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Environmental Factors and Natural Resource Stock

– Atlantic Herring Case –

Jung-Hee Cho* · John M. Gates**

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Ⅰ. Introduction

When fish stocks are declining, fishery managers often blame overfishing for the decline. So, management plans have attempted to reduce the catch from commercial fishing or fishing capacity through Vessel

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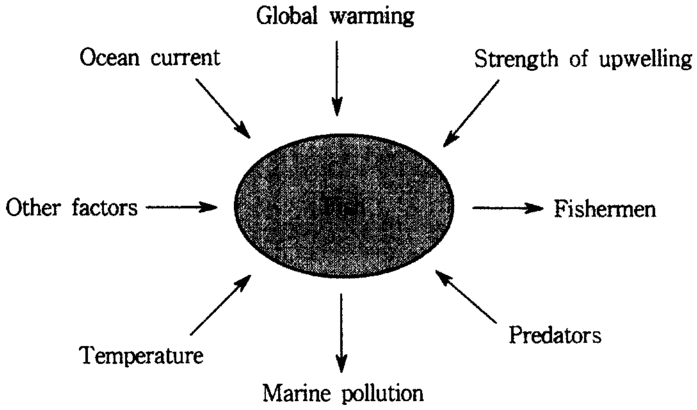
* Senior Researcher, Korea Maritime Institute.
** Professor, Department of Environment and Natural Resource Economics, University of Rhode Island, U.S.A.

〈Figure 1〉 Factors Affecting Fish Stock



Buy-Back programs. However, there are additional factors that may account for the decreasing fish populations such as change in ocean currents and global warming, to name two (See <Figure 1>). Furthermore, it may not be possible to isolate the separate effects of all these factors on the variability of stocks. Therefore, the importance of increasing ecosystem considerations in fishery management practices and procedures is increasing.

Atlantic herring, *Clupea harengus*, is important as bait in lobster fisheries and is a component of the food web of Northwest Atlantic Ocean. Also, the most remarkable characteristic of Atlantic herring is the high variability from year to year in recruitment level (Anthony and Fogarty, 1985). Even though a reduced spawning stock produces fewer eggs and fewer juvenile survivals, this is not the only reason for poor recruitment. Due to the environmental factors such as temperature, food supply, and type of sediment on the bottom floor, there is variation in recruitment at any given level of stock size.

Statistically significant correlation between environmental factors and fish abundance have been reported by Bell and Puter (1958), Cushing (1982), Corten (1986), and Mendelssohn and Cury (1987). 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 a recent study by Klyashtorin (1998), the Atmospheric Circulation Index (ACI), which characterizes a dominant direction of air mass transport, was found to be closely related with long-term global fluctuations of important commercial stocks such as herring, Atlantic cod, sardine, anchovy, Pacific salmon and Alaska pollock. The estimated correlation coefficient is 0.70~0.90 in the period 1900~1994. Also, significant correlations from linear regression of landings as a function of environmental variable (= water temperature) were studied by Sutcliffe *et al.* (1997). They estimated that the correlation coefficient is 0.74 for Atlantic herring using Boothbay Harbor data. These studies, however, used only commercial catch data, and even though the changes in catch may reflect real changes in stock size, 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.1) Presumably, the catch is also changed by fishing capacity that responds to revenues and costs of fishing effort.

Fisheries management based on ecosystem is increasingly accepted in many fisheries. Sea surface temperature (SST) has been demonstrated to be a key parameter in determining the production of pelagic fisheries in a

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1) United states landings increased from 50 kilotons in 1978 to 83 kilotons in 1980 due to a depressed Northeast Atlantic herring stock.

changing environment. In this paper, juvenile and larval stage herring are hypothesized to be very sensitive to low temperature. We focused only on the effects of sea surface temperature (SST) on Atlantic herring stock using the two-year-old stock size instead of actual catch, and then estimated the regression.

Ⅱ. Data

The Atlantic herring 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 (See <Figure 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[2] 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.

Temperature was measured for specific areas that are defined as essential fish habitat (EFH)[3](See <Figure 2>). In <Figure 2>, EFH areas are shown in solid block. The spawning areas include Jeffrey's Ledge

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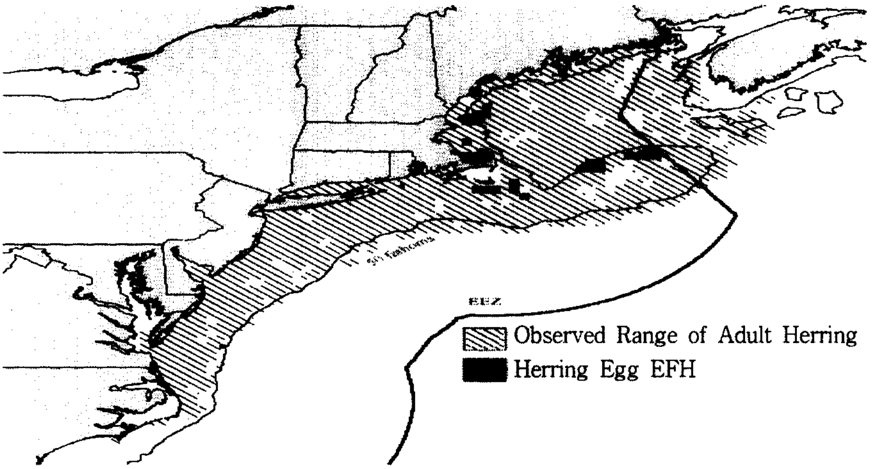
[2] Larvae are about 4-10mm in length at hatching that occurs 10~15 days after depositing eggs on the bottom (Fahay, 1983).

[3] The definition of EFH is that those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity by Congress in Magnuson-Stevens Fishery Conservation and Management Act. EFH is particularly important to long-term productivity of populations.

〈Figure 2〉 Atlantic Herring Migration and Essential Fish Habitat (EFH) for Atlantic Herring Eggs[4]



(the most important spawning ground in the Gulf of Maine), Nantucket Shoals and Georges Banks. We used the monthly sea surface temperature (SST). However, the SST effecting a change of fish stock is more reasonable in wintertime 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 period is from mid-October to December and the critical stage of larval/juveniles is winter, usually from November to February.

In previous studies, mean SST at Boothbay Harbor, Maine was used because it is the longest consistently recorded environmental data in the

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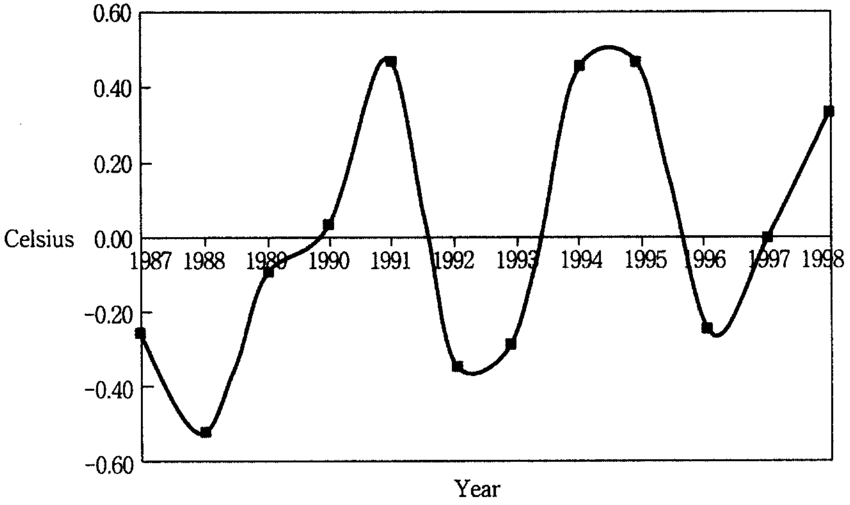
[4] Source: www.nefmc.org/documents/habitat/herring-EFH.htm

〈Figure 3〉 SST Anomaly (1987~1998)



Gulf of Maine. In our study we used mean monthly satellite SST data to have more accurate SST measurement during 1987~1998.[5] Due to the characteristics of satellite use and our attempt to increase accuracy, we used monthly SST for daytime during the least-declouded time of the day while nighttime data was excluded. Also 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[6] showing an oscillating pattern over time.

For a sensitivity analysis, we took annual data and divided it into 4 time periods: 1) winter (September-April), 2) September-December (egg

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5) It was not possible to have SST satellite data before 1987, downloading from JPL/PODAAC.

6) Anomalies were estimated by subtracting the 1987~1998 January mean SST from SST in January of each year. Anomalies are therefore deviations from average values.

and early larval development), 3) January-April (overwintering-late larval period), and 4) 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.

Ⅲ. Analysis and Results

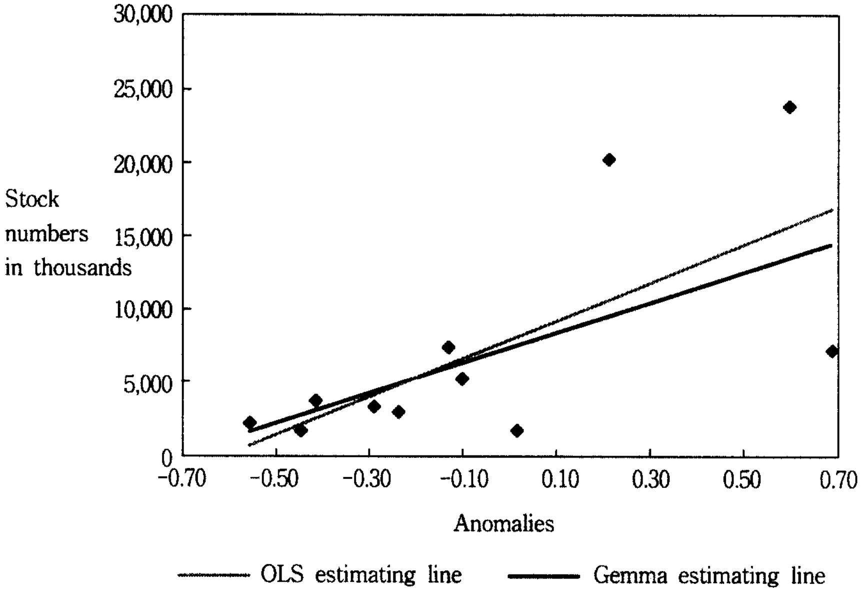
For each period the mean, maximum, and minimum monthly SST were computed and analyzed to show correlation with recruitment. <Table 1> shows the correlation coefficient between SST at t and recruitment at $t+1$. This table suggests that the January-April period may be important for recruitment. The p-values are in parentheses. At the 5 percent significance level January-April and annual periods are statistically significant.

We observe from <Figure 4> that, as anomalies grow, the observed data points (◆) have a tendency to deviate more and more from the estimated mean function (OLS estimating line), i.e. the error term, increases in absolute value as anomalies grow. This pattern is not consistent that the disturbances are not correlated with one another. i.e.

〈Table 1〉 Correlations between SST and Recruitment 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

〈Figure 4〉 Autocorrelation and Regressions



one of the assumptions in the OLS model. Therefore, the existence of autocorrelation must be checked using the Durbin-Watson test.

Due to the autocorrelation, we ran the generalized least squares model using the GENMOD that is a new maximum likelihood procedure in SAS to estimate a regression of recruitment on the mean abnomalies SST for the January-April period. The user can specify any one of a variety of likelihood functions including Normal, Binomial, Poisson, Gamma, etc. We chose gamma because it allows for autocorrelation and skew. The upper line is the OLS estimating line and the lower one is the Gamma estimating line (<Figure 4>).

The Gamma equation was

$$R = \underset{(1398)}{7396} + \underset{(2752)}{10409} * SST_{JA}$$

Versus the OLS equation; $R = \underset{(1780)}{7945} + \underset{(4496)}{12902} * SST_{JA}$ R-square 0.47

where R is recruitment at age 2, SST_{JA} is the mean SST for January-April, and standard errors appear in parentheses.

Aside from statistical considerations, the implication of the Gamma form is to predict a smaller recruitment response to higher SST anomalies than would the OLS form predict. The Gamma form is superior to the OLS in terms of statistical advantages. However, with such a small data set (11 years), one must not place too much confidence in the statistical results. Determining cause and effect in a complex oscillating system is very difficult.

However, if we feel more confident of our relationship between SST and recruitment and if we could forecast SST, we might incorporate the average fishing mortality on predicted SST. For example, if SST information predicts unusually strong juvenile survival, we might wish to allow higher harvest rates for a few years.

Ⅳ. Conclusions and Suggestions

Generally, fishery modeling has focused on relationships between stock size and recruitment, i.e. recruitment $= f$ (stock size). Typical stock-recruitment models include the 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. For the pelagic fish species, it is difficult to develop or adopt a traditional population dynamic model due to the environmental variability. It is possible that with more scientific data of the effects of climate change on fisheries, we can improve our understanding of ecosystem effects on fisheries, even though it is difficult to generate the correct effect of environmental perturbation on fisheries. Also, future landings may be predicted in advance from the predicted environmental indices.

Using the SST and recruitment, the correlation was estimated. Our results suggest that the SST effects on recruitment are more important during the late larval period than during any other period. 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 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 the fishery optimally and environmental variability could be included in future management of fishery for better management.

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ABSTRACT

환경요인과 대서양 청어자원량과의 관계

조정희 · John M. Gates

대서양 청어는 바닷가재 어업에 있어 주요 미끼로서 사용되어지고 있고 해양 생태계내에서 다른 어류들의 먹이로서 중요한 위치를 차지하고 있다. 그러나 해양생태계의 환경적인 요소, 즉 해수면 온도, 플랑크톤량, 서식지 해저퇴적물 상태에 따라 자원이 민감하게 영향을 받는다. 특히 미성어의 단계에서는 낮은 해수 온도에 대해 영향을 받기가 쉽다.

이 연구에서는 인공위성을 이용하여 측정된 해수면 온도와 2년생 가입자원의 상관관계를 분석하였다. 해수면 온도의 측정지역은 대서양 청어의 산란지역으로 한정하였다. 연구 결과 상관계수는 0.69로 나타났고 이는 어업자원의 변동성을 설명함에 있어 환경적인 요인이 중요하게 고려되어야 한다는 것을 의미한다.