Environmental Factors and Natural Resource Stock: Atlantic Herring Case

Jung-Hee Cho and John M. Gates
Department of Environmental and Natural Resource Economics
University of Rhode Island
Kingston, RI 02881 USA

Abstract. Herring is an important stock as bait for lobster fisheries and a component of the food web of the Northwest Atlantic Ocean. However, herring is very vulnerable to environmental variables such as temperature, food supply, and to the type of sediment on the bottom floor. Egg and larval stage herring are hypothesized to be very sensitive to low temperatures. This paper will analyze the correlation between temperature and two year-old recruitment stock, using satellite sea surface temperature (SST) data and stock size data from Northeast Fishery Science Center. Temperature is measured for specific areas that are defined as Essential Fish Habitat (EFH) designated habitat for Atlantic herring eggs. The preliminary results suggest that including environmental factors is necessary to understand the cycle of fluctuating stock and is a necessary variable in the production model for a fishery.

Keywords: Atlantic herring, variable stock, sea surface temperature (SST), Essential Fish Habitat (EFH).

1. INTRODUCTION

When fish stocks are declining, even though the marine fish stocks are influenced by other species (predator-prey relations) and by environmental changes, fishery managers often blame over-fishing for the decline in fish stock. Management plans may be set up for reducing the catch from commercial fishing or for fishing capacity reduction through Vessel Buy-Back programs. However, there are many sources of decreasing fish populations such as ocean currents, global warming, to name a few (Fig.1).

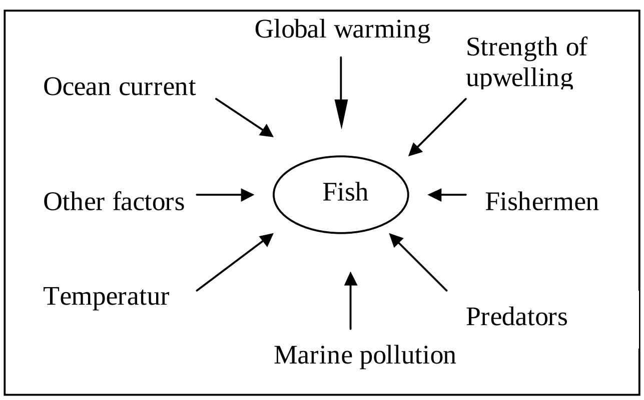

Figure 1: Affecting factors on fish stock

It may not be possible to isolate the separate effects of all these factors on the variability of stocks. In response to changing environmental factors, some stocks may increase and the others may decrease depending on the species. For example, in 1950, the California sardine fishery collapsed, and anchovy increased dramatically (Butler,1991). The North Sea herring fishery collapsed in 1969; and several valuable demersal species increased in abundance. The North Sea collapse also lead to increased demand for herring from the Northwest Atlantic stocks and their subsequent collapse. The latter sequence of heightened market demand, increased exploitation and its subsequent collapse illustrate the multiplicity of factors affecting variability. In 1972, after the Peruvian anchovy fishery collapsed due to the El Nino-Southern Oscillation (ENSO)[1], sardines increased dramatically. Statistically significant correlation between environmental factors and fish abundance have been reported by Bell and Puter (1958), Cushing (1982), and Corten (1986). Also, significant improvement of statistical performance of models has been shown by Haldorson et al. (1988), Quinn and Collie (1992), Quinn and Niebauer (1993), and Criddle, et al. (1998) by including environmental and oceanographic variables. In addition, in an analysis of the dynamics of all European herring fisheries and climate variation, Alheit and Hagen (1997) conclude that climate change must be taken into account in herring fisheries.

In the recent study by Klyashtorin (1998), the Atmospheric Circulation Index (ACI) characterizing a dominant direction of air mass transport is closely related with long-term fluctuations of important commercial stocks such as herring, Atlantic cod, sardine, anchovy,

[1] The invasion of warm, nutrient-poor water into an upwelling area that is normally cold and nutrient rich. The collapse of the Peruvian anchovy fishery in 1972 was the typical example of effect from climate change.

Pacific salmon and Alaska pollock. The estimated correlation coefficient is 0.70-0.90 in the period 1900-1994. Also, significant correlations between Atlantic herring landings and water temperature were studied by Sutcliffe et al. (1977). However these studies used only commercial catch data, and even though the changes in catch may reflect real changes in stock size, as in the case of the Atlantic herring, it may not be valid to assume that the change of commercial catch is due solely to either variations in population size or to fluctuations in market demand[2]. Presumably, the catch is changed by fishing capacity that responds to revenues and costs of fishing effort.

The Atlantic herring, *Clupea harengus*, is a pelagic species that is widely distributed in the continental shelf waters along the Atlantic coast, from the Gulf of Maine to Cape Hatteras (Fig. 2). The range of the herring migration is indicated by cross-hatching lines in Figure 2. Schools of adult herring undertake extensive seasonal migrations. They spend the summer in the north and winter in the south. The larvae[3] spend the winter in bays, estuaries, and near shore waters, and become juveniles in the spring. Spawning occurs from mid-October in the Jeffrey ledge area to November-December on Georges Bank.

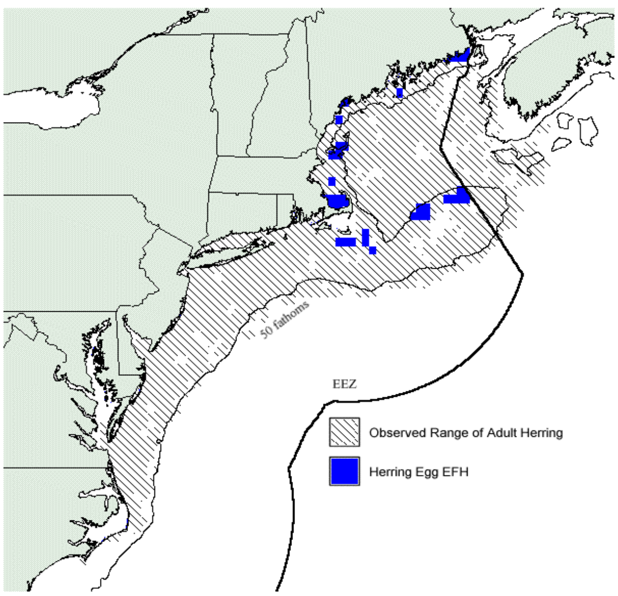

Figure2: Atlantic herring migration and Essential Fish habitat (EFH) for Atlantic herring eggs (Source: www.nefmc.org)

In the study by Robert and Sutinen (1996), a bioeconomic model of uncertain biomass shifts, due to an exogenous environmental perturbation, is used to examine optimal harvest policy. They concluded that if there is a biomass shift due to an exogenous environmental change, optimal harvest rate is more rapid than in the no-collapse case. The economic reasoning of this conclusion is that the possibility of a future stock collapse by environmental changes decreases the shadow price of the fishery stock because the prospect of a collapse reduces the expected added future value of a unit of the initial stock. As a result, fishermen would accelerate harvests to maximize net profit. So if we know the correlation between environmental factors such as SST and recruitment, and can forecast the SST, fishery managers may wish to adjust harvest policy to make maximize net profit socially. It should be noted that demand uncertainty can have similar effects. Specifically, during a period of unusually high demand it may be optimal to accelerate harvesting, since, future revenues will probably be lower.

Management based on ecosystem principles is increasingly accepted in many fisheries. Sea surface temperature has been demonstrated to be a key parameter in determining the production of pelagic fisheries in a changing environment. In this paper, juvenile and larval stage herring are hypothesized to be very sensitive to low temperature. We focus only on sea surface temperature (SST) effects on Atlantic herring stock by estimating the correlation coefficient between the SST and the change of stock using the two year-old stock size instead of actual catch. The expected result is that including environmental factors is necessary to understand the cycle of fluctuating stock and is a necessary variable in the production model for a fishery.

2. DATA

2.1 Sea Surface Temperature and Recruitment Stock

Temperature is measured for specific areas that are defined as Essential Fish habitat (EFH) designated habitat for eggs (Fig. 2). In Figure 2, EFH areas are shown in solid black. The spawning areas include Jeffrey's Ledge (the most important spawning ground in the Gulf of Maine), Nantuckel Shoals and Georges Banks. We used the monthly SST. However, the SST effecting on fish stock is more reasonable in winter times to use in our analysis. There are two reasons for this. First, in the winter the low sun angle decreases the depth of the euphotic layer, while the mixing depth increases due to intensified wind. This fact may justify using sea surface temperature instead of using temperature at the spawning depth. Second, the spawning seasons are during the interval from mid-October to December. The critical stage of larval and juveniles is winter, usually from November to February.

[2] United states landings increased from 50 Kilo mt in 1978 to 83 Kilo mt in 1980 due to a depressed Northeast Atlantic herring stock.

[3] Larvae are about 4-10 mm in length at hatching that occurs 10-15 days after depositing eggs on the bottom (Fahay, 1983)

In previous studies, mean SST at Boothay Harbor, Maine was used because it has the longest consistently recorded environmental data in Gulf of Maine. In our study data on mean monthly SST from 1987-1998[4] was used. Due to the characteristics of satellite use, and our attempt to increase the accuracy, we used monthly SST during daytime which is the best-declouded time of the day, and nighttime data were excluded. Instead of using mean monthly SST, we used SST anomalies for herring stocks in a correlation analysis. Figure 3 shows the temporal variation of SST anomalies. Anomalies were estimated by subtracting the 1987-1998 January mean SST from SST in January of each year. Figure 3 shows an oscillating pattern over time

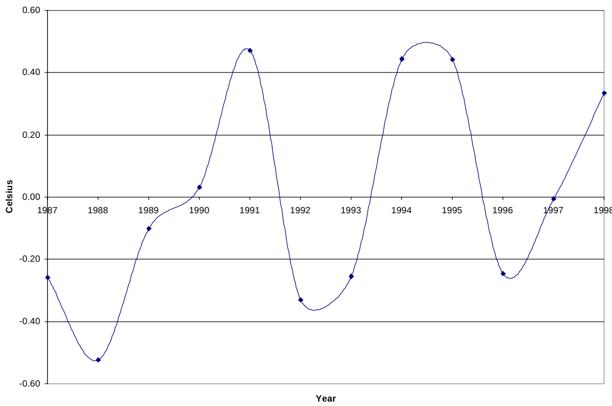

Figure3: Anomaly of SST, 1987-1988

For a sensitive analysis, we took annual data and divided it into 5 time periods, corresponding annual, winter (September-April), September-December (egg and early larval development), January-April (overwintering- late larval period), and May-August (early juvenile phase). Based on virtual population analysis, detailed abundance were available since 1967. Recruitment is defined as the biomass of two year-old Atlantic herring.

3. ANALYSIS & RESULTS

For each period, the mean, maximum, and minimum monthly SST were computed and analyzed to show correlation with recruitment. Table 1 shows the correlation coefficient between SST at t and recruitment at t+1.

			Period		
SST	Annual	Winter	Sep.- Dec.	Jan.-April	May-Aug.
Mean	0.46	0.39	0.42	**0.69 (0.02)**	-0.14
Max.	0.04	0.38	0.30	0.55	-0.28
Min.	**0.64 (0.03)**	0.55	0.57	0.58	0.06

[4] It is not possible to have SST satellite data before 1987, downloading from JPL/PODAAC.

This table suggests that the January-April period may be important for recruitment. The p-values are in parentheses. At the 5 percent significance level Jan.-April and annual periods are statistically significant.

To estimate a regression of recruitment on the mean SST for the January- April, we run the generalized least squares model using the GENMOD in SAS. GENMOD is a new maximum likelihood procedure in SAS. The user can specify any of a variety of likelihood functions including Normal, Binomial, Poisson, Gamma, etc. We chose gamma because it allow for heteroskedasticity and skew. The upper line is the OLS estimating line, and the lower one is the Gamma estimating line (Fig. 4).

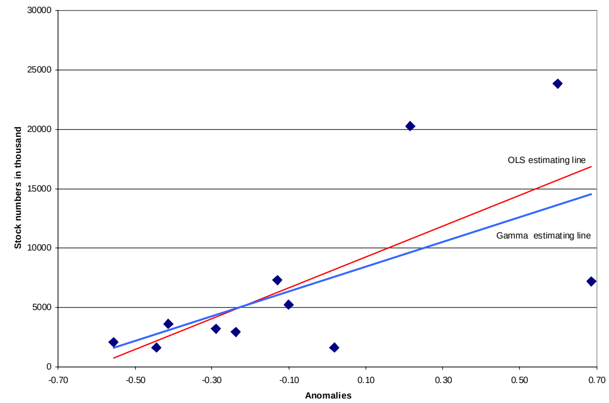

Figure 4: Heteroskedasticity and regressions

The Gamma equation was

$$R = 7396 + 10409*SST_{JA}$$

Where R is recruitment at age 2, and T_{JA} is the mean SST for January-April.

4. CONCLUSIONS and SUGGESTIONS

Generally, fisheries modeling has focused on relationships between stock size and recruitment, recruitment = f (stock size). Typical stock-recruitment models include Ricker, Beverton/Holt, and Cushing models. However, these models do not consider explicitly the interactions among environmental factors, life history patterns, primary production, predator-prey relationships, and interspecies competition (Frye, 1983). It is possible that, with more scientific data on effects of climate change on fisheries, we can improve our understanding of ecosystem effects on fisheries. Due to the current level of empirical scientific knowledge, it is difficult to generate the correct effect of environmental perturbation on fisheries.

Using the SST and recruitment, the correlation was estimated. Our results suggest that the SST effects on recruitment are more important in late larval period than any other periods. If the independent variable such as

SST can be determined, then the dependent variable may be forecasted at a given degree of confidence and variance. Even though SST is only one of the many variables affecting the stock size of two year old herring, it has the potential to enhance and to improve models used both to forecast fisheries production and to explain fisheries. So the fishery manager can use the forecasted value of stocks to manage fishery optimally, and environmental variability must be included in future management of fishery.

5. ACKNOWLEDGEMENTS

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