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Climate variability and fisheries of black hakes (*Merluccius polli* and *Merluccius senegalensis*) in NW Africa: A first approach

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ABSTRACT

Fish populations and fisheries fluctuations are closely linked to climate dynamics through environmental variability that determines distribution, migration, and abundance. Fisheries science has largely focused on the larger fisheries of the northern hemisphere, some of which fluctuate at decadal time scales and show patterns of synchrony with low frequency signals, as reflected by climatic indices such as the North Atlantic Oscillation (NAO). However, there is limited information on these patterns for the NW African coast, where important international fisheries have been established for decades. In order to improve our understanding of the impacts of climate variability (in particular the NAO) on black hake dynamics in northwest Africa, we used catch-based relative abundance indices from commercial fisheries off Mauritania and Senegal as dependent variables in correlation analyses with the NAO index. Then we tested the mechanistic dependence between the NAO index and north–south (v) component of the wind stress as a proxy of upwelling variability. Black hake abundance was highly and negatively correlated with the NAO index, with a time lag of 3 years. The NAO explained around 40 to 50% of abundance variability between 1960 and 2003. At the same time, the wind stress fields were positively correlated with NAO during the same year, which was responsible for 53% of their variability. In contrast to what we expected, these results suggest that black hake abundance is inversely related with intensified and extended upwelling processes along the Mauritanian and Senegalese coast, causing the cold oceanographic season to extend more southwards than normal.

1. Introduction

The impact of large-scale climate changes on oceanic fishery production worldwide is a highly relevant scientific and economic issue, especially since the major fisheries have been found to show temporal variations in phase with climate oscillations (Klyashtorin, 1998).

Considerable attention has been focused in recent years on how ecosystems respond to natural climate variability at different time scales, with the understanding that this knowledge will be useful for managing natural resources in the face of the interaction with anthropogenic-induced changes. However, the impact of climate variations on ecological processes is difficult to elucidate because climate affects ecosystems in a number of ways rather than through a single factor (Stenseth et al., 2003).

One of the simplest ways to analyze the relationship between climate and its ecological impact is comparing ecological time-series with proxies of climate conditions, such as the North Atlantic Oscillation (NAO) index. These proxies reduce the space and time variability in simple measures by representing a 'weather package' that provides, at least at an initial stage, a robust assessment of the ecological effects of climate fluctuations (Stenseth et al., 2003). The NAO describes the atmospheric mass oscillation between the pressure centers of Iceland (low) and the Azores (high), and is the most robust pattern of recurrent atmospheric behavior in the North Atlantic region (Barnston and Livezey, 1987; Hurrell and Dickson, 2003).

One of the main methodological obstacles to determine the ecological effect of climate is the scarcity of ecological time-series large enough to detect the influence of the NAO. However, because of the economic importance of multinational fisheries of black hakes *Merluccius polli* and *Merluccius senegalensis* in NW Africa (mainly in Mauritania and Senegal) during the last 40 years, these fisheries time-series could be an adequate alternative to approach the ecological responses to the NAO. These fisheries are supported by one of the world's four largest productive marine regions: the NW African wind-induced upwelling system. It is a variable hydro-climatic unit that responds to seasonal displacement (north–south) in the Northeast trade winds (Wooster and McLain, 1976; Speth et al., 1978; Belvèze and Erzini, 1983). The upwelling events take place along a coastal belt that extends approximately 50 km offshore, mainly over the shelf (Van Camp et al., 1991; Nykjaer and Van Camp, 1994). South of 20° N, upwelling events are seasonal (winter–spring), and between 20° N

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and 25° N take place all year around, but they show large-scale temporal variations due to changes in wind conditions during certain years (Sedykh, 1979; Belvèze and Erzini, 1983). These changes are in phase and positively related, at least in the north part of the system, with NAO fluctuations (Meiners, 2007).

The coastal area off Mauritania is highly dynamic because the upwelled water belongs to two different sources. South of Cabo Blanco (21° N) upwelled water comes from the South-Central Atlantic Water SCAW (nutrient rich and low salinity). On the other hand, North of Cabo Blanco, the upwelled waters belongs to the North-Central Atlantic Water NCAW (less enriched and saltier waters). The two regions are separated off Cabo Blanco (Fraga, 1974) by a thermohaline front of more than 3°C and 1 psu (Elmoussaoui et al., 2003).

A recent study hypothesized that a strong, time-lagged, positive relationship exists between abundance of European hake *Merluccius merluccius* and NAO index in Moroccan and Saharan waters, as a consequence of variations in the productive regime induced by NAO (Meiners, 2007). Therefore the aim of this study was to test the possible deterministic relationships between the climate variability described by the NAO index and the abundance of black hakes *Merluccius polli* and *Merluccius senegalensis* fished in Mauritania and Senegal.

2. Methods

2.1. Fishery data

The fishery time-series of black hakes presented here is the largest and most complete data series for these species at present (Table 1). It comprises 40 years (1964 to 2003) divided into two well-defined periods according to the data source and the fishing fleet diversity. The first period (1964 to 1982) included data from the U.N. Food and Agriculture Organization (FAO) assessment working group of 1986 (FAO, 1986), where the catches are given for the Fishery Committee for the Eastern Central Atlantic (CECAF) area as a whole (Morocco, Mauritania and Senegal), therefore the data were taken for the entire area. The Russian, Spanish and Portuguese trawling fleets were the most important fleets fishing in the area. At the beginning, the Portuguese fleet was responsible of almost the 100% of the catch. Since the 1970s, the Spanish fleet increased its catch to close to 50% of the total. The Russian trawlers had the highest catch by far between 1973 and 1976 (around 80,000 t in 1974) and the Spanish fleet doubled its catch during the same period. In this working group the fishing effort (fishing days) was calculated for all the fleets based on Spanish catch per unit effort (CPUE) (see report FAO, 1986).

The second data period (1983 to 2003) was characterized by two facts. First, the data source was basically the last FAO assessment working group of Senegal in 2004 (FAO, 2006) corrected in a reviewing *ad hoc* working group in Spain (FAO, 2005) by recommendation of FAO staff. The correction was proposed because the biodynamic model did not fit properly with Mauritanian data due to high CPUE observed variability. Second, between 1983 and 1990 except the Spanish trawlers, all the foreign fleets ceased fishing in Mauritania and Senegal. After 1991, the bottom long-line and frozen Spanish fleets and Mauritanian trawlers started fishing in Mauritanian waters (FAO, 2006). The by-catch data of black hake of other fleets were included into the time-series. The total fishing effort in Senegal was estimated from the Spanish fleet as standard measure (FAO, 2006).

The catches of black hake in Mauritanian waters represented the 85% of the total reported for these species in the second period (FAO, 2006). Based on recent exhaustive observations aboard of Spanish trawlers and bottom long-liners, the proportion of *Merluccius polli* reaches 84% respect to *Merluccius senegalensis* (Fernández et al., 2006).

Table 1
Black hake fisheries time-series, 1964–2003.

Year	Catches (t)	Effort (fishing days)
1964	7014	2263
1965	14,118	3069
1966	16,994	3399
1967	22,626	4190
1968	19,615	3632
1969	21,396	4195
1970	30,092	6687
1971	30,711	6676
1972	36,755	9672
1973	105,493	21,529
1974	114,475	24,886
1975	99,583	24,288
1976	88,806	25,373
1977	35,041	18,443
1978	14,548	9699
1979	17,205	7820
1980	26,326	9750
1981	18,298	7319
1982	25,437	6001
1983	17,393	4024
1984	12,758	4743
1985	9415	4042
1986	9392	2801
1987	9329	2822
1988	9511	2883
1989	10,229	3509
1990	11,299	5000
1991	10,832	6156
1992	19,517	4834
1993	19,757	6214
1994	15,478	6569
1995	17,332	6183
1996	13,711	3996
1997	12,776	5298
1998	12,887	4078
1999	12,955	4199
2000	14,649	3585
2001	17,791	5396
2002	16,202	7762
2003	10,769	4776

2.2. NAO index

The annual winter NAO index was obtained from the National Center for Atmospheric Research (NCAR) http://www.cgd.ucar.edu/cas/jhurrell/indices.html (last visit May 2nd 2009). The index is based on the SLP difference between Lisbon (Portugal) and Stykkisholmur/Reykjavik (Iceland) (Hurrell, 1995). These NAO data were smoothed by running average of 3 years to reduce time-series noise.

2.3. Wind stress

Because the Mauritanian and Senegalese coast runs north to south, we developed a monthly mean time-series of north–south (v) wind stress component (τ_y) of the trade winds between 21° N to 15° N and 23° W to 30° W, as a proxy of Ekman transport of the wind-induced upwelling from 1960 to 2004. The Ekman transport is an adequate proxy of subsurface upwelled water to surface layers (Mann and Lazier, 1991). The wind stress data were obtained from the NOAA-CIRES Climate Diagnostic Center, Boulder, Colorado http://www.cdc.noaa.gov/data/gridded/data.coads.1deg.html (last visit May 2nd 2009).

2.4. Analysis

Correlation techniques were used to analyze and quantify the relationships between climate variability (NAO index) and the annual yields of black hake with different time lags between 1964 and 2003.