Effect of Climate Variability on Fish Stocks of the Northern Gulf of Mexico

Efecto de la Variabilidad Climática sobre las Pesquerías del Norte del Golfo de México

Effet de la Variabilité Climatique sur les Pêches le Nord du Golfe du Mexique

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ABSTRACT

The study of climatic variability through the last two decades has shown that in the long term, climate has been playing a significant role driving catch trends; in the case of declines, the fishing intensity and the climate have played a synergistic role; multiple regression analysis of the main fisheries shows high correlation between each of two climate indices and the catch of the most abundant stocks. This effect was evaluated in the most important exploited fish stocks of the Northern Gulf of Mexico, from a total of more than sixty six species recorded. The effect of climate variability, evidenced after the use of the Southern Oscillation Index and the North Atlantic Oscillation Index as independent variables and the catch of the most abundant stocks as dependent variable; results displayed the same correlation with each species tested, even though independent variables were formulated after different sources. This indicates the strong influence of climate, expressed by indices arisen from different and independent sources of information. Some resulting lines suggest an upward trend, and others suggest a downward trend. These lines may be interpreted as the most likely expectations of the catch in the near future. Here, those with declining trends will be difficult to separate from effects of fishing intensity or other kinds of impact.

KEY WORDS: Fisheries, climate indices, fishing intensity, northern Gulf of Mexico

INTRODUCTION

It is believed that the impact of climate change on fisheries occurs over a long period of time. However, abrupt climate changes have been discovered in recent years. These sudden changes have had a great influence on the ecosystems around the world (Beamish et al. 1999, Klyashtorin 2001). The response of many exploited populations to climate change seems to be a worldwide phenomenon. Only the phenomenon of El Niño-Southern Oscillation (ENSO), which varies with a periodicity from five to seven years, has been recognized for several decades; it has had a significant impact in some fisheries in western America, especially sardine and anchovy (Lluch-Belda et al. 1989). The response is not the same in all cases; some species and intensities respond differently to changes of regime. The response analysis of fisheries in the context of climate change is limited to sixty years covered by the catch records. These data are used as indices proportional to the stock sizes (Lluch-Belda et al. 1989, Klyashtorin 2001). In addition, records of fish catch are the most accessible source of information available and were used trying to determine the nature and intensity of impacts on exploited populations.

The theory of fish stock assessment assumes that the biomass has been limited by the carrying capacity of the ecosystem they inhabit, which has been relatively constant over time. However, the scientific problem is to separate it from the anthropogenic and natural causes responsible for the variability (Steele 1998). A constant carrying capacity suggests that the relative rates between the number of adults and recruits in the population have been more or less constant over long periods of time and fishing mortality is the main cause of changes in the stock size. Environmental influences on short-lived species such as sardines and anchovies are intuitively perceived and because of high natural mortality and the great uncertainty in rates of recruitment, the sizes of these populations are difficult to assess using traditional fisheries models. This apparent relationship has stimulated recent efforts to analyze the potential impact of climate change with more detailed approaches (Schwartzlose et al. 1999, Beamish et al. 2000, Klyashtorin 2001). In contrast, in density-dependent species are long-lived and more stable, their response to climate variability is expected to be less intense. At the same time, they are less resilient to the intensity of exploitation, and evidence of depletion is often clear when the stocks are exhausted and their restoration may take much longer than in the case of short-lived species.

CLIMATE CHANGE INDICES

The indices describe the main attributes of climate and ocean processes that occur in these systems, which appears to be a good way to test their effects on biological systems. All available indices were tested and the results are similar in all cases; however, the North Atlantic Oscillation Index (NAOI) and the Southern Oscillation Index (SOI), or El Niño, were used for the analysis described and presented in this document.

The North Atlantic Oscillation (NAO) is a climatic phenomenon in the North Atlantic Ocean based on standardized sea -level atmospheric pressure at Iceland subtracted from that at Portugal (Hurrell 1995). Through east-west oscillation motions of the Icelandic low and the Azores high, it controls the strength and direction of westerly winds and storm tracks across the North Atlantic. The trend described by this index is shown in Figure1.

El Niño-La Niña-Southern Oscillation, or ENSO, whose index is represented by the acronym SOI or Southern Oscillation Index, is a periodic climate pattern that occurs across the tropical Pacific Ocean roughly every five years (warming and cooling known as *El Niño* and *La Niña* respectively). The Southern Oscillation refers to variations in the temperature of the surface of the tropical eastern Pacific Ocean (Darwin, Galapagos) and in air surface pressure in the tropical western Pacific, in Tahiti (Beamish et al. 2000). The two variations are coupled: The warm oceanic phase, El Niño, accompanies high air

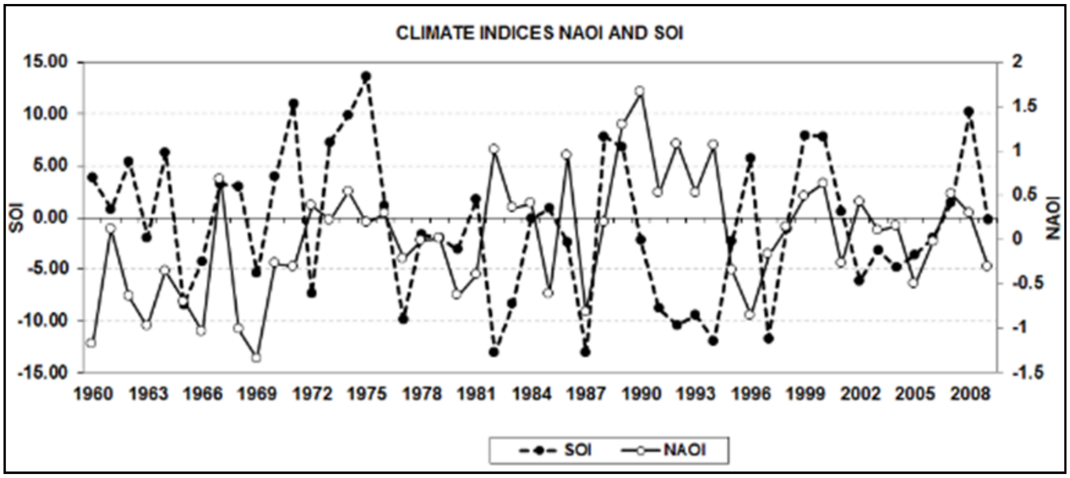

Figure 1. Trend of the climate indices Southern Oscillation Index (SOI) and the North Atlantic Oscillation Index (NAOI), for the period 1960 to 2009, used as independent variables to compare their effects on the exploited stocks of the Gulf of Mexico.

surface pressure in the western Pacific, while the cold phase, La Niña, accompanies low air surface pressure in the western Pacific. The trend described by its index is also shown in Figure1.

EFFECT OF THE CLIMATE VARIABILITY ON FISH STOCKS

The patterns of climate variability and their impact on the main exploited stocks of the Northern Gulf of Mexico and their possible correlation were examined. Large variations in the scale of decades were observed in these fisheries; variations in the abundance do not seem to occur randomly, nor appear to be caused only by the effect of fishing intensity. The stocks examined here include species of tropical distribution, some which are widespread and others that are distributed only in the warm-temperate region, this is, from Southern Texas to Massachusetts, often absent in Southern Florida.

Previous analysis with fish stocks of western Mexico were examined, and in some cases high correlations were found, suggesting a strong influence of climate (Chávez and Castro 2008). These previous results justified the attempt to analyze the response of the fisheries of the northern Gulf of Mexico, in order to provide some evidence that allows discriminating changes caused by fishing intensity from those caused by the environment.

Three main models of climate change and their effects on fisheries have been identified Chávez and Castro 2008):

i) A response to the change in the mid-seventies, in which five populations show a positive response,
ii) A change in the late eighties, characterized by moderate negative response and then a sharp response to dramatic increases in catches, and
iii) Changes in the stock biomass in response to the effect of El Niño with warmer temperatures than normal, followed by La Niña with cold periods, each one occurring every five to seven years. Still unclear is the relationship of cause and effect related to these changes.

The implication of these effects on fisheries management leads one to suspect that in the long term climate change may have a stronger influence on the size of some populations than the application of any management regulations.

The goal of this paper, was to find evidence of the effect of climate variability on exploited stocks, rather than unveiling changes of stock biomass associated with changes of regime, as in the study of the Pacific fisheries (Chávez and Castro 2008), which used a somewhat different approach. Multiple regression analysis based on the longest possible time scale, limited by the catch data series available, was used. In some cases catch data was available from 1950 through 2009. The first step of the analysis was to apply a three-year running mean to catch data, in order to reduce the uncertainty caused by abnormal variations or noise, so that the first and last data were associated to the years of the first and last mean values. The climate indices were used without any transformation.

The multiple regression analysis includes three, four, and five degree regression equations (meaning three, four and five independent variables). Resulting equations are shown in Tables 1 - 3 for using the SOI as an independent variable. Dependent variables were each of the species chosen for this purpose. In Tables 1 - 6, resulting regression equations using the NAOI as independent variable and in all these (Tables 4 - 6), the same catch data of the exploited stocks were used as dependent variables.

After examining the equations and the resulting R^2 values, dependence on the climate variability displayed by each stock is not the same, so that some of them seem are strongly dependent on the climate ($R^2 > 0.8$), while others seem to be poorly dependent on it ($R^2 < 0.5$). For a brief summary description of this correlation of catch with the climate, in the following paragraphs the degree of the regression equation that is used as reference are the three degree regressions, because the stock dependence from the climate are indicated by these. In all cases the four degree equations have a higher R^2 value; the fifth degree regression equations have a higher R^2 value than the former ones, as seen in Tables 1 - 6. For this reason, it is evident that in the description that follows, some fishery data may indicate weak dependence from the climate i.e. $R^2 = 0.8 – 0.9$ when an equation of 3rd degree is used, but the R^2 may be higher if referred to a fourth or fifth degree equation. When the R^2 value is higher than 0.9 in the 3rd degree equation, it means a stronger dependence on climate variability than the former case, and will display even higher values when equations of fourth or fifth degree are applied. Only two stocks do not seem to be sensible to climate indices, the Atlantic bonito and the weakfish, where R^2 values are lower than 0.5 even with fifth degree regression equations. All other stocks display some dependence on climate variability in one way or another.

The effect of climate variability, evidenced after the use of the SOI or the NAOI, displayed the same correlation with each species tested. In this paragraph, the reference is made to the application of third degree regression equations, because they are good indicators of the effect of climate change on fish stocks, and as it was mentioned above, when fourth and fifth degree regression equations were applied, the R^2 values are always higher than in the first case. In brief, ten fisheries seem to be poorly affected by the climate, with an $R^2 < 0.5$, amberjack, Atlantic bonito, black fin tuna, bluefin tuna, grunts, mojarras, sharks, snappers, tilefish, and weakfish. A weak correlation ($R^2 = 0.5$ to 0.6) is displayed only by the yellowfin tuna (Tables 1 - 6). A higher correlation ($R^2 = 0.6 - 0.8$) is displayed by fourteen stocks, black drum, blue runner, chub mackerel, dolphinfish, herring, jacks, ladyfish, menhaden, mullets, red grouper, other groupers, skipjack tuna, Spanish mackerel, and swordfish. An even stronger correlation with climate variability ($R^2 > 0.8$) was found in four stocks, barracuda, cobia, king mackerel, and shortfin mako (Tables 2 and 5). Finally, the rays had a correlation of $R^2 = 1$ (Table 5), even though it is suspected that despite they may be very sensitive to climate variability, the insufficient number of catch data evidently overestimates the apparent correlation.

Another aspect of the effect of climate variability on fish stocks that deserves mention is the trend described by the regression lines in the last few years of the series examined here. Some lines suggest an upward trend, but another group suggests a downward trend. In only two stocks the trend is indefinite. Those regression lines may be interpreted as the most likely expectations of the catch in the near future. Here, those with declining trends will be difficult to separate from effects of fishing intensity or other kinds of impact; they are the amberjack, Atlantic bonito, black drum, black fin tuna, blue runner, blue fin tuna, chub mackerel, and cobia. Other groups with the same trend include the dolphinfish, grunts, herring, ladyfish, menhaden, red grouper, sharks, swordfish shortfin mako, skipjack tuna, and the yellowfin tuna (see Tables 1 - 6 and Figures 2 and 3).

In the group of stocks displaying an upward trend, if any perturbation occurs in the near future, is expected that will be perceived as a sudden decline. These stocks are the barracuda, jacks and mullets (Figures 2 and 3). Trends of other stocks are difficult to interpret in this sense.

CONCLUSIONS

i) The evidence suggests that the effect of climate is clear and strong on most stocks everywhere,
ii) Regression lines may be interpreted as the most likely expectations of the catch in the near future,
iii) The most recent trends suggest that some stocks are expected to increase while others are expected to decline,
iv) In declining trends, fishing intensity may play a synergistic effect, accelerating the process of over exploitation, and
v) In the long term, climate change may have a stronger influence on the stock size than the application of any management regulation.

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Table 1. First group of multiple regression equations of third, fourth, and fifth degree, and their coefficients of determination (R^2), resulting after comparing the catch data as three-year running means of each stock indicated in the left column. The names of stocks are in alphabetic order. The independent variable is the Southern Oscillation Index (SOI).

Species - SOI	Multiple regression equation	R^2
Amberjack	$y = -0.0546x^3 + 3.1292x^2 - 29.863x + 38.372$	0.4858
	$y = 0.0034x^4 - 0.3903x^3 + 13.995x^2 - 153.48x + 375.44$	0.5695
	$y = 0.0004x^5 - 0.0449x^4 + 1.7646x^3 - 27.049x^2 + 151.91x - 205.63$	0.7354
Atlantic bonito	$y = -0.0102x^3 + 0.4489x^2 + 1.0265x - 11.823$	0.3743
	$y = 0.0005x^4 - 0.0616x^3 + 2.1135x^2 - 17.912x + 39.816$	0.3940
	$y = 7E-05x^5 - 0.0084x^4 + 0.337x^3 - 5.4776x^2 + 38.57x - 67.652$	0.4507
Barracudas	$y = 5E-05x^3 + 0.005x^2 - 0.2479x + 2.4296$	0.8753
	$y = -4E-06x^4 + 0.0004x^3 - 0.0068x^2 - 0.1128x + 2.0614$	0.8769
	$y = -1E-06x^5 + 0.0002x^4 - 0.0074x^3 + 0.1418x^2 - 1.2189x + 4.1659$	0.9107
Black drum	$y = 0.2122x^3 - 17.359x^2 + 294.93x + 2348.5$	0.7568
	$y = 0.0091x^4 - 0.6975x^3 + 12.084x^2 - 40.045x + 3261.8$	0.7776
	$y = -0.0006x^5 + 0.0821x^4 - 3.9612x^3 + 74.245x^2 - 502.56x + 4141.8$	0.7905
Blackfin tuna	$y = -0.0352x^3 + 1.6024x^2 - 23.394x + 161.15$	0.4323
	$y = 0.0088x^4 - 0.5631x^3 + 11.902x^2 - 94.845x + 284.58$	0.7571
	$y = -0.0007x^5 + 0.0594x^4 - 1.924x^3 + 27.63x^2 - 167.05x + 373.92$	0.8554
Blue runner	$y = 0.0281x^3 - 2.4915x^2 + 46.309x + 511.53$	0.7689
	$y = -0.0017x^4 + 0.2009x^3 - 8.0837x^2 + 109.93x + 338.05$	0.7993
	$y = 0.0002x^5 - 0.0294x^4 + 1.4353x^3 - 31.594x^2 + 284.86x + 5.2103$	0.8741
Bluefin tuna	$y = -0.0054x^3 + 0.3278x^2 - 3.0126x + 1.7991$	0.4592
	$y = 0.0004x^4 - 0.0471x^3 + 1.6772x^2 - 18.365x + 43.658$	0.5513
	$y = 4E-05x^5 - 0.004x^4 + 0.1494x^3 - 2.0669x^2 + 9.4931x - 9.3469$	0.6497
Chub mackerel	$y = -0.0451x^3 - 0.8709x^2 + 17.554x - 0.6448$	0.6551
	$y = 0.1103x^4 - 3.1346x^3 + 27.675x^2 - 79.323x + 89.392$	0.8623
	$y = 0.016x^5 - 0.4508x^4 + 3.9998x^3 - 12.165x^2 + 13.293x + 23.98$	0.9020
Cobia	$y = -0.0047x^3 + 0.2598x^2 - 1.3689x + 20.061$	0.8224
	$y = -0.0001x^4 + 0.0098x^3 - 0.2099x^2 + 3.9749x + 5.4905$	0.8421
	$y = 1E-05x^5 - 0.0014x^4 + 0.0638x^3 - 1.2368x^2 + 11.616x - 9.0478$	0.8552
Dolfinfish	$y = -0.0353x^3 + 2.3888x^2 - 33.826x + 110.74$	0.712
	$y = -0.0003x^4 - 0.0073x^3 + 1.4826x^2 - 23.517x + 82.634$	0.7143
	$y = 0.0002x^5 - 0.0216x^4 + 0.9452x^3 - 16.658x^2 + 111.46x - 174.18$	0.8464
Grunts	$y = -0.0162x^3 + 1.1668x^2 - 18.32x + 130.06$	0.4600
	$y = -0.0018x^4 + 0.1654x^3 - 4.7113x^2 + 48.556x - 52.284$	0.7278
	$y = 2E-05x^5 - 0.0039x^4 + 0.2578x^3 - 6.4711x^2 + 61.65x - 77.198$	0.7311

Table 2. Second group of multiple regression equations of third, fourth, and fifth degree, and their coefficient of determination (R^2), resulting after a comparison of the catch data as three-year running means of each stock indicated in the left column. The names of stocks are in alphabetic order. The independent variable is the Southern Oscillation Index (SOI).

Species - SOI (2)	Multiple regression equation	R^2
Herring	$y = -0.512x^3 + 33.28x^2 - 597.2x + 3578$	0.651
	$y = 0.018x^4 - 2.033x^3 + 74.68x^2 - 994.7x + 4502$	0.733
	$y = 0.000x^5 - 0.013x^4 - 0.866x^3 + 55.95x^2 - 876.7x + 4309$	0.735
Jacks	$y = 0.1242x^3 - 2.3983x^2 + 11.122x + 25.249$	0.7149
	$y = -0.0301x^4 + 0.9671x^3 - 10.187x^2 + 37.553x + 0.6846$	0.9236
	$y = -0.0026x^5 + 0.0618x^4 - 0.2011x^3 - 3.6625x^2 + 22.386x + 11.396$	0.938
King mackerel	$y = -0.4618x^3 + 6.5513x^2 + 27.189x + 8.6897$	0.9543
	$y = 0.16x^4 - 5.2603x^3 + 53.966x^2 - 144.19x + 176.5$	0.9853
	$y = 0.0011x^5 + 0.1193x^4 - 4.7078x^3 + 50.675x^2 - 136.08x + 170.5$	0.9854
Ladyfish	$y = -0.0841x^3 + 3.8955x^2 + 9.5705x + 145.48$	0.7414
	$y = 0.0064x^4 - 0.7265x^3 + 24.685x^2 - 226.95x + 790.39$	0.8244
	$y = 0.0005x^5 - 0.0592x^4 + 2.2052x^3 - 31.153x^2 + 188.51x - 0.1063$	0.9075
Menhaden	$y = -4.044x^3 - 328.8x^2 + 26377x + 30698$	0.5670
	$y = 1.821x^4 - 182.5x^3 + 5332.x^2 - 36778x + 47602$	0.6650
	$y = -0.066x^5 + 9.915x^4 - 536.9x^3 + 11951x^2 - 85079x + 56632$	0.6830
Mojarras	$y = -0.0068x^3 + 0.5613x^2 - 11.041x + 107.84$	0.4761
	$y = -0.0004x^4 + 0.0331x^3 - 0.7305x^2 + 3.6562x + 67.764$	0.5391
	$y = 2E\text{-}05x^5 - 0.003x^4 + 0.1489x^3 - 2.9373x2 + 20.076x + 36.522$	0.5646
Mullets	$y = 0.0034x^3 - 0.1163x^2 + 0.6759x + 0.9303$	0.6571
	$y = -0.0003x^4 + 0.0291x^3 - 0.9463x^2 + 10.119x - 24.816$	0.6731
	$y = -4E\text{-}05x^5 + 0.0052x^4 - 0.2166x^3 + 3.7338x^2 - 24.703x + 41.44$	0.7438
Other groupers	$y = 0.2122x^3 - 17.359x^2 + 294.93x + 2348.5$	0.7568
	$y = 0.0091x^4 - 0.6975x^3 + 12.084x^2 - 40.045x + 3261.8$	0.7776
	$y = -0.0006x^5 + 0.0821x^4 - 3.9612x^3 + 74.245x^2 - 502.56x + 4141.8$	0.7905
Red grouper	$y = -1.0499x^3 + 36.467x^2 - 365.7x + 3776.9$	0.6476
	$y = -0.072x^4 + 2.2622x^3 - 13.266x^2 - 97.891x + 3407.8$	0.7147
	$y = 0.0108x^5 - 0.6911x^4 + 15.076x^3 - 127.81x^2 + 314.04x + 2993.9$	0.7581
Sharks	$y = -0.2281x^3 + 14.684x^2 - 196.26x + 529.61$	0.4847
	$y = 0.006x^4 - 0.8311x^3 + 34.201x^2 - 418.3x + 1135$	0.5065
	$y = 0.0013x^5 - 0.1582x^4 + 6.5059x^3 - 105.54x^2 + 621.47x - 843.34$	0.6614
Shark, shortfin mako	$y = 0.0302x^3 - 1.1334x^2 + 10.811x + 4.0351$	0.8400
	$y = 2E\text{-}06x^4 + 0.0301x^3 - 1.1324x^2 + 10.806x + 4.042$	0.8400
	$y = -0.0005x^5 + 0.0301x^4 - 0.5658x^3 + 3.9722x^2 - 6.8282x + 21.177$	0.8935
Skipjack tuna	$y = 0.0003x^3 - 0.004x^2 - 0.123x + 2.0597$	0.6416
	$y = -0.0001x^4 + 0.0063x^3 - 0.0944x^2 + 0.3639x + 1.3887$	0.6739
	$y = 5E\text{-}05x^5 - 0.0031x^4 + 0.0676x^3 - 0.6427x^2 + 2.3358x - 0.5927$	0.8186
Snappers	$y = -0.0066x^3 + 0.404x^2 - 4.6641x + 8.3596$	0.3546
	$y = 0.0004x^4 - 0.042x^3 + 1.5474x^2 - 17.673x + 43.829$	0.4099
	$y = 5E\text{-}05x^5 - 0.0057x^4 + 0.2272x^3 - 3.5787x^2 + 20.468x - 28.741$	0.5642
Spanish mackerel	$y = 0.1407x^3 - 10.546x^2 + 152.1x + 2241.6$	0.7765
	$y = -0.0075x^4 + 0.8881x^3 - 34.735x^2 + 427.29x + 1491.2$	0.8151
	$y = 0.0003x^5 - 0.04x^4 + 2.3418x^3 - 62.423x^2 + 633.31x + 1099.2$	0.8221

Table 3. Third group of multiple regression equations of third, fourth, and fifth degree, and their coefficient of determination (R^2), resulting after comparing the catch data as three-year running means of each stock indicated in the left column. The names of stocks are in alphabetic order. The independent variable is the Southern Oscillation Index (SOI).

Species - SOI (3)	Multiple regression equation	R^2
Swordfish	$y = -0.0014x^3 - 1.336x^2 + 64.638x - 174.54$	0.7370
	$y = 0.0052x^4 - 0.4141x^3 + 9.3667x^2 - 33.363x + 43.705$	0.8009
	$y = -0.0002x^5 + 0.0254x^4 - 1.1383x^3 + 20.448x^2 - 100.02x + 148.34$	0.8102
Tilefish	$y = -0.0395x^3 + 0.8971x^2 - 5.0589x + 8.1439$	0.4615
	$y = 0.0065x^4 - 0.2619x^3 + 3.38x^2 - 15.131x + 19.01$	0.5881
	$y = 0.0019x^5 - 0.0749x^4 + 0.9906x^3 - 5.0119x^2 + 7.9232x + 0.4337$	0.7466
Weakfish	$y = -6E-05x^3 + 0.0033x^2 - 0.0153x + 0.044$	0.1248
	$y = -4E-06x^4 + 0.0003x^3 - 0.0094x^2 + 0.1287x - 0.3485$	0.1392
	$y = 9E-08x^5 - 1E-05x^4 + 0.0008x^3 - 0.0186x^2 + 0.1972x - 0.4789$	0.1402
Yellowfin tuna	$y = -0.3168x^3 + 21.101x^2 - 287.34x + 732.55$	0.5801
	$y = 0.0058x^4 - 0.8939x^3 + 39.778x^2 - 499.83x + 1311.9$	0.5902
	$y = 0.0016x^5 - 0.1903x^4 + 7.8676x^3 - 127.1x^2 + 741.81x - 1050.5$	0.7014

Table 4. First group of multiple regression equations of third, fourth and fifth, degree, and their coefficient of determination (R^2), resulting after comparing the catch data as three-year running means of each stock indicated in the left column. The names of stocks are in alphabetic order. The independent variable is the North Atlantic Oscillation Index (NAOI).

Species - NAOI	Multiple regression equation	R^2
Amberjack	$y = -0.0415x^3 + 3.2228x^2 - 55.461x + 197.66$	0.4946
	$y = 0.0001x^4 - 0.0542x^3 + 3.7045x^2 - 61.904x + 218.12$	0.4950
	$y = 0.0002x^5 - 0.0237x^4 + 1.2015x^3 - 24.447x^2 + 183.7x - 322.78$	0.6728
Atlantic bonito	$y = -0.0103x^3 + 0.71x^2 - 8.8387x + 23.375$	0.4134
	$y = 0.0001x^4 - 0.0239x^3 + 1.2203x^2 - 15.55x + 44.358$	0.4172
	$y = 3E\text{-}05x^5 - 0.004x^4 + 0.1906x^3 - 3.5085x^2 + 25.031x - 43.664$	0.4623
Barracudas	$y = -0.0002x^3 + 0.0258x^2 - 1.0376x + 11.631$	0.8888
	$y = 9E\text{-}06x^4 - 0.0012x^3 + 0.0651x^2 - 1.5638x + 13.303$	0.9096
	$y = -6E\text{-}07x^5 + 0.0001x^4 - 0.0061x^3 + 0.1749x^2 - 2.522x + 15.413$	0.9324
Black drum	$y = -0.0965x^3 + 7.7553x^2 - 114.97x + 1018.4$	0.6959
	$y = 0.0006x^4 - 0.1661x^3 + 10.414x^2 - 150.54x + 1131.4$	0.6970
	$y = 0.0003x^5 - 0.0466x^4 + 2.3221x^3 - 45.37x^2 + 336.15x + 59.51$	0.7624
Blackfin tuna	$y = -0.0352x^3 + 1.6024x^2 - 23.394x + 161.15$	0.4323
	$y = 0.0088x^4 - 0.5631x^3 + 11.902x^2 - 94.845x + 284.58$	0.7571
	$y = -0.0007x^5 + 0.0594x^4 - 1.924x^3 + 27.63x^2 - 167.05x + 373.92$	0.8554
Blue runner	$y = 0.0201x^3 - 2.4726x^2 + 76.786x + 9.5263$	0.7083
	$y = 0.0004x^4 - 0.0219x^3 - 0.8699x^2 + 55.348x + 77.624$	0.7137
	$y = -6E\text{-}05x^5 + 0.009x^4 - 0.4777x^3 + 9.3476x^2 - 33.794x + 273.94$	0.7446
Bluefin tuna	$y = -0.0045x^3 + 0.3481x^2 - 5.5552x + 16.396$	0.4927
	$y = 7E\text{-}05x^4 - 0.0129x^3 + 0.656x^2 - 9.5367x + 28.644$	0.5015
	$y = 2E\text{-}05x^5 - 0.003x^4 + 0.1438x^3 - 2.7399x^2 + 19.122x - 32.562$	0.6514
Chub mackerel	$y = -0.0451x^3 - 0.8709x^2 + 17.554x - 0.6448$	0.6551
	$y = 0.1103x^4 - 3.1346x^3 + 27.675x^2 - 79.323x + 89.392$	0.8623
	$y = 0.016x^5 - 0.4508x^4 + 3.9998x^3 - 12.165x^2 + 13.293x + 23.98$	0.9020
Cobia	$y = -0.0036x^3 + 0.2686x^2 - 3.3357x + 19.881$	0.8694
	$y = -7E\text{-}05x^4 + 0.005x^3 - 0.0583x^2 + 1.0375x + 5.9906$	0.8851
	$y = -1E\text{-}06x^5 + 0.0001x^4 - 0.0044x^3 + 0.153x^2 - 0.8061x + 10.051$	0.8860
Dolfinfish	$y = -0.0211x^3 + 1.7496x^2 - 31.731x + 119.95$	0.6902
	$y = -0.0007x^4 + 0.0602x^3 - 1.3006x^2 + 8.3924x - 5.4936$	0.7414
	$y = 4E\text{-}05x^5 - 0.007x^4 + 0.3888x^3 - 8.5441x^2 + 70.554x - 140.32$	0.7820
Grunts	$y = -0.007x^3 + 0.6207x^2 - 11.344x + 100.14$	0.4519
	$y = -0.0008x^4 + 0.0854x^3 - 2.9049x^2 + 35.815x - 49.653$	0.6556
	$y = -3E\text{-}05x^5 + 0.0036x^4 - 0.1437x^3 + 2.2304x^2 - 8.988x + 49.02$	0.7164

Table 5. Second group of multiple regression equations of third, fourth, and fifth degree, and their coefficient of determination (R^2), resulting after comparing the catch data as a three-year running means of each stock indicated in the left column. The names of stocks are in alphabetic order. The independent variable is the North Atlantic Oscillation Index (NAOI).

Species - NAOI (2)	Multiple regression equation	R^2
Herring	$y = -0.512x^3 + 33.28x^2 - 597.2x + 3578$	0.6510
	$y = 0.018x^4 - 2.033x^3 + 74.68x^2 - 994.7x + 4502.$	0.7330
	$y = 0.000x^5 - 0.013x^4 - 0.866x^3 + 55.95x^2 - 876.7x + 4309.$	0.7350
Jacks	$y = 0.1242x^3 - 2.3983x^2 + 11.122x + 25.249$	0.7149
	$y = -0.0301x^4 + 0.9671x^3 - 10.187x^2 + 37.553x + 0.6846$	0.9236
	$y = -0.0026x^5 + 0.0618x^4 - 0.2011x^3 - 3.6625x^2 + 22.386x + 11.396$	0.9380
King mackerel	$y = -0.4618x^3 + 6.5513x^2 + 27.189x + 8.6897$	0.9543
	$y = 0.16x^4 - 5.2603x^3 + 53.966x^2 - 144.19x + 176.5$	0.9853
	$y = 0.0011x^5 + 0.1193x^4 - 4.7078x^3 + 50.675x^2 - 136.08x + 170.5$	0.9854
Ladyfish	$y = -0.0831x^3 + 6.071x^2 - 78.347x + 418.44$	0.7979
	$y = 0.0013x^4 - 0.2391x^3 + 12.022x^2 - 157.94x + 671.26$	0.8105
	$y = 0.0002x^5 - 0.0336x^4 + 1.5989x^3 - 29.186x^2 + 201.57x - 120.51$	0.8952
Menhaden	$y = -4.975x^3 - 86.99x^2 + 26277x + 94369$	0.7650
	$y = 0.61x^4 - 76.95x^3 + 2659x^2 - 10454x + 21104$	0.7960
	$y = 0.020x^5 - 2.426x^4 + 82.98x^3 - 926.8x^2 + 20831x + 14214$	0.8030
Mojarras	$y = -0.0008x^3 + 0.1074x^2 - 2.4688x + 71.967$	0.3239
	$y = -0.0004x^4 + 0.0426x^3 - 1.5484x^2 + 19.679x + 1.6174$	0.5315
	$y = 3E-06x^5 - 0.0007x^4 + 0.0626x^3 - 1.9979x^2 + 23.601x - 7.0194$	0.5337
Mullets	$y = 0.0034x^3 - 0.1537x^2 + 1.666x - 3.091$	0.6633
	$y = -0.0001x^4 + 0.0167x^3 - 0.6167x^2 + 7.3445x - 19.709$	0.6706
	$y = -3E-05x^5 + 0.0034x^4 - 0.1525x^3 + 2.8582x^2 - 20.493x + 36.964$	0.7281
Other groupers	$y = 0.1177x^3 - 13.054x^2 + 337.32x + 1107.5$	0.7313
	$y = 0.0064x^4 - 0.6318x^3 + 15.537x^2 - 45.116x + 2322.3$	0.7771
	$y = -3E-05x^5 + 0.0108x^4 - 0.8659x^3 + 20.786x^2 - 90.913x + 2423.1$	0.7773
Rays	$y = -2.1667x^3 + 15.8x^2 - 33.1x + 24.533$	1.0000
Red grouper	$y = -1.0499x^3 + 36.467x^2 - 365.7x + 3776.9$	0.6476
	$y = -0.072x^4 + 2.2622x^3 - 13.266x^2 - 97.891x + 3407.8$	0.7147
	$y = 0.0108x^5 - 0.6911x^4 + 15.076x^3 - 127.81x^2 + 314.04x + 2993.9$	0.7581
Sharks	$y = -0.1404x^3 + 11.462x^2 - 211.86x + 784.5$	0.4730
	$y = -0.0024x^4 + 0.1417x^3 + 0.7028x^2 - 67.947x + 327.39$	0.4876
	$y = 0.0004x^5 - 0.0683x^4 + 3.6123x^3 - 77.106x^2 + 610.9x - 1167.7$	0.5953
Shark, shortfin mako	$y = 0.0302x^3 - 1.1334x^2 + 10.811x + 4.0351$	0.8400
	$y = 2E-06x^4 + 0.0301x^3 - 1.1324x^2 + 10.806x + 4.042$	0.8400
	$y = -0.0005x^5 + 0.0301x^4 - 0.5658x^3 + 3.9722x^2 - 6.8282x + 21.177$	0.8935

Table 6. Third group of multiple regression equations of third, fourth, and fifth degree, and their coefficient of determination (R^2), resulting after a comparison of the catch data as three-year running means of each stock indicated in the left column. The names of stocks are in alphabetic order. The independent variable is the North Atlantic Oscillation Index (NAOI).

Species - NAOI (3)	Multiple regression equation	R^2
Skipjack tuna	$y = 0.0003x^3 - 0.004x^2 - 0.123x + 2.0597$	0.6416
	$y = -0.0001x^4 + 0.0063x^3 - 0.0944x^2 + 0.3639x + 1.3887$	0.6739
	$y = 5E\text{-}05x^5 - 0.0031x^4 + 0.0676x^3 - 0.6427x^2 + 2.3358x - 0.5927$	0.8186
Snappers	$y = -0.0051x^3 + 0.4048x^2 - 7.5301x + 32.571$	0.3433
	$y = 5E\text{-}06x^4 - 0.0057x^3 + 0.4265x^2 - 7.8162x + 33.466$	0.3434
	$y = 2E\text{-}05x^5 - 0.0032x^4 + 0.1588x^3 - 3.1998x^2 + 23.304x - 34.035$	0.5102
Spanish mackerel	$y = 0.1046x^3 - 10.721x^2 + 270.2x + 735.46$	0.7041
	$y = 0.0011x^4 - 0.0271x^3 - 5.6962x^2 + 202.99x + 948.93$	0.7080
	$y = 0.0003x^5 - 0.0466x^4 + 2.3221x^3 - 45.37x^2 + 336.15x + 59.51$	0.7624
Swordfish	$y = -0.0014x^3 - 1.336x^2 + 64.638x - 174.54$	0.7370
	$y = 0.0052x^4 - 0.4141x^3 + 9.3667x^2 - 33.363x + 43.705$	0.8009
	$y = -0.0002x^5 + 0.0254x^4 - 1.1383x^3 + 20.448x^2 - 100.02x + 148.34$	0.8102
Tilefish	$y = -0.0395x^3 + 0.8971x^2 - 5.0589x + 8.1439$	0.4615
	$y = 0.0065x^4 - 0.2619x^3 + 3.38x^2 - 15.131x + 19.01$	0.5881
	$y = 0.0019x^5 - 0.0749x^4 + 0.9906x^3 - 5.0119x^2 + 7.9232x + 0.4337$	0.7466
Weakfish	$y = -0.0005x^3 + 0.0393x^2 - 0.9893x + 7.1038$	0.2218
	$y = 3E\text{-}05x^4 - 0.0035x^3 + 0.1445x^2 - 2.2567x + 10.749$	0.3197
	$y = -2E\text{-}06x^5 + 0.0004x^4 - 0.019x^3 + 0.4571x^2 - 4.7164x + 15.675$	0.4403

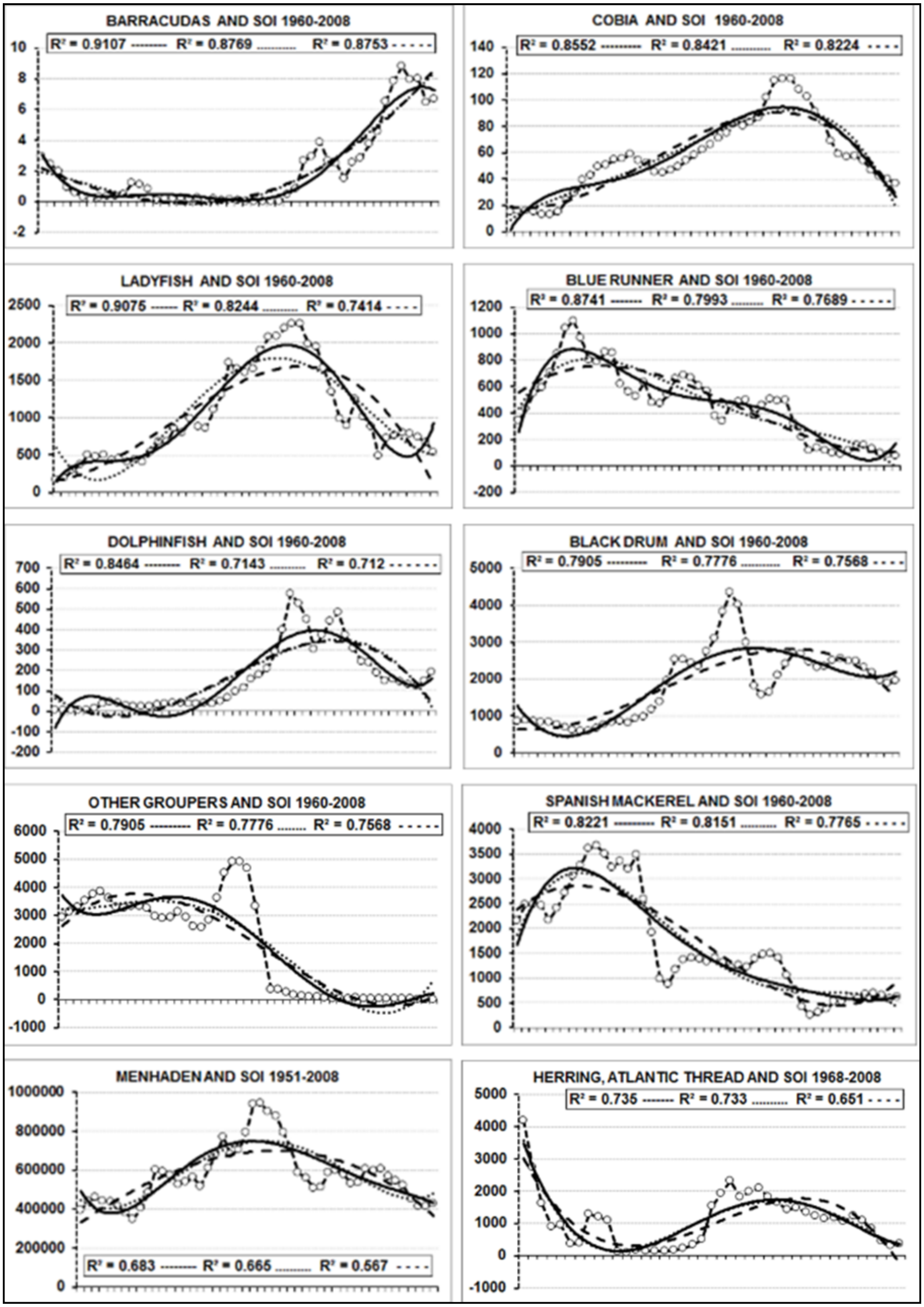

Figure 2. The first group of stocks displaying multiple regression lines of third, fourth, and fifth degree, and their coefficient of determination (R^2), resulting after comparing the catch data as three-year running means of each stock indicated in the left column. The names of stocks are in alphabetic order. The independent variable is the Southern Oscillation Index.

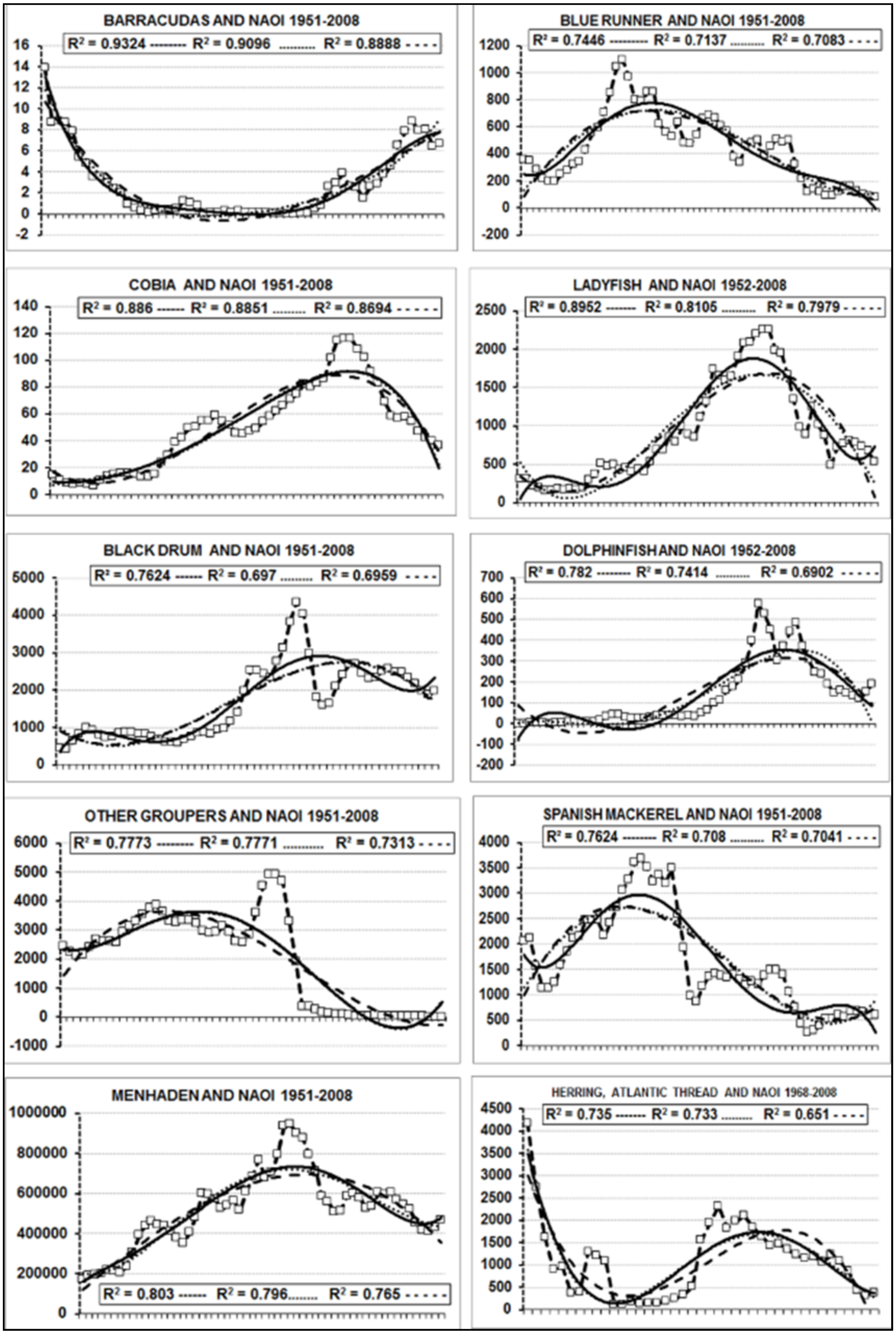

Figure 3. First group of stocks displaying multiple regression lines of third, fourth, and fifth degree, and their coefficient of determination (R^2), resulting after comparing the catch data as three-year running means of each stock indicated in the left column. The names of the stocks are in alphabetic order. The independent variable is the North Atlantic Oscillation Index.