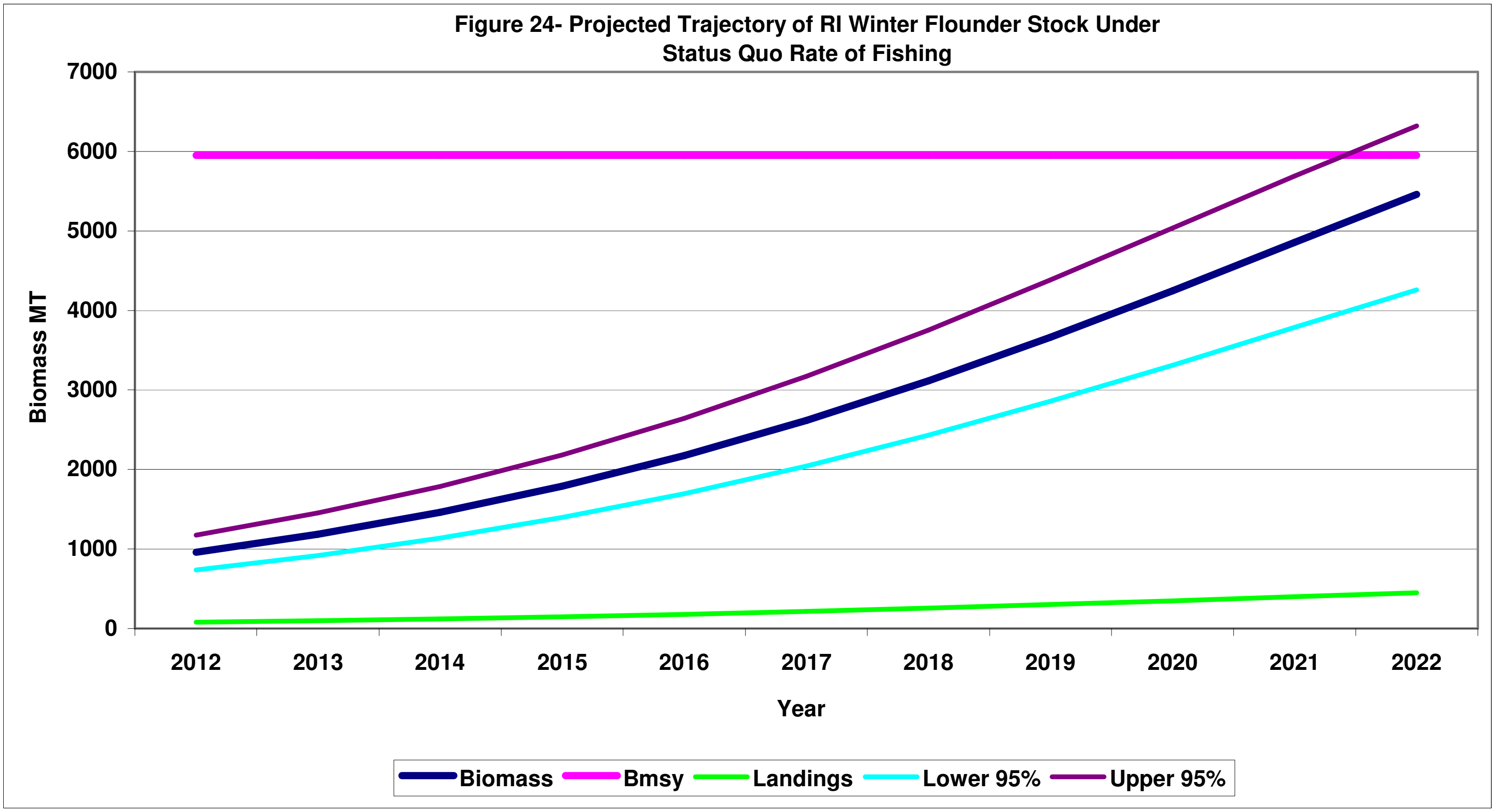


Figure 24- Projected Trajectory of RI Winter Flounder Stock Under Status Quo Rate of Fishing
Biomass MT
7000
6000
5000
4000
3000
2000
1000
0
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Year
Biomass
Bmsy
Landings
Lower 95%
Upper 95%

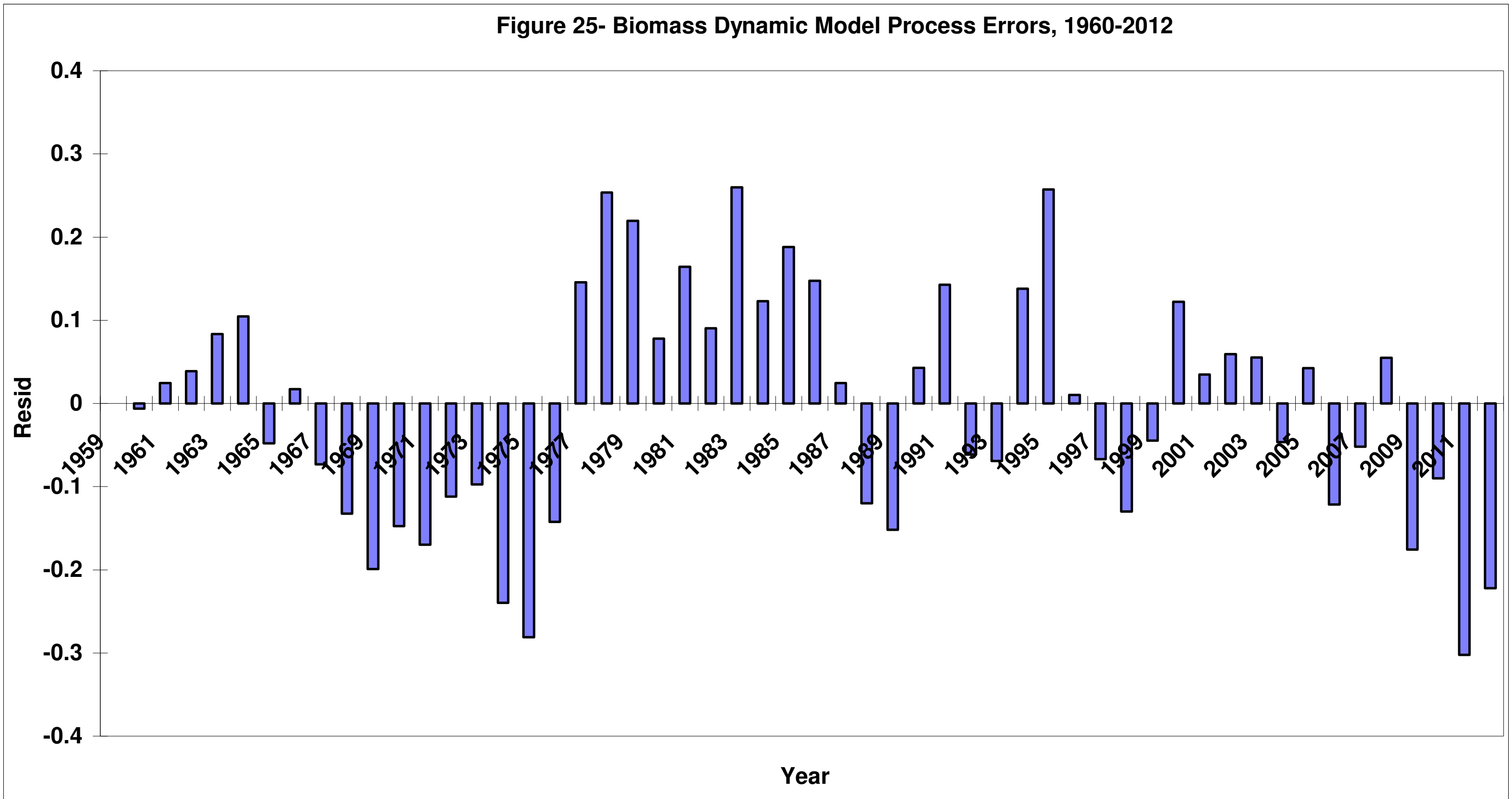


Figure 25- Biomass Dynamic Model Process Errors, 1960-2012
Resid
Year
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011

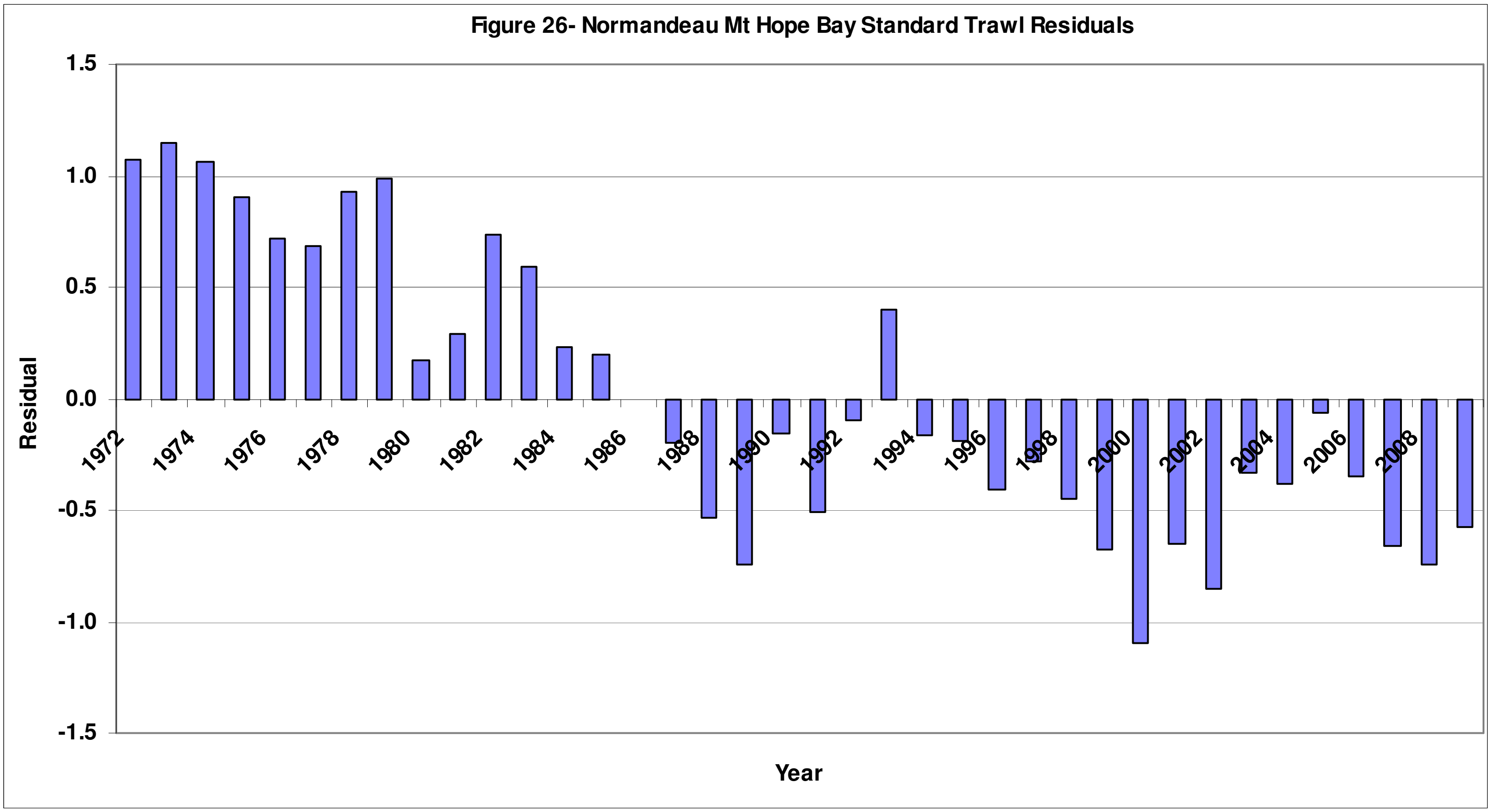


Figure 26- Normandeau Mt Hope Bay Standard Trawl Residuals
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Residual
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
Year

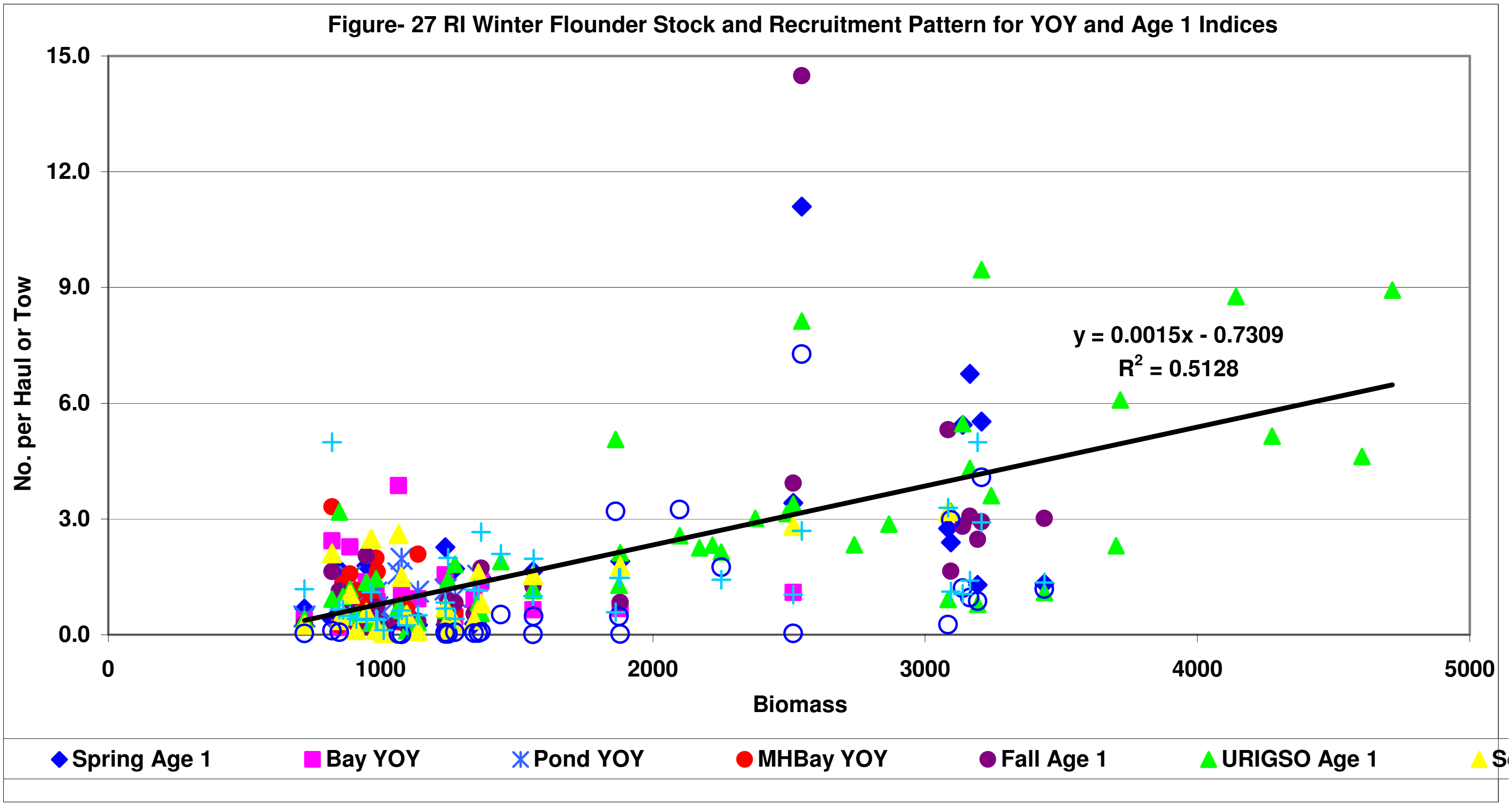


Figure- 27 RI Winter Flounder Stock and Recruitment Pattern for YOY and Age 1 Indices
15.0
12.0
9.0
6.0
3.0
0.0
No. per Haul or Tow
0
1000
2000
3000
4000
5000
Biomass
y = 0.0015x - 0.7309
R2 = 0.5128
Spring Age 1
Bay YOY
Pond YOY
MHBay YOY
Fall Age 1
URIGSO Age 1

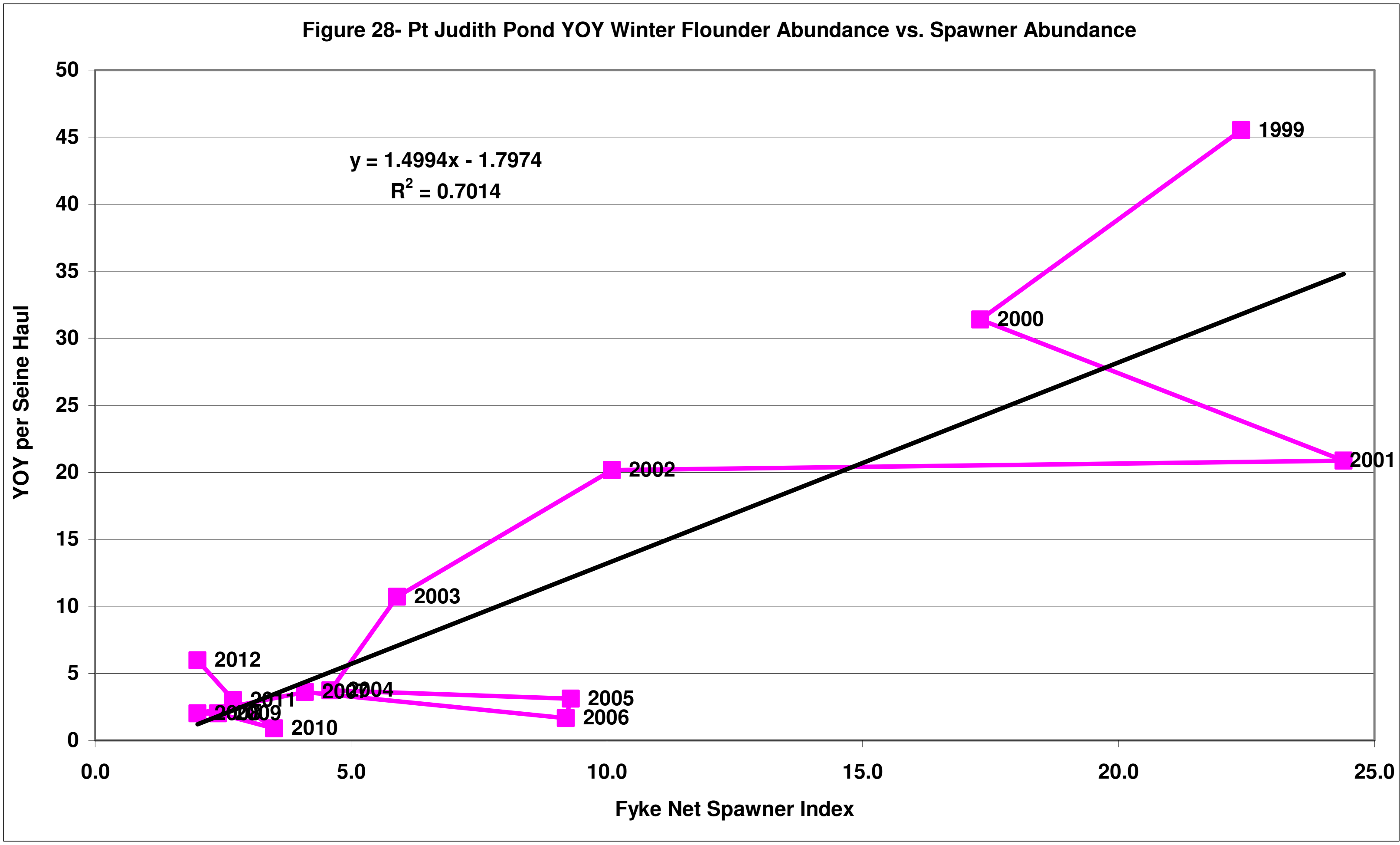


Figure 28- Pt Judith Pond YOY Winter Flounder Abundance vs. Spawner Abundance
y = 1.4994x - 1.7974
R2 = 0.7014
YOY per Seine Haul
Fyke Net Spawner Index
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
0
5
10
15
20
25
30
35
40
45
50
0.0
5.0
10.0
15.0
20.0
25.0

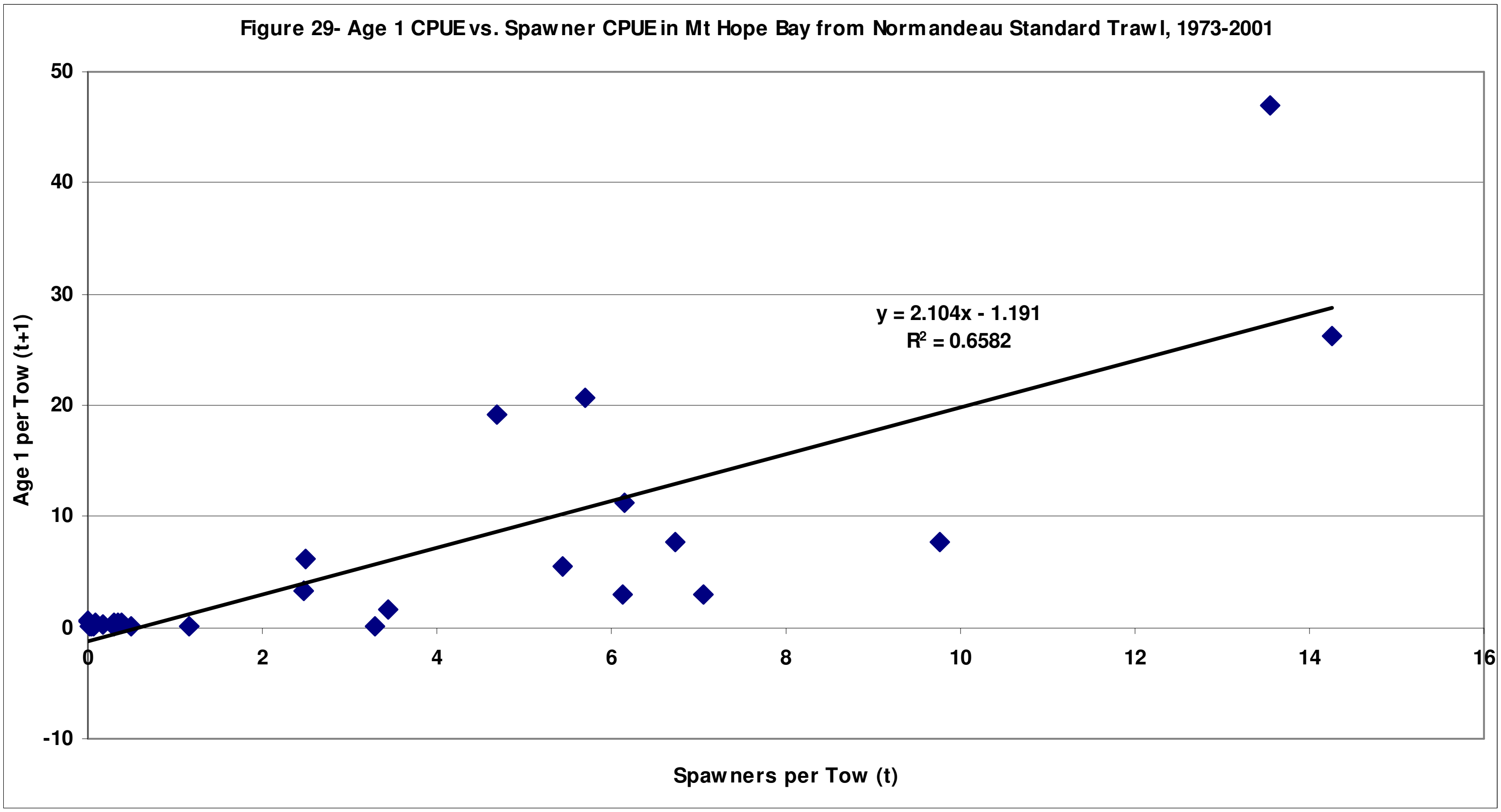


Figure 29- Age 1 CPUE vs. Spawner CPUE in Mt Hope Bay from Normandeau Standard Trawl, 1973-2001
y = 2.104x - 1.191
R2 = 0.6582
Age 1 per Tow (t+1)
Spawners per Tow (t)
50
40
30
20
10
0
-10
0
2
4
6
8
10
12
14
16

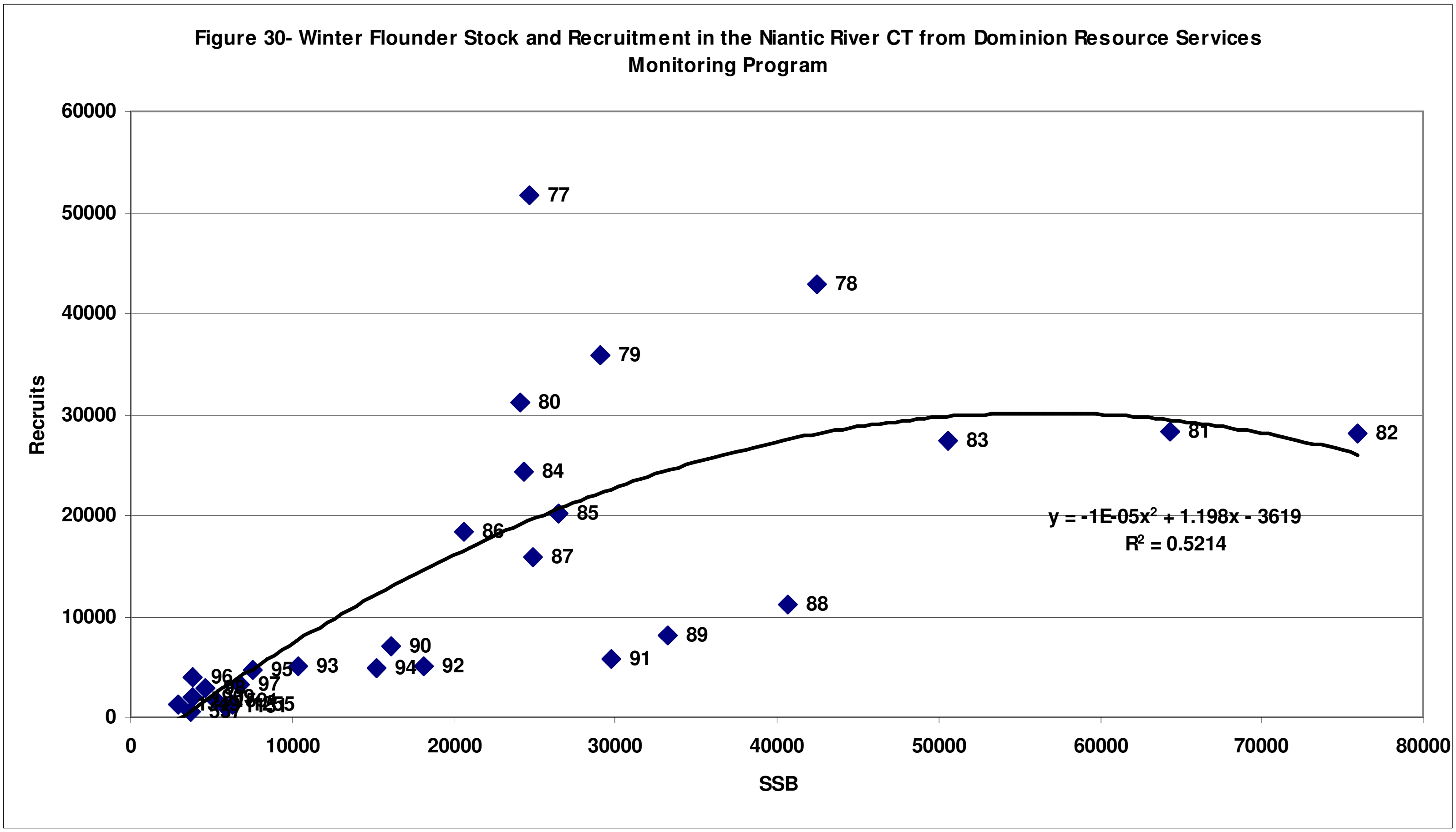


Figure 30- Winter Flounder Stock and Recruitment in the Niantic River CT from Dominion Resource Services Monitoring Program
Recruits
SSB
y = -1E-05x2 + 1.198x - 3619
R2 = 0.5214
60000
50000
40000
30000
20000
10000
0
10000
20000
30000
40000
50000
60000
70000
80000
77
78
79
80
84
85
86
87
88
89
90
91
92
93
94
95
96
97
81
82
83

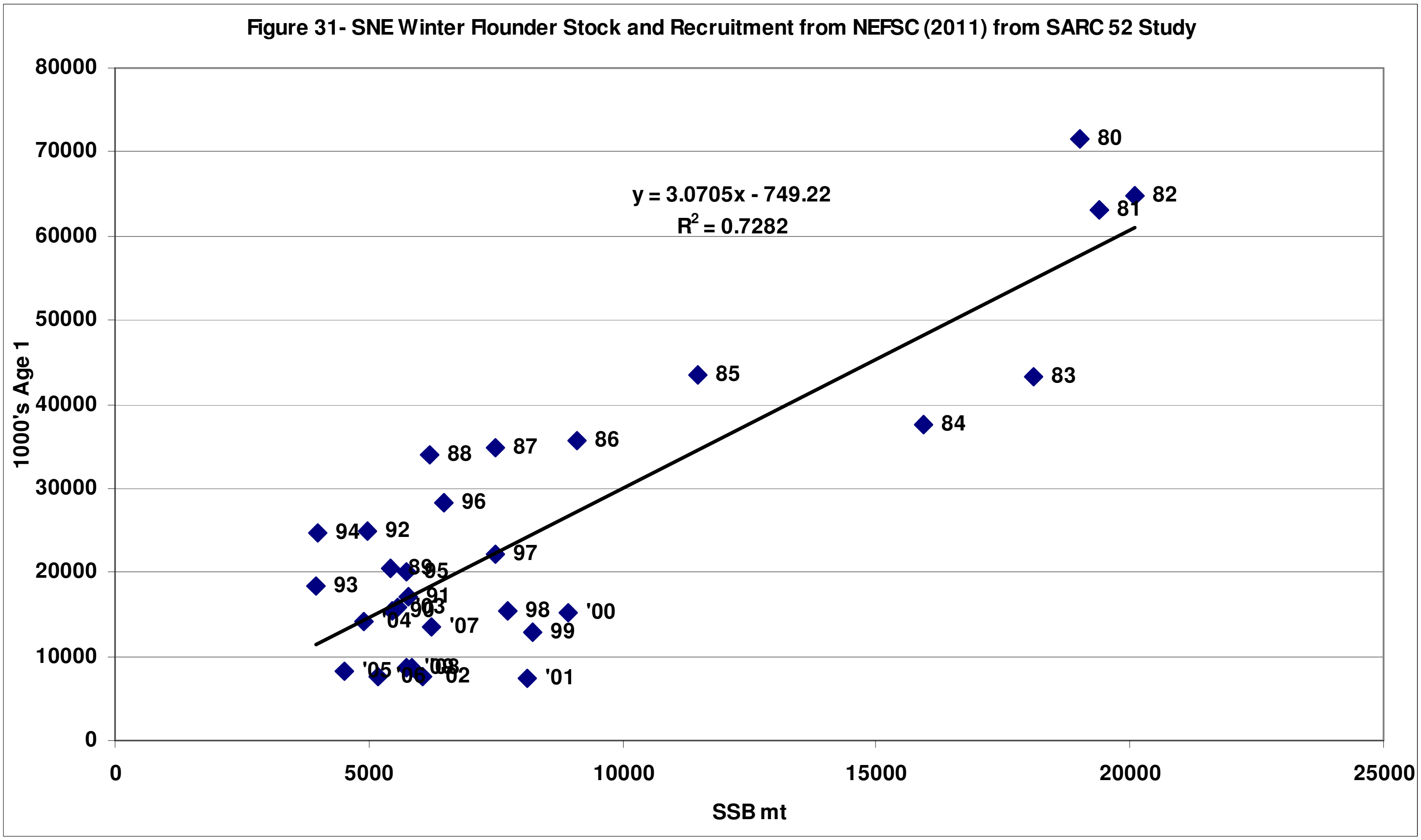


Figure 31- SNE Winter Flounder Stock and Recruitment from NEFSC (2011) from SARC 52 Study
y = 3.0705x - 749.22
R2 = 0.7282
1000's Age 1
SSB mt
80000
70000
60000
50000
40000
30000
20000
10000
0
5000
10000
15000
20000
25000
80
82
81
85
83
84
88
87
86
96
94
92
97
93
95
91
98
'00
'04
'07
99
'05
'06
'02
'01

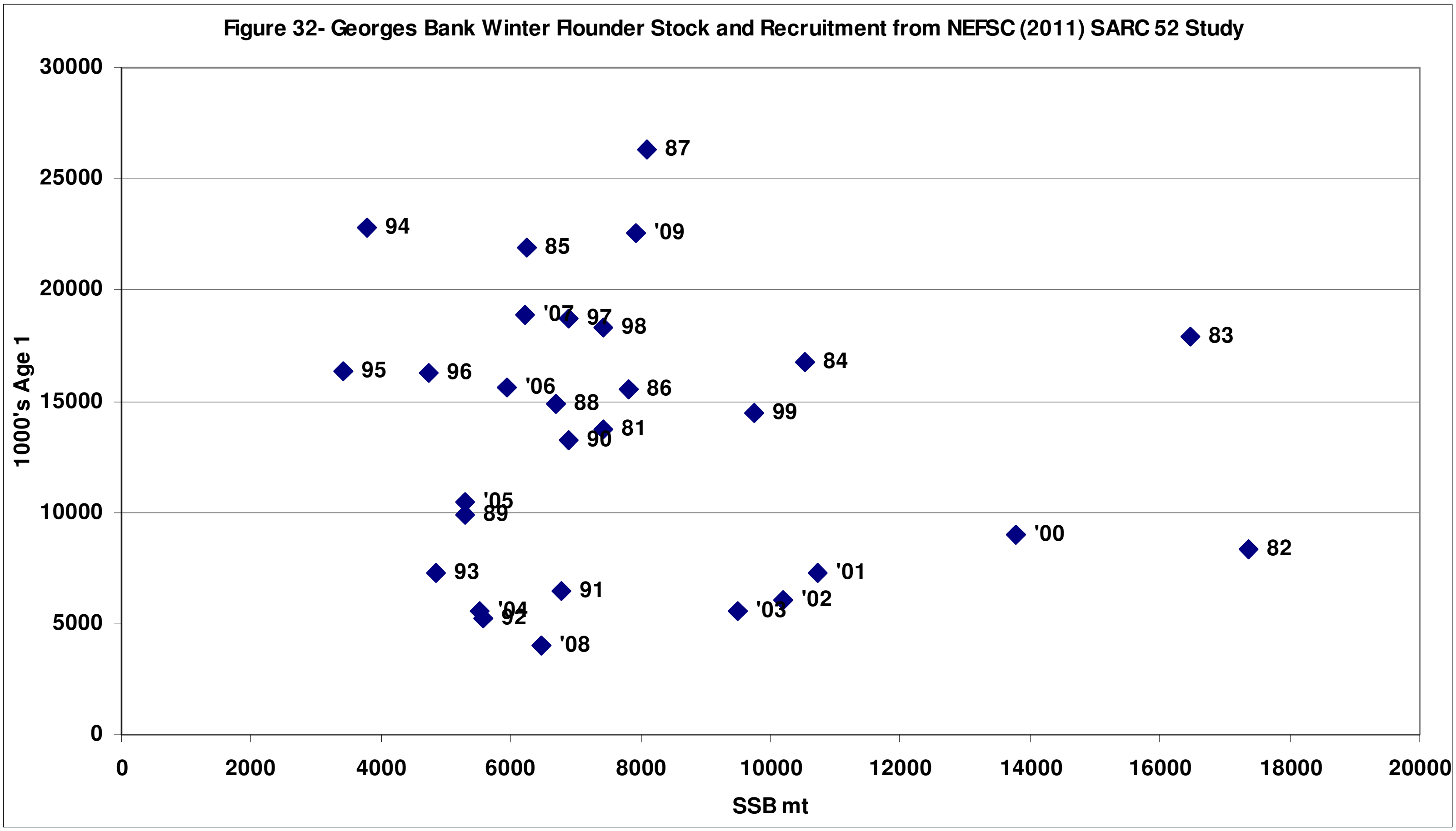


Figure 32- Georges Bank Winter Flounder Stock and Recruitment from NEFSC (2011) SARC 52 Study
1000's Age 1
SSB mt
0
5000
10000
15000
20000
25000
30000
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
87
94
'09
85
'07
97
98
83
95
96
'06
84
86
88
99
81
90
'05
89
'00
82
93
'01
91
'02
'04
'03
92
'08

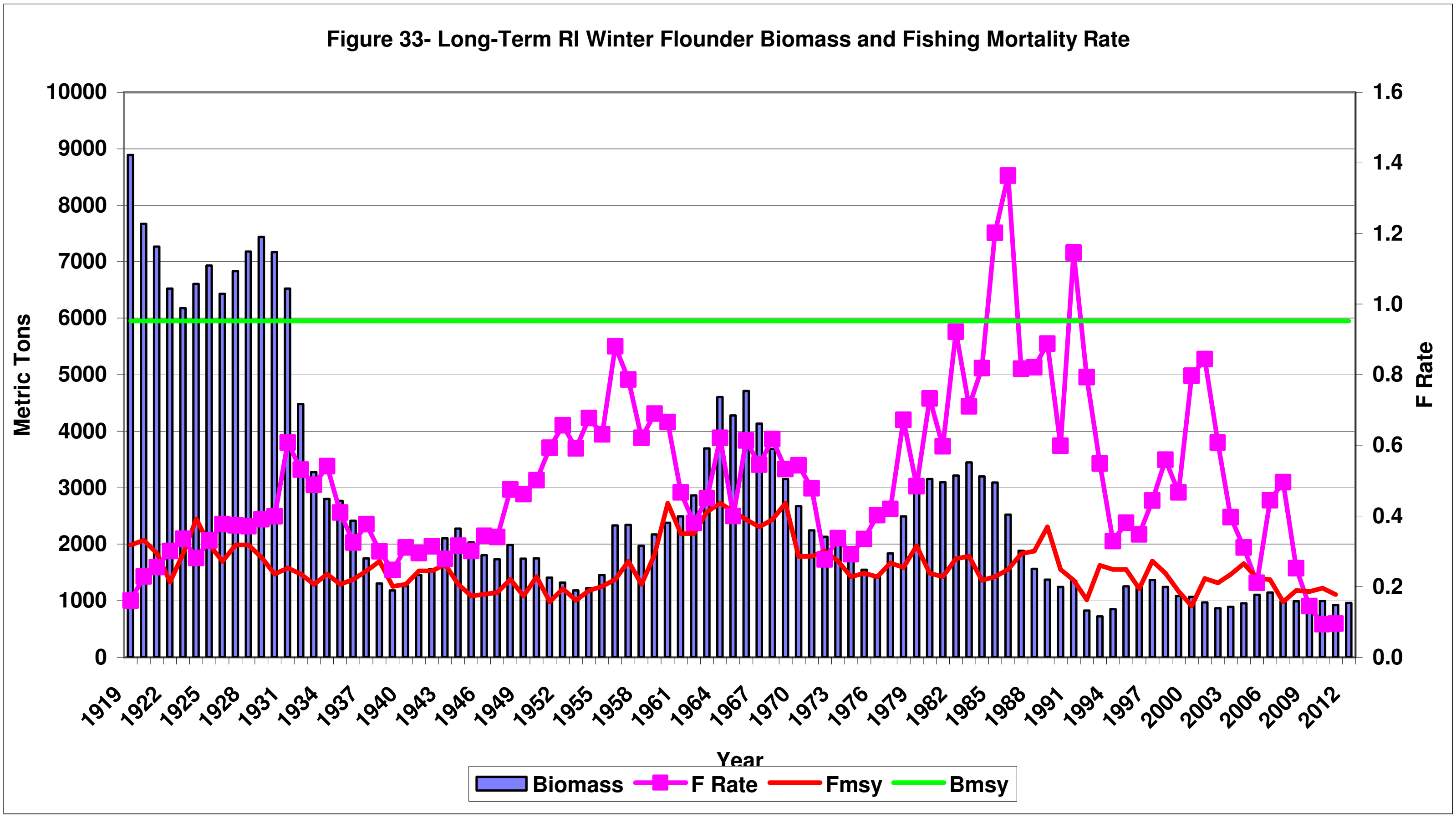


Figure 33- Long-Term RI Winter Flounder Biomass and Fishing Mortality Rate
Metric Tons
F Rate
Year
Biomass
F Rate
Fmsy
Bmsy