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Investigating the effects of variation in surplus production, stock biomass, catch and climate on the Grand Bank yellowtail flounder population.

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Abstract

We examined a 38 year time series of biomass, surplus production and nominal catch of yellowtail flounder on the Grand Bank in NAFO Divisions 3LNO, for the period 1969-2006. Annual surplus production and annual average stock biomass were generated using a Schaefer surplus production model from the computer software program ASPIC commonly used by NAFO Scientific Council to assess stock trends and yields for the fishery. The relationships between surplus production, biomass and catch were explored. High surplus production often coincided with low biomass (and low surplus production at high biomass) as expected from the surplus production model assumption of density dependence. However, this trend was not always clear when an semi-independent estimate of surplus production was used in the analysis indicating the factors other then density dependence could be influencing the production indices.

We also explored the effects of large scale and regional scale environmental variability on surplus production, stock biomass and nominal catches from the fishery using correlation and multiplicative regression analyses. The results suggest that biomass, but not surplus production, was influenced by the negative phase of the NAO which is associated with warm bottom temperatures on the Grand Bank. Both surplus production and stock biomass estimates of yellowtail flounder were strongly influenced by regional scale bottom temperatures on the Grand Bank suggesting that stock enhancement occurs during warm periods. Long term changes in stock biomass are often explained by changes in fishing mortality, but now there is evidence to suggest that productivity in yellowtail flounder on the Grand Bank also varies in response to environmental variations. The strength of the temperature relation suggests that it should be considered for incorporation into the logistic surplus production model used in the assessment of yellowtail flounder on an annual basis.

Introduction

Annual surplus production (ASP) is the amount of biological production, i.e. net result of recruitment growth and natural mortality, to be fished in a given year without affecting the biomass of the stock. In the absence of a fishery it would simply be the change in stock biomass from one year to the next. When it is fished then the catch is entered into the equation for calculating ASP. ASP is important to fisheries management since ASP, stock biomass and catch are closely related (Jacobsen et al. 2002). According to the production model assumptions, biomass should increase in those years when the catch is less than the ASP and decrease in those years when catch exceeds ASP. ASP is closely related to the projected yield used in TAC management. Relationships between biomass, and ASP and hence catch may be density dependent (variable over stock sizes) or density independent (variable due to environmental effects) or both.

Yellowtail flounder have been classified as depth seekers, preferring shallow water depths and tolerating wide fluctuations in temperature and salinity (Scott 1982; Walsh 1992; Perry and Smith 1994). During the past decade there have been several analyses on the effects of environmental variation on abundance and spatial variation of various life stages of the Grand Bank yellowtail flounder stock.

Walsh et al. (2004) examined the spatial structure and environmental characteristic defining the nursery habitat and their relationship to recruitment variability, population size and stock resiliency to over-exploitation. Density and depth played the most influential role affecting spatial variation of juveniles in the nursery area when compared to temperature, sediment type, location and salinity. Salinity, but not temperature was significantly (negatively) correlated with recruitment variability. Simpson and Walsh (2004) modeled the changes in spatial structure of the adult population using environmental covariates of temperature, depth, sediment type, density and location from the 1975-2001 Canadian surveys. During periods of low abundance when the population was contracted and aggregated in the southern Grand Bank the environmental covariates had less influence on spatial variation. Similarly Brodie et al. (1998) found that the area occupied by yellowtail flounder from 1975-1995 was correlated with abundance but not temperature and although no linear associations were investigated with depth, it was shown that when the stock was lowest it was found in greater frequency in shallower waters than when the abundance was high. Simpson and Walsh (2004) showed that during periods of high abundance when the population expanded into the northern Grand Bank the environmental covariates had more influence on spatial variation. At high abundance, depth had the most influence (38%) on spatial variation when compared to temperature (19%) and sediment type (2%).

Colbourne and Walsh 2006, following on the investigations by Colbourne and Bowering 2001, analyzed the near-bottom temperatures on the Grand Bank in relation to the spatial distributions and abundance of yellowtail flounder for the years 1990 to 2005. They reported that a shift in the thermal habitat from the cold sub-zero ^{o}C conditions during the first half of the 1990s to a relatively warm environment during the latter half of the 1990s and early 2000s resulted in an increase in bottom temperatures to >0^{o}C values over almost 100% of the traditional bottom habitat of yellowtail flounder. A strong linear association was found between bottom temperatures and mean catches rates on the southern Grand Bank with catch rates increasing with temperatures. Coincidental with this thermal shift in the second half of their time series, the population had increased in abundance and expanded into the northern Grand Bank as reported by Walsh and Simpson (2004; see also Walsh et al. 2007)

Spatial and temporal patterns in the catches of the Canadian fleet in the 2004 fishery were investigated using traditional tag returns, and temperature and depth data from data storage tags along with near-bottom temperature data from an oceanographic mooring on the Grand Bank (Walsh and Brodie 2006). The authors reported a temporal shift in the spatial pattern of the fleet with catches being taken in shallower depths and localized to the Southeast Shoal area in the winter when compared to a more wide spread pattern of catches being taken in deeper waters during the other seasons. They also reported a temperature trend in catch rates with greater catches being taken in warmer waters than in colder waters.

In summary these studies support a general linkage between ocean climate and variation in recruitment, distribution, abundance and fishery of yellowtail flounder on the Grand Bank. Such linkage has been indicated in a variety of marine ecosystems (see for example Rosseig et al. 2004; Buch et al. 2004). Many of these recent yellowtail flounder studies used time series indices ranging from 1 to 30 years and many of the analyses were based only on Canadian survey data with only one analysis using fishery and experimental data collections. An all more inclusive study of the influence of climate on productivity in yellowtail flounder on the Grand Bank using data sources other than trawl surveys has not been attempted. The annual NAFO Scientific Council stock assessment of yellowtail flounder is carried out using a non-equilibrium surplus production model (ASPIC, Prager 1994, 1996) applied to nominal catch and survey biomass indices for the time period 1965-2006 (Walsh et al. 2006). Meteorological and oceanographic data data exists for the same time period.

In this paper we investigate the variation in annual surplus production and stock biomass of yellowtail flounder on the Grand Bank using the output from the ASPIC production model, and we also evaluate the effect of climate variability on these production indices at various temporal and spatial scales.

Material and Methods

Surplus production model

We fitted a Schaefer surplus production model (Schaefer 1954) which assumes logistic population growth in which the rate of increase or decrease in stock biomass over time is a quadratic function of the current biomass in the absence of a fishery. For a fished stock the rate of change is also a function of catch. This ASPIC surplus production model estimates surplus production that exactly match predictions, i.e. it is an all-measurement (estimation) error model (Prager 1994). This type of model assumes that any lack of fit is not due to natural variability in surplus production but due to measurement errors in the data (see Jacobsen et al. 2002 for a discussion). The model assumes non-equilibrium conditions since the probability that fished stocks reaching equilibrium, i.e., when yield equals surplus production, is low. However, it assumes a relationship between surplus production and stock biomass as seen in Figure 1 where surplus production is zero at zero biomass levels and at carrying capacity (K) and estimates the biomass (B_{msy}) at which maximum surplus production occurs (i.e. MSY).

In fitting the production model with the ASPIC computer program we used a time series of nominal landings (no estimate of discards included) from the fishery and survey biomass indices of the yellowtail flounder for the period 1965 to 2006. The input and output data is taken from the 2006 NAFO assessment of this stock (see Walsh et al 2006 for model formulation, time series of indices and output estimates). The model is tuned with survey biomass indices while simultaneously estimating model parameters. The model estimates the 'adult' stock biomass, surplus production and fishing mortality for each year.

The estimated annual average stock biomass that produced the annual surplus production was taken from the 2006 ASPIC model output and used to investigate the relationship between surplus production, stock biomass and catch. ASPIC measures the absolute estimates of fishing mortality and biomass less precisely than the biological reference points MSY and Fmsy because of uncertainty in the estimates of catchability coefficient 'q' (relative interquartile range IQR is 17 to 24%) so the more precise relative index of stock biomass B/B_{msy} (IQR is 13%) which is used as the relative biomass index in analyzing trends in the stock for the assessment, was also used in these investigations (see Walsh et al. 2006 for bootstrapped output parameter estimates and variances). However, as seen in Figure 2 there is a strong predictive relationship ($r^2 = .9776$) between absolute stock biomass and relative biomass because B_t is standardized to the B_{msy} estimated by the current model run. For ease of discussion we used the average stock biomass (similar results would be obtained with relative biomass using B/B_{msy}). Since the starting estimate of stock biomass in the first year is very imprecise and biased, Prager (1994) recommended not making inferences from the ASPIC surplus production model for the first 2- 4 years of the time series. We adopted a conservative approach of 4 years and used model output data only for the years 1969-2006.

An independent estimate of stock biomass, e.g., from an SPA was not available whereby annual surplus production could be calculated external from the ASPIC model and then compared with the estimate from the ASPIC model. Thus all production indices used in the ASPIC output and used in the analysis are not entirely independent. Realizing this we also created a second annual surplus production index which we called the 'observed ASP or OASP" which uses the estimated average biomass from ASPIC model output and the nominal fishing catch (again realizing that these are still not strictly independent) in the following formulation:

$$OASP_t = B_{t+1} - B_t + \delta C_t \qquad (1)$$

where δ is a correction factor that accounts for growth and mortality that would have taken place between the time the catch was taken and next year's average biomass. Jacobsen et al. (2001) reported that for many commercial demersal stocks this correction factor was close to 1 and for our analysis we assumed it was 1.

Environment

We examined the relationship between production and both regional and large scale environmental indices to investigate the effect of climate variation on surplus production, stock biomass and fishery catches for yellowtail flounder.

Recruitment to the current yellowtail fishery was set at 25 cm based on the 25% selection length derived for the current NAFO regulated 130 mm codend mesh size (Walsh and Hickey 2000) and this corresponds to approximately to age 5 (Walsh unpubl. data). Our analysis covers the period 1969 to 2006 and mesh sizes prior to 1982 would have been smaller and larger in some instances.

To investigate the effects of environmental conditions on recruitment and growth of juveniles and adult stages we used regional and large scale indices averaged over the previous 5 years to match the time period of recruitment to the fishery at age 5. The moving average of 5 years should reflect environmental conditions during the juvenile stage to recruitment stage (ages 1-5 yrs).

For long scale environmental analysis we used the annual NAO index and for the regional scale data we used the annual temperature (integrated over 0-175 m) and salinity (integrated over 0-50m) indices from DFO/NAFC 's Station 27 monitoring station. Environmental conditions at Station 27 are fairly representative of trends in conditions over a large part of the Grand Banks over similar depth ranges, particularly over northern areas of 3NO and 3L.

The NAO

The strength of the winter time atmospheric circulation over the north Atlantic largely determines ocean climate variations through much of the year on the Newfoundland and Labrador Shelf accounting for about 40% of the variability in the ocean climate on the shelf during the decades of the 1970s to 1990s. There are some exceptions to this trend, for example in 1999 and 2000 the Newfoundland Shelf experienced very warm conditions however the spatial patterns in the sea-level atmospheric pressure fields were such that the North Atlantic Oscillation (NAO) index was strongly positive. The standard meteorological index representing the strength of the circulation is the NAO index and is defined as the difference in the winter sea level air pressure between the quasi-stationary winter high and low pressure cells over the Azores and Iceland, respectively (Rogers, 1984). A high NAO index corresponds to an intensification of the Icelandic Low and Azores High. In most years since the 1960s when the NAO index is strongly negative, warm saline ocean conditions generally prevail in the northwest Atlantic and colder fresher conditions predominate in the northeast Atlantic; and conversely when the NAO index is high, i.e., positive.

Station 27

Ocean temperature and salinity have been measured routinely since 1946 at a standard hydrographic monitoring Station 27 located in the inshore branch of the Labrador Current on the Newfoundland inner shelf. This inshore site is representative of ocean conditions over much the Newfoundland Shelf and Grand Banks down to a water depth of 176 m.

For both the NAO, temperature and salinity data we created 5 year moving average indices to match the conditions during the time period before yellowtail flounder recruits to the fishery at age 5. That is, for the year of recruitment to the fishery we average the environmental conditions over the pre-recruit stage of the fish, i.e. includes the current year and the previous 4 years. We then created a subset of the regional scale indices for temperature and salinity by focusing on the summer spawning time period of June to August and used an annual average summer temperature and salinity index and also a 5 year moving average summer index.

Pearson's correlation analysis was used to investigate relationships between annual surplus production, stock biomass and catch and all environmental variables. A multiplicative analysis was used to investigate contributions of environmental variables to surplus production biomass and nominal catches. All analyses were carried out using Statistix version 8 analytical software.

Results and Discussion

Trends in production indices

The 1969-2006 production curve (curve of surplus production vs average biomass) is symmetrical around stock biomass, B_{msy} (79 000 mt) that can produce maximum sustainable yield (MSY) of 17 500 mt (Figure 1). Here MSY is equivalent to maximum surplus production.

Table 1 shows the correlation matrix for all production indices. Significantly positive correlations are seen in many comparisons especially with ASP from the ASPIC production model and OASP derived from Equation 1, and ASP and OASP with biomass. This fits well with the logistic model assumption that production of biomass is a deterministic function of the current biomass, i.e. density dependence. Annual surplus production is affected by biomass because fishing reduces stock biomass but increases the rate of production per unit biomass. However, a catch-biomass relationship was only moderately and positively correlated with biomass ($r = .35$; $p=.04$ level). Catch was not correlated with either ASP or OASP ($p > .05$).

Figure 3 shows the catch, and estimated stock biomass and ASP history with the latter 2 indices being estimated by the ASPIC production model for the period 1969-2006. There are 4 period of interest and in the absence of modeling any environmental data for the same time series, they are expected to represent density dependent effects based on model assumption. At the beginning of the time series, 1969-1973 the biomass showed an opposite trend with ASP because catches were larger than ASP which led to a reduction in the biomass, i.e., fishing reduces the biomass but increases the rate of production. By 1975 the stock has seen its first near-collapse. Catches remained low during the recovery period 1975-1984 as the biomass slowly rebuilt because when catches are below ASP the biomass increases. The high catches, often greater than the recommended TAC, during the 1985-1993 period contributed to the second collapse because larger catches reduced the ASP and hence the biomass which lead to the 1994-1998 fishing moratorium. During the moratorium, ASP increased leading to a rebuilding of the stock because there was no fishing to take ASP. After the start of fishing in August 1998 and onward to 2005, catches have been lower than ASP and the stock biomass has increased substantially. ASP leveled off in 1998-2000 period before dropping as catches increased with TACs and because the catches were still lower than the ASP the stock biomass continued to increase. Throughout the time series, it is apparent that ASP reaches it maximum at 17 0 00 mt, i.e., MSY based on the ASPIC formulation used in the 2006 assessment. Figure 4 summarizes the annual catch and surplus production (ASP) relationship. Before each stock collapse catches were above annual surplus production (ASP) and after each stock collapse, catches remained below ASP during the rebuilding phases.

The density dependent relationship between ASP and stock biomass was further explored by using the 'observed ASP or OASP' which uses the ASPIC estimated average stock biomass and the nominal catch. Figure 5 overlays the OASP data on the quadratic fitted symmetrical curve ($r^2 = 0.41$; $p = 0.001$) seen in Figures 1 and 4. At low biomass levels (below arithmetic mean of 63Kt (SD=30.5) as seen during the periods 1974-1984, and 1985-1998 OASP was just as equally likely to be above or below predicted OASP curve. From 1974-1984, biomass was slowly increasing at a time when catches were mainly below OASP (exception 1974 and 1975). During the 1985-1993 period catches exceeded OASP and the biomass decreased. During the 1994-1997 directed fishing moratorium, biomass increased because by-catches of yellowtail flounder were lower than OASP. Noticeably surplus biomass decreased to negative levels at low biomass levels in 1976, 1987 and 1994. The 1976 and 1994 decreases occurred when stock biomass was lowest representing possible first and second stock collapses and 1987 followed the 1985 and 1986 fishery when the nominal catches doubled the TACs (Walsh et al. 2006) and stock size was 37% below the long term average of 63 000 mt. With the resumption of the fishery in 1998 increasing biomass levels, above arithmetic mean of 63Kt, and also above the B_{msy} of 79.5kt from the ASPIC model were estimated because fishery catches still remained below OASP. From about 2000-2005 there was more or less a decreasing trend in OASP with increasing biomass.

Figure 4 summarizes the catch and surplus production (OASP) relationship. Similar to ASP catch relationship, before and after each stock collapse, catches remained above and below, respectively, annual surplus production (OASP) during the rebuilding phase. However, although the analysis of the OASP index follows the expected theory of density dependence there is more variability in the annual estimates. A lack of a clear relationship between surplus production, biomass and catches may be due to fluctuations in productivity and carrying capacity along with density dependent responses to fishing as seen in some Peruvian and Californian pelagic fisheries (Jacobsen et al. 2001) and in some groundfish stocks in the Bering Sea and Gulf of Alaska (Mueter and Megry 2006)

Environmental influences on production indices

Correlations between annual surplus production (ASP and OASP) and environmental indices were small ($r<0.5$) and only the 5 year average temperatures had any statistical significant effect on all production indices. Table 2 shows the correlation matrix of production indices and environmental indices for the period 1969-2006. For the large scale influences of climate and production indices we found a significant negative correlation between the 5 year average NAO and average stock biomass. On the regional scale we found significant positive correlations between annual and stock biomass, and the 5 year average temperature and all production indices. The NAO 5 year average index is significantly negatively correlated ($r = -0.6731$; $p=.0000$?) with the 5 year average temperature index but not with salinity($p>.05$). The NAO was mainly in a negative phase during the 1960s and when the NAO index is strongly negative, warm saline ocean conditions generally prevail in the northwest Atlantic (Fig. 6) (Colbourne 2004). Since the early 1970s the NAO has undergone near-decadal oscillations and in the most recent years it has been mostly negative. No significant correlations (P>0.05) were found with regional scale estimates of salinity and production indices. The increasing trend of biomass and temperature as seen in Figure 8 and decreasing trend with NAO in Figure 7 may reflect stock enhancement during warm periods, i.e. an increase in growth and recruitment (Hollowed and Wooster 1991; Simpson and Walsh 2004). These results are consistent with the results of Colbourne and Walsh (2006).

Model Building

With the exception of the summer indices of temperature and salinity, we included all of the environmental indices, to estimate their effects on production indices: ASP, OASP, stock biomass and catch, into separate multiplicative analysis using stepwise linear regression (no variables were forced into the model) with the following results:

1. For ASP and OASP there was a poor fit with environmental variables and inclusion of biomass and catch did not improve the fit. (r^2 <0.2) .

2. For stock biomass there was a significantly good fit with 5 year average temp (r^2=0.8818) and 5 year salinity (r^2=0.9005) and inclusion of catch and surplus production indices did not improve the fit (see Table 3).

3. For B/Bmsy there was a significantly good fit with 5 year average temp (r^2=0.8644) and 5 year salinity (r^2=0.8842). With inclusion of catch and ASP salinity exits the model, the 5 year average temp (r^2=0.8685) stays in and both catch (r^2=0.8894) and the NAO 5 yr index (r^2=0.9026) enter the model improving the fit. Similar results were seen with OASP analysis..

4. For catch there was a significantly moderate fit with 5 year average NAO and temperature (total r^2 = 0.4130). Inclusion of biomass with either ASP or OASP allowed biomass to enter the model making a small overall improvement to the fit (r^2 = 0.4635).

This exploratory multiplicative analysis suggests that stock biomass, and catch to some extent, but not surplus production, varies in response to environmental fluctuations in a predictive manner. Based on both the correlation and regression analysis, temperature plays the most important role in the enhancement of the stock productivity possible through changes in intrinsic rate of growth parameter ‘r’ or the carrying capacity ‘K’ during warm years. The contribution of other environmental and production variables often only marginally improved the model fits. Figure 8 shows that the 5 year average bottom temperature data for the period which represent conditions up to recruiting age to the fishery, along with annual bottom temperatures, track the trends in the adult stock biomass for the 1969-2006 study period. Improvements to the adult stock size coincides when average temperatures in the pre-recruit stage were >0^0C. We interpret this trend to mean that the influence of warm temperatures are reflected in improvements to recruitment, growth and less natural mortality of yellowtail flounder (ages 1-5) and hence to the adult biomass estimated by the production model.

Surplus production models are a simple view of reality and assumes logistic population growth in which a the rate of increase or decrease in stock biomass over time is a quadratic function of the current biomass. Stock biomass will not change if fish are removed at the same rate as the stock’s capacity for increase (Jensen 2005). Since biomass production varies as a result of environmental fluctuations then the logistic production model should be modified to incorporate temperature on an annual basis because of its influence on ‘r’ or ‘K’. Similar conclusions have been reported for West Greenland fish stocks (Buch et al. 2004) and Bering Sea and Gulf of Alaska demersal stocks (Mueter and Megrey 2006). Jensen (2005) argued that Fox’s (1970) surplus production model could easily accommodate environmental variation in its formulation and recommended its use over the Schaefer logistic model when conservative harvesting strategies are needed in stock management especially when stock biomass is low or when the stock is over-exploited.

Summary

Large changes in annual surplus production and stock biomass indices are not expected in long-lived species such as yellowtail founder because of low recruitment variability, slow growth rates and low natural mortality unlike that seen in small pelagics such as sardines and anchovies (Jacobsen et al. 2001). Detecting density dependent or density independent effects would therefore require several years of data on the stock size and the environment. We have examined a 38 year time series of stock production and environmental variables and found evidence of both density dependent and density independent effects. Long term changes in stock biomass are often explained by changes in fishing mortality, but now there is evidence to suggest that productivity in yellowtail flounder on the Grand Bank also varies in response to environmental variations. Temperature plays a large contributing role and the strength of the temperature relation would suggest that it should be considered for incorporation into the logistic surplus production model used in the assessment of yellowtail flounder on an annual basis. Using temperature in the model could improve hindcasts of stock status and forecasts of adult biomass for 2 year periods (Hare and Able 2007). Long term changes in biomass could also be explained by a change in catchability with warm waters as suggested by Colbourne and Walsh (2006) and Walsh and Brodie (2006). Although there is little empirical evidence to say that catch rates should increase with warmer temperatures (Winger and Walsh 2001), it may prove difficult to distinguish varying catchability from trends in biomass itself. The results of these analysis could also be influenced by fishing effects, economics and management decisions.

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Table 1 Correlational analysis between stock indices; n=38 except for Observed ASP where n=37

	Estimated ASP		Observed ASP		Average Biomass		B/Bmsy	
Variable	r	p	r	p	r	p	r	p
Est. ASP								
Obs. ASP	0.568	**0.0002**						
Biomass	0.4057	**0.0115**	0.4301	**0.0079**				
B/Bmsy	0.3747	**0.0205**	0.4213	**0.0094**	0.9887	**0.0000**		
Catch	0.2494	0.1366	0.2770	0.097	0.3452	**0.0364**	0.4765	**0.0029**

Table 2. Correlational analysis between environment effects and stock indices. Number of years in the analysis , 1969-2006
5 yr average environmental indices are for the 5 years leading up to recruitment to the fishery at age 5 yrs.
Summer temperatures are those for June to August. Values in bold are statistically significant at $p<.05$

	Estimated ASP		Observed ASP		Average Biomass		Nominal Catch	
Variable	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**
NAO anomaly	-0.0407	0.8084	-0.1644	0.3309	-0.3023	0.0651	-0.1074	0.5268
n=	38		37		38		37	
NAO anomaly-5yr average	-0.2270	0.1706	-0.1854	0.2718	**-0.5614**	**0.0002**	**-0.4387**	**0.0066**
n=	38		37		38		37	
Stn 27 0-50m Salinity annual	0.1092	0.5139	-0.0903	0.5951	-0.1052	0.5294	-0.0746	0.661
n=	38		37				37	
Stn 27 0-50m salinity--5 yr average	-0.2045	0.2182	0.0024	0.9887	-0.0281	0.8669	-0.0854	0.6153
n=	38		37		38		37	
Stn 27 0-50 Salinity Summer annual	0.2263	0.1719	0.0574	0.7356	-0.0478	0.7758	-0.1155	0.4962
n=	38		37		38		37	
Stn 27 0-50m Salinity Summer-5yr average	-0.0667	0.6909	0.1524	0.3677	0.0239	0.8867	-0.0276	0.8712
n=	38		37		38		37	
Stn 27 0-175m Temp annual	0.1973	0.2351	0.1278	0.4508	**0.5808**	**0.0001**	-0.2133	0.2092
n=	38						37	
Stn 27 0-175m Temp-5 yr average	**0.4506**	**0.0045**	**0.4692**	**0.0034**	**0.9390**	**0.0000**	**0.3670**	**0.0255**
n=	38		37		38		37	
Stn 27 0-175m Temp Summer annual	0.0339	0.8399	-0.0697	0.6819	**0.3931**	**0.0146**	-0.1321	0.4358
n=	38		37		38		37	
Stn 27 0-175m Temp Summer-5yr average	**0.3446**	**0.0341**	**0.3496**	**0.0339**	**0.8487**	**0.0000**	**0.3555**	**0.0308**
n=	38		37		38		37	

Table 3. Multiplicative analysis of the influence of climate and surplus production on stock biomass of yellowtail flounder. ASP is the estimated surplus production form ASPIC and OASP is the observed surplus production derived from equation 1.

Stepwise Linear Regression of Biomass

Unforced Variables: Anomaly NAO_5yr Temp_5yr Sal_an5 Sal_anual Temp_an
P to Enter 0.0500
P to Exit 0.0500

Step	Variable	Coefficient	T	P	R Sq	MSE
1	Constant	63.1655	12.78		0.0000	928.599
2	Constant	48.1846	24.70		0.8818	112.813
	Temp_5yr	129.380	16.39	0.0000		
3	Constant	48.4665	26.66		0.9005	97.6351
	Temp_5yr	131.562	17.79	0.0000		
	Sal_an5	-44.1495	-2.57	0.0146		

Resulting Stepwise Model

Variable	Coefficient	Std Error	T	P	VIF
Constant	48.4665	1.81786	26.66	0.0000	
Temp_5yr	131.562	7.39363	17.79	0.0000	1.0
Sal_an5	-44.1495	17.1900	-2.57	0.0146	1.0

Cases Included	38	R Squared	0.9005	MSE	97.6351
Missing Cases	1	Adjusted R Sq	0.8949	SD	9.88105

Variables Not in the Model

	Correlations			
Variable	Multiple	Partial	T	P
Anomaly	0.2612	-0.2124	-1.27	0.2136
NAO_5yr	0.7112	0.1771	1.05	0.3014
Sal_anual	0.4559	-0.0503	-0.29	0.7709
Temp_an	0.6432	-0.0455	-0.27	0.7921

Table 3 continued With CATCH AND ASP added to the model

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Stepwise Linear Regression of Biomass

Unforced Variables: Anomaly NAO_5yr Temp_5yr Sal_an5 Sal_anual Temp_an Catch Surplus

P to Enter 0.0500

P to Exit 0.0500

Step	Variable	Coefficient	T	P	R Sq	MSE
1	Constant	62.0214	12.55		0.0000	903.264
2	Constant	48.1478	25.17		0.8833	108.464
	Temp_5yr	133.677	16.27	0.0000		
3	Constant	48.4149	26.81		0.8993	96.3295
	Temp_5yr	134.573	17.36	0.0000		
	Sal_an5	-40.3665	-2.33	0.0261		

Resulting Stepwise Model

Variable	Coefficient	Std Error	T	P	VIF
Constant	48.4149	1.80617	26.81	0.0000	
Temp_5yr	134.573	7.75125	17.36	0.0000	1.0
Sal_an5	-40.3665	17.3566	-2.33	0.0261	1.0

Cases Included	37	R Squared	0.8993	MSE	96.3295
Missing Cases	2	Adjusted R Sq	0.8934	SD	9.81476

Variables Not in the Model

	Correlations			
Variable	**Multiple**	**Partial**	**T**	**P**
Anomaly	0.2648	-0.2049	-1.20	0.2378
NAO_5yr	0.7467	0.2635	1.57	0.1261
Sal_anual	0.4496	-0.0458	-0.26	0.7940
Temp_an	0.5886	0.0006	0.00	0.9972
Catch	0.3814	-0.0440	-0.25	0.8020
Surplus	0.5165	-0.2086	-1.23	0.2291

Table 3 continued WITH CATCH AND OASP added to the model

Stepwise Linear Regression of Biomass
Unforced Variables: Anomaly NAO_5yr Temp_5yr Sal_an5 Sal_anual Temp_an Catch Obs_ASP
P to Enter 0.0500
P to Exit 0.0500

Step	Variable	Coefficient	T	P	R Sq	MSE
1	Constant	62.0214	12.55		0.0000	903.264
2	Constant	48.1478	25.17		0.8833	108.464
	Temp_5yr	133.677	16.27	0.0000		
3	Constant	48.4149	26.81		0.8993	96.3295
	Temp_5yr	134.573	17.36	0.0000		
	Sal_an5	-40.3665	-2.33	0.0261		

Resulting Stepwise Model

Variable	Coefficient	Std Error	T	P	VIF
Constant	48.4149	1.80617	26.81	0.0000	
Temp_5yr	134.573	7.75125	17.36	0.0000	1.0
Sal_an5	-40.3665	17.3566	-2.33	0.0261	1.0

Cases Included	37	R Squared	0.8993	MSE	96.3295
Missing Cases	2	Adjusted R Sq	0.8934	SD	9.81476

Variables Not in the Model
Correlations

Table 3 continued

Variable	Multiple	Partial	T	P
Anomaly	0.2648	-0.2049	-1.20	0.2378
NAO_5yr	0.7467	0.2635	1.57	0.1261
Sal_anual	0.4496	-0.0458	-0.26	0.7940
Temp_an	0.5886	0.0006	0.00	0.9972
Catch	0.3814	-0.0440	-0.25	0.8020
Obs_ASP	0.4697	-0.0483	-0.28	0.7830

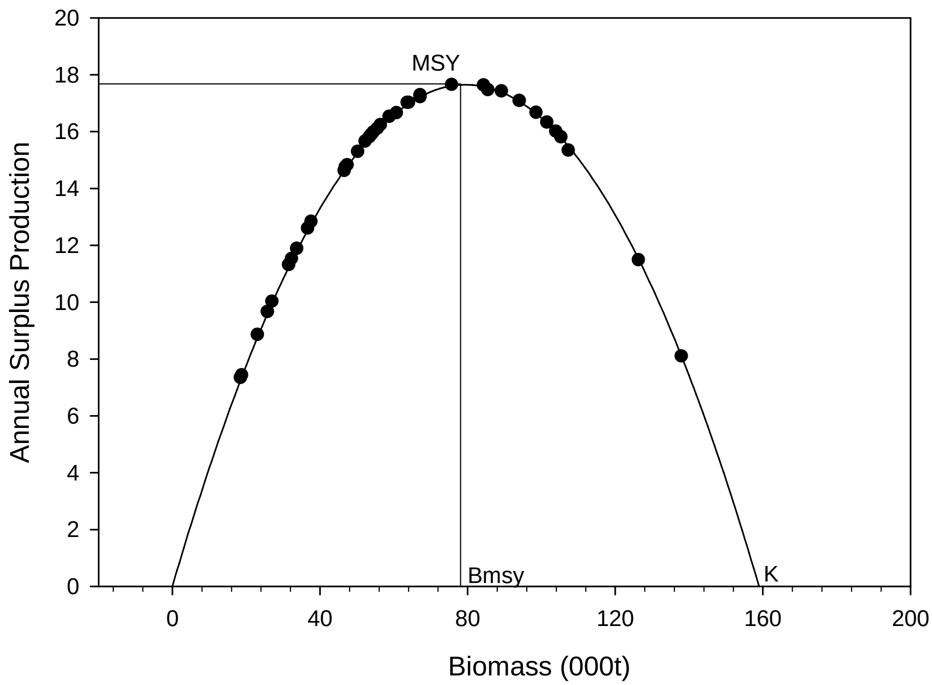

Fig. 1. Surplus production-biomass realtionship from the Schaefer logistic model. Maximum surplus production is equal to MSY and Bmsy is biomass at which MSY (maximum surplus production) occurs and K the carrying capacity or unfished biomass. The curve is fitted with the 2006 output from the ASPIC model used in the current assessment.

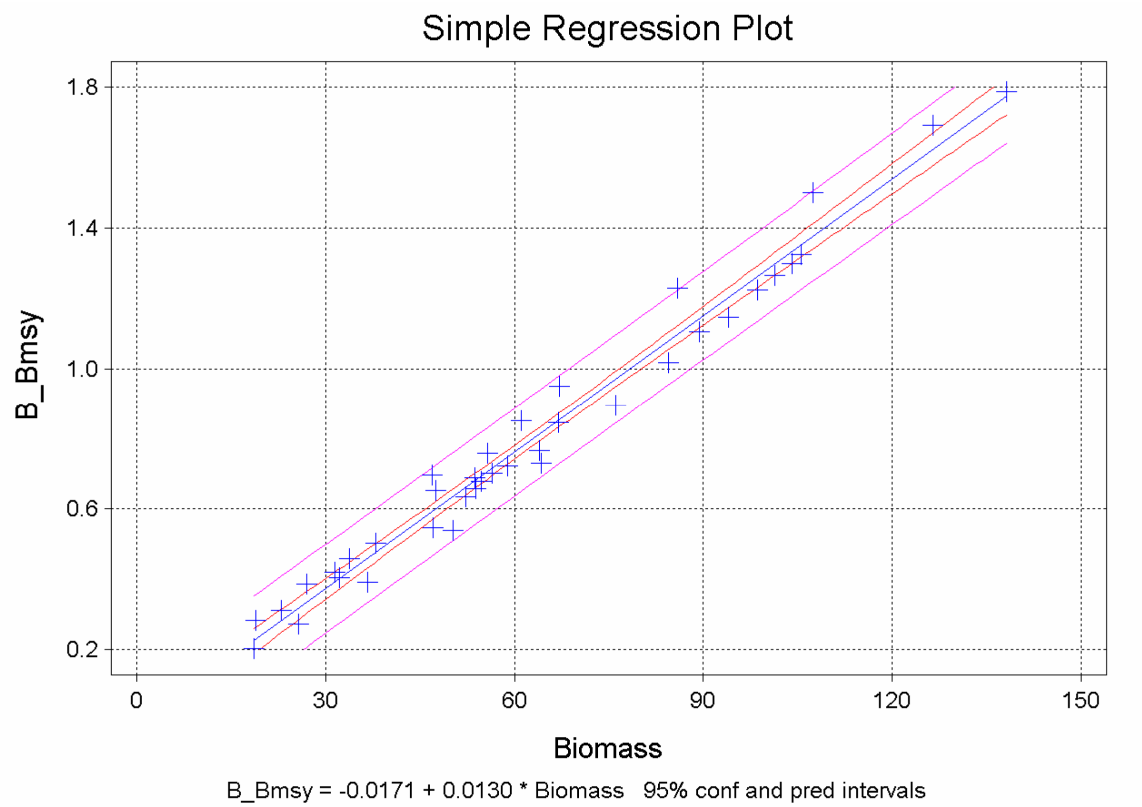

Fig. 2. The relationship between absolute average biomass and B/Bmsy indices from ASPIC surplus production model. Linear trends is significant at the 95% level (r^2 = .9770; p=0.0000). The 95% CI are the inside lines and the predicted CI are the outside lines.

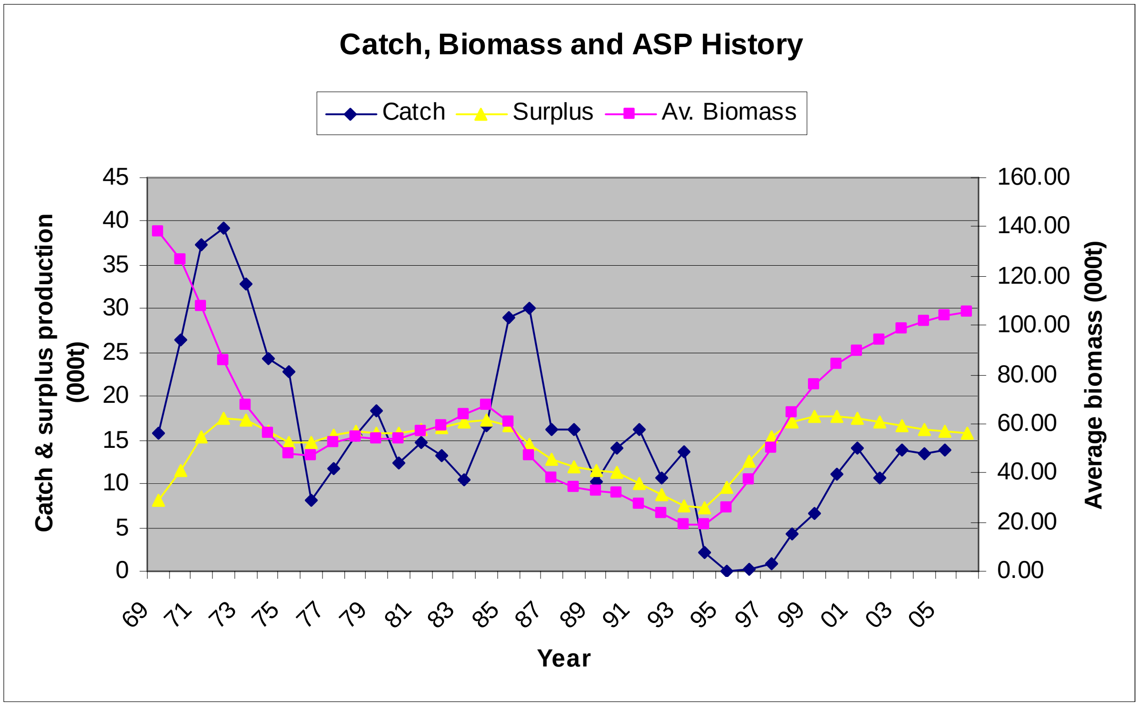

Fig. 3 Trends in annual estimated surplus production, biomass and nominal catch from the ASPIC model used in the NAFO 2006 stock assessment of yellowtail flounder.

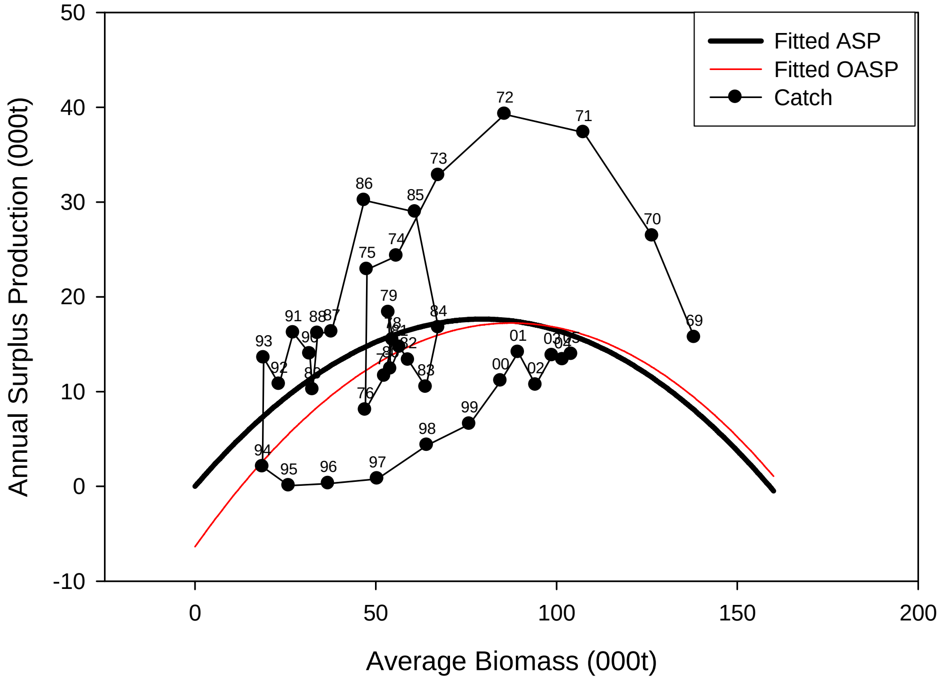

Fig. 4 Nominal catch landings (000t) overlaid onto the ASP (solid thick line) and the OASP (solid thin line) fitted production curves.

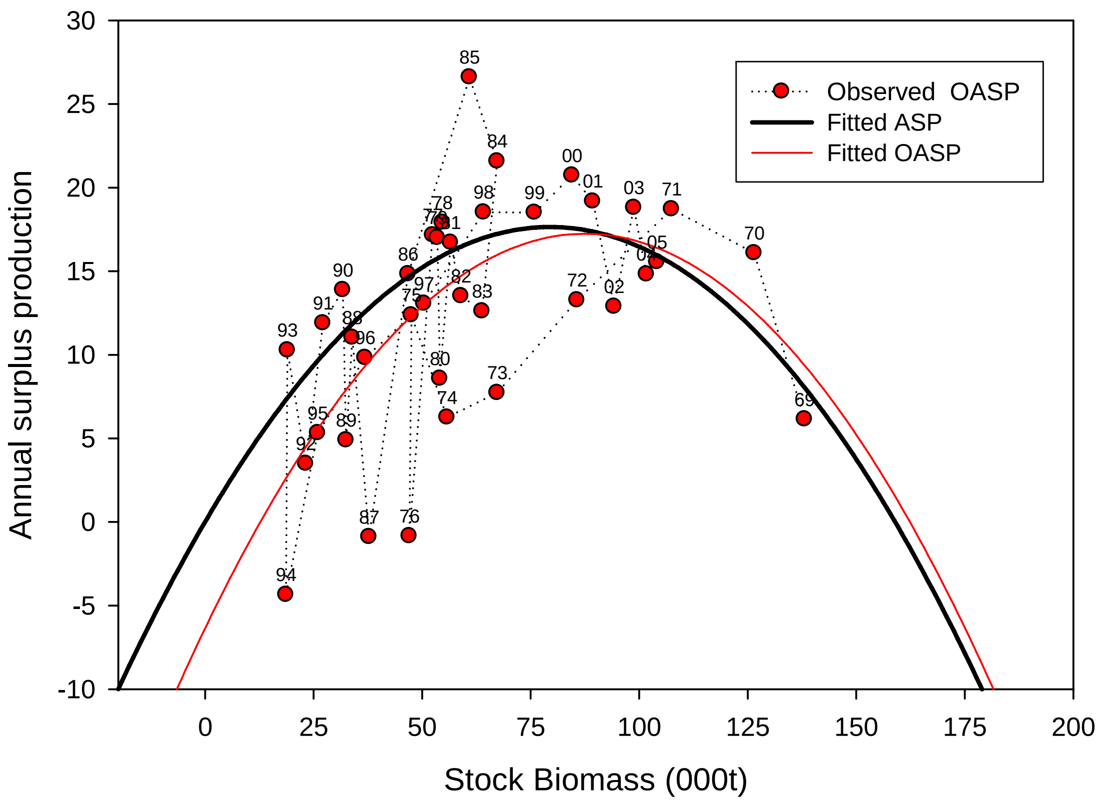

Fig. 5. Annual surplus production-stock biomass relationship for yellowtail flounder on the Grand Bank, 1969-2006. Solid heavy line is the ASPIC fitted surplus production (ASP) fittted with a quadratic regression . Dotted line connects observed OASP-biomass estimates. The solid thin line is the fitted quadratic regression to the OASP-biomass relationship.

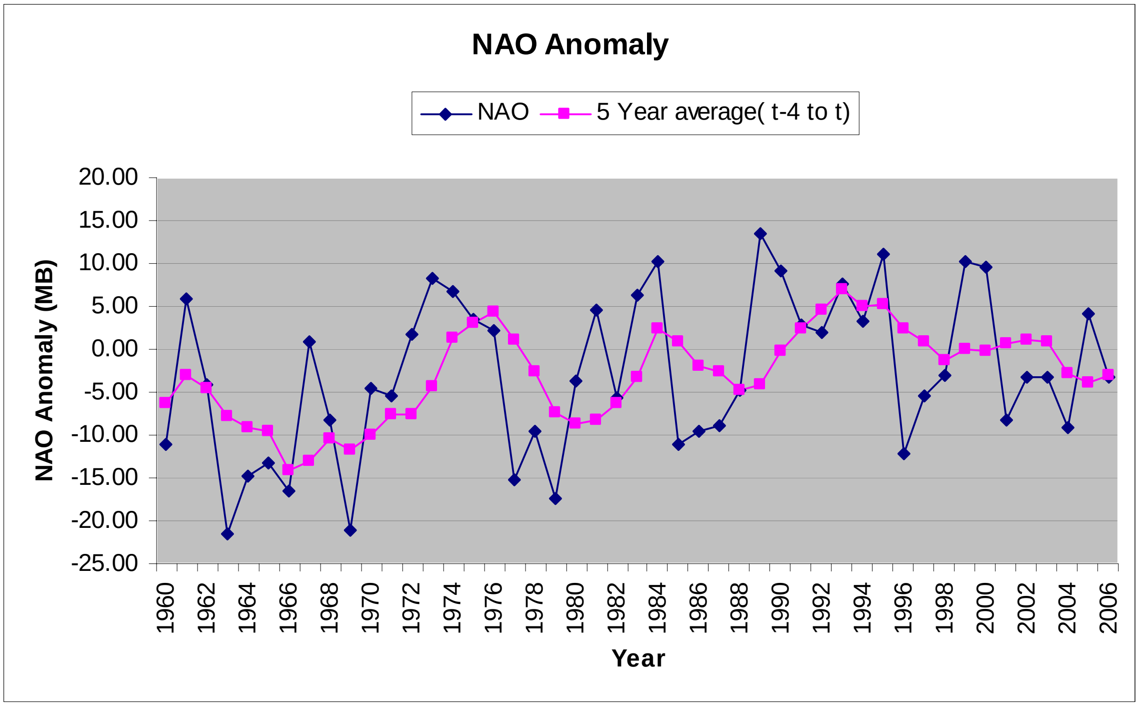

Fig. 6. The trends in the NAO and the 5 year average for the study period 1969-2006.

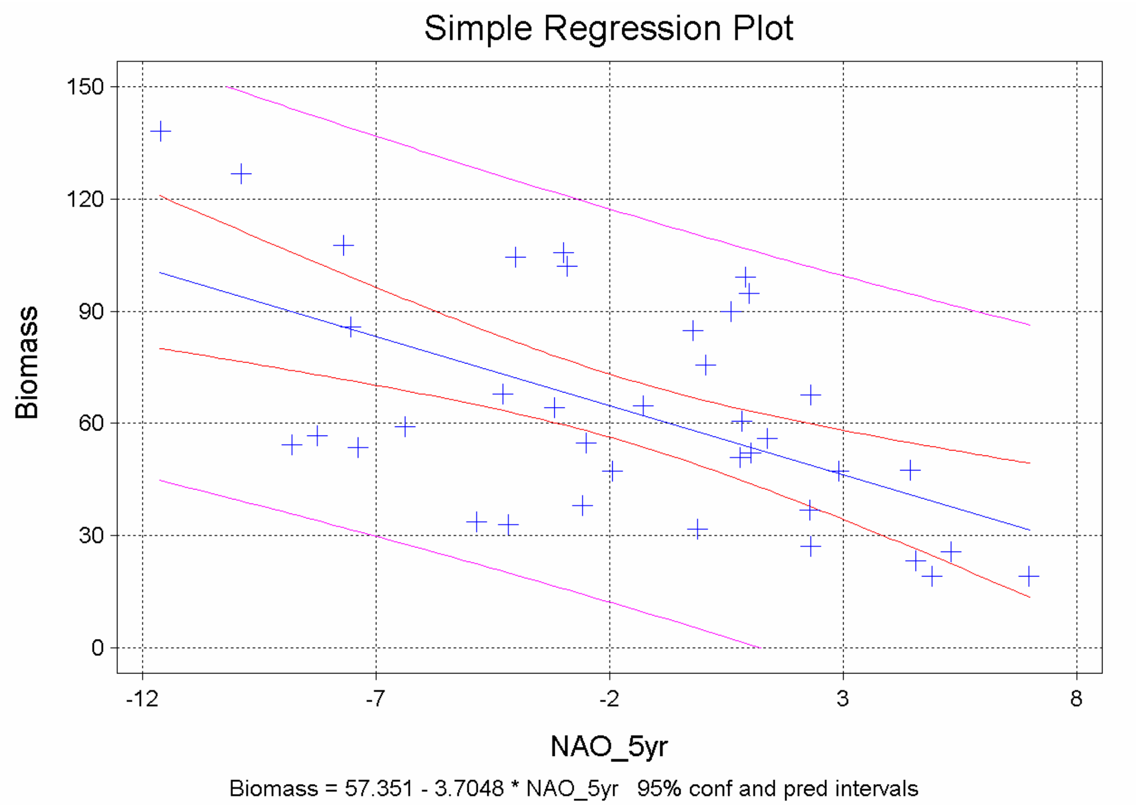

Fig. 7. Relationship between average stock biomass and the NAO index. Linear trends is significant at the 95% level (r^2 = .8818; p=0.0000). The 95% CI are the inside lines and the predicted CI are the outside lines.

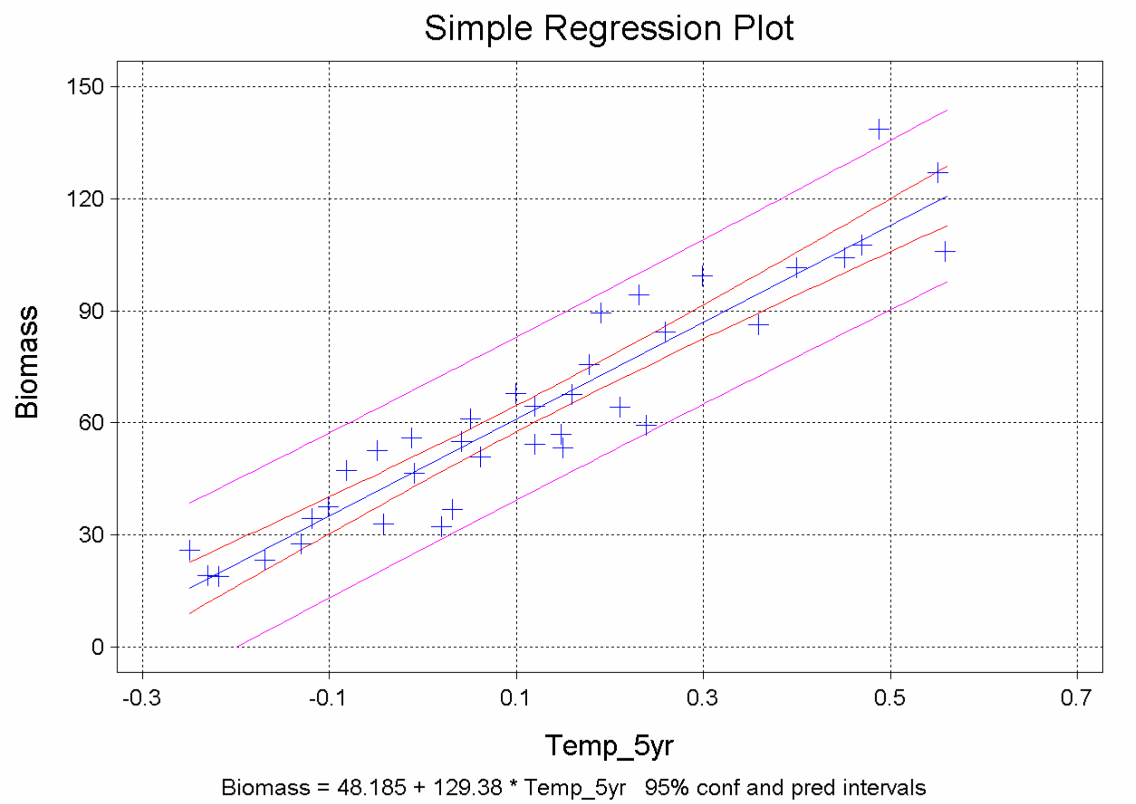

Fig. 8. Relationship between average stock biomass and 5yr average temperatures From Station 27. Linear trends is significant at the 95% level (r^2 = .9776; p=.0000). The 95% CI are the inside lines and the predicted CI are the outside lines.

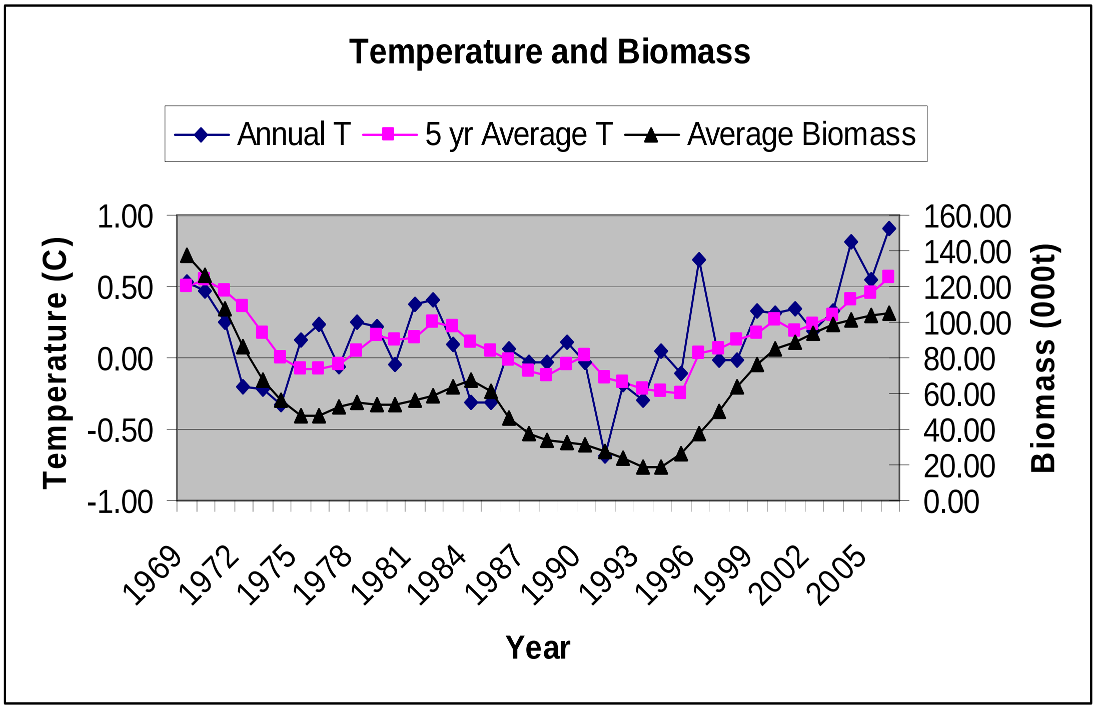

Fig. 9. Trends in bottom temperatures from Station 27 and yellowtail flounder biomass during the 1969-2005 study period.