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ARTICLE

Assessing the influence of the atmospheric oscillations on pelagic and highly migratory sharks bycatches from Spanish Mediterranean Sea, a meta-analytic approach

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Resumen

Evaluación de la influencia de las oscilaciones atmosféricas sobre las capturas accesorias de tiburones pelágicos y altamente migratorios desde el Mediterráneo español, un enfoque meta-analítico

El objetivo principal del presente estudio fue analizar el efecto de las oscilaciones atmosféricas sobre los patrones de descarga de los tiburones pelágicos capturados de forma accesoria en palangre de superficie (fundamentalmente tintoreras, marrajos, y tiburones zorros) desde el Mediterráneo español, utilizando un enfoque meta-analítico. El objetivo final es conocer la respuesta de los tiburones altamente migratorios a los fenómenos climáticos de gran escala, y su posible relación con el efecto del calentamiento global. Se utilizaron dos fuentes de datos diferentes, ambas de áreas geográficas diferentes: mar de Alborán y mar Balear. Los resultados indican que la abundancia local de tiburones pelágicos podría estar mediada por la oscilación ártica.

Palabras clave: Oscilación ártica, Calentamiento Global, Oscilación del Atlántico Norte, tiburones.

Abstract

Blue shark, shortfin mako shark and the thresher sharks are the three taxa of pelagic sharks most caught as bycatch in the Spanish pelagic longline fishery from Mediterranean Sea. The main aim of the present study was to analyse the effect of atmospheric oscillations about landing patterns of blue shark, shortfin mako shark, and thresher sharks from Spanish Mediterranean Sea, using a meta-analytical approach. The ultimate goal was to understand the response of highly migratory sharks to large-scale climate phenomena, and its possible link with the effect of global warming. Two different data sources were used from different geographical areas: Alboran Sea and Balearic Sea. The results indicate that the local abundance of pelagic sharks could be mediated by the Arctic Oscillation.

Key words: Arctic Oscillation, Global warming, North Atlantic Oscillation, Sharks.

Introduction

Evidence for severe declines in large predatory fishes is increasing around the world. For example, recent estimates suggest that populations of large sharks have declined regionally by 90% or more (Heithaus *et al.* 2008). According to Ferretti *et al.* (2008), Hammerhead (*Sphyrna* spp., Rafinesque, 1810), blue shark *Prionace glauca* (L., 1758), mackerel sharks, e.i. *Isurus oxyrinchus* Rafinesque, 1810 and *Lamna nasus* (Bonnaterre, 1788), and thresher shark *Alopias vulpinus* (Bonnaterre, 1788), declined between 96 and 99.99% relative to their former abundance. According to World Conservation Union (IUCN) criteria, these species would be considered critically endangered.

Blue shark, shortfin mako shark, and the thresher sharks (including: *Alopias superciliosus* Lowe, 1841 and *A. vulpinus*) are the three taxa of pelagic sharks most caught as bycatch in the Spanish pelagic longline fishery from Mediterranean Sea (Megalofonou *et al.* 2005; Báez *et al.* 2009). Blue shark is the predominant shark species caught as bycatch in the drifting longline fisheries from Mediterranean Sea. Thus, in the Spanish surface longline fisheries in the Mediterranean targeting swordfish *Xiphias gladius* Linnaeus, 1758 from 1999 to 2001 represented 2% of the total catch (Valeiras & de la Serna 2003a, 2003b).

Alboran Sea showed the highest shark landings from the Mediterranean Sea (Castro *et al.* 1999, Valeiras *et al.* 2003a, Macías *et al.* 2004, Megalofonou *et al.* 2005), while there is a minimum from Strait of Sicilia (Megalofonou *et al.* 2005). These high bycatches of the sharks from Alboran Sea, could be probably related to its location, i.e. an important migratory channel, adjacent to the Atlantic Ocean (Megalofonou *et al.* 2005).

Blue shark, shortfin mako shark, and thresher sharks (*Alopias* sp.), are considered oceanic, pelagic, and highly migratory sharks. In this context, many authors have proposed to model the response of migratory species to large-scale climate phenomena, like the North Atlantic Oscillation (NAO), that integrate weather conditions over large areas, rather than local weather conditions (Forchhammer *et al.* 2002, Forchhammer & Post 2004, Robison *et al.* 2009).

The NAO is related with the different pressures between the low pressure center, that is typically located near Iceland, and the high pressure center that is typically located over the Azores. NAO is responsible for most of the climatic variability in the North Atlantic region, modifying direction and intensity of Westerlies, and the location of anticyclones, which could affect to the marine ecosystems and fisheries from Mediterranean Sea (Vicente-Serrano & Trigo 2011).

Another important atmospheric oscillation that drives the response of climate phenomena in the North Hemisphere is the Arctic Oscillation (AO). The AO refers to the pressure anomalies in the Arctic region, *i.e.*, if this pressure system over the Arctic is weaker than normal atmospheric pressure, which results in weaker upper level winds, or if this pressure system over the Arctic is higher than normal atmospheric pressure, which forces cold air and storms to remain further north (Thompson & Wallace 1998, Ambaum *et al.* 2001).

Both the NAO and AO describe the varying pressure gradients in the northern latitudes and the resultant effects on temperature and storm tracks across the continent. However, many authors have discussed if AO and NAO are two separate indices that are ultimately describing the same phenomenon (to see Thompson & Wallace 1998, Thompson *et al.* 2000, Lohmann *et al.* 2005), or two different indices that are affected for the same causal external parameters (Frias *et al.* 2005, Baldwin *et al.* 2007, Báez *et al.* 2013a).

The main aim of the present study was to analyze the effect of atmospheric oscillation (NAO and AO) on landing patterns of blue shark, shortfin mako shark, and thresher sharks (*Alopias* sp.) from Spanish Mediterranean Sea, using a meta-analytical approach. The ultimate goal was to understand of the response of highly migratory sharks to large-scale climate phenomena, and its possible link with the effect of global warming.

Material and Methods

For this study two different databases were used. On the one hand, the registered landings obtained for blue shark, shortfin mako shark, and thresher sharks (*Alopias* sp.) from the annual fisheries statistics published by the Junta de Andalucía (Andalusian Regional Government) (Galisteo *et al.*

2001a, 2001b, 2002, 2004, 2005, Alonso-Pozas *et al.* 2007, Galisteo *et al.* 2007, 2008, 2009a, 2009b, 2011, 2012, 2013 and JAND 2013), available for the period between 2000-2013 from Mediterranean harbours; which imply Alboran Sea. On the other hand, the registered landings obtained for blue shark, shortfin mako shark, and thresher sharks (*Alopias* sp.) from FishStat (Fisheries Data Analysis Software for Windows™) provided by the Fisheries and Aquaculture Department of Food and Agriculture Organization of the United Nations (FAO), available from link: http://www.fao.org/fishery/statistics/software/fishstatj/en (last accessed 15 May of 2014)

From FishStat the data landing of sharks reported for Spain from Balearic Sea fishing ground available for the period 1997-2011 were used. Thereby, two different data sources and from different geographical areas: Alboran Sea and Balearic Sea (Table 1).

	$Blue_{alb}$	$Shortfin_{alb}$	$Alopias_{alb}$	$Blue_{bal}$	$Alopias_{bal}$	$shortfin_{bal}$	NAO	NAO_{py}	NAO_w	AO	AO_{py}	AO_w
1997	n.a	n.a	n.a	146,000	3,000	6,000	-0.157	-0.214	-1.187	-0.040	-0.456	-0.477
1998	n.a	n.a	n.a	59,000	7,000	7,000	-0.481	-0.157	0.100	-0.271	-0.040	0.066
1999	n.a	n.a	n.a	20,000	5,000	5,000	0.391	-0.481	0.820	0.113	-0.271	0.549
2000	3,342	1,011	58	26,000	0	3,000	0.207	0.391	-0.193	-0.046	0.113	-1.206
2001	38,493	60,121	4,060	6,000	0	2,000	-0.183	0.207	-0.147	-0.162	-0.046	0.068
2002	9,089	2,664	910	3,000	0	2,000	0.039	-0.183	-1.133	0.072	-0.162	-1.502
2003	9,993	2,545	1,994	9,000	0	2,000	0.098	0.039	0.080	0.152	0.072	0.079
2004	112,173	30,617	25,057	7,000	3,000	2,000	0.243	0.098	0.280	-0.192	0.152	0.464
2005	24,944	5,903	1,147	9,000	3,000	2,000	-0.268	0.243	-0.577	-0.375	-0.192	-0.615
2006	15,783	1,707	2,382	61,000	4,000	4,000	-0.208	-0.268	-0.153	0.138	-0.375	0.591
2007	50,610	13,608	6,087	3,000	2,000	1,000	0.173	-0.208	0.457	0.269	0.138	0.228
2008	77,717	10,480	3,731	9,000	4,000	2,000	-0.378	0.173	-0.213	0.177	0.269	0.805
2009	9,894	1,562	2,184	7,000	4,000	2,000	-0.243	-0.378	-0.993	-0.330	0.177	-1.498
2010	31,763	7,993		39,000		8,000	-1.153	-0.243	-1.467	-1.043	-0.330	-1.158
2011	51,656	11,874		59,850		12,980	0.293	-1.153	1.423	0.526	-1.043	1.493
2012	40,076	10,341		n.a		n.a	-0.456	0.293	-0.823	-0.182	0.526	-1.125
2013	35,393	2,728.25		n.a		n.a	0.210	-0.456	0.190	0.001	-0.182	1.256

Tabla 1. Variables de estudio por año. Descargas, en kg, de: **$Blue_{alb}$:** tiburón azul en el mar de Alborán; **$Blue_{bal}$:** tiburón azul en el mar Balear; **$Shortfin_{alb}$:** marrajo en el mar de Alborán; **$Shortfin_{bal}$:** marrajo en el mar Balear; **$Alopias_{alb}$:** tiburones zorro en el mar de Alborán; **$Alopias_{bal}$:** tiburones zorro en el mar Balear. **NAO:** Oscilación del Atlántico Norte; **NAO_{py}:** Oscilación del Atlántico Norte en el año anterior; **NAO_w:** Oscilación del Atlántico Norte en el invierno anterior; **AO:** Oscilación Ártica; **AO_{py}:** Oscilación Ártica en el año anterior; **AO_w:** Oscilación Ártica en el anterior invierno. **n.a.:** datos no disponibles.

Table 1. Study variables by year. Landings, in kg, of: **$Blue_{alb}$:** blue shark from Alboran Sea; **$Blue_{bal}$:** blue shark from Balearic Sea; **$Shortfin_{alb}$:** shortfin mako shark from Alboran Sea; **$Shortfin_{bal}$:** shortfin mako shark from Balearic Sea; **$Alopias_{alb}$:** thresher sharks landings from Alboran Sea; **$Alopias_{bal}$:** thresher sharks from Balearic Sea. **NAO:** North Atlantic Oscillation; **NAO_{py}:** North Atlantic Oscillation in the previous year; **NAO_w:** North Atlantic Oscillation in the previous winter; **AO:** Arctic Oscillation; **AO_{py}:** Arctic Oscillation in the previous year; **AO_w:** Arctic Oscillation in the previous winter. **n.a.:** data not available.

Although, pelagic sharks have been reported as bycatch on trawl fisheries (e.g. Zeeberg *et al.* 2006), and tuna purse seines (for example Amandè *et al.* 2011) from other seas, in the Spanish trawl and purse seine Mediterranean fisheries it is an unusual bycatch. For example, Abad *et al.* (2007) did not report pelagic sharks as bycatch from trawl fisheries Alboran Sea, similarly Fromentin and Farrugio (2005) did not report any pelagic shark as bycatch from tuna purse seine fisheries from Mediterranean Sea. However, pelagic sharks are usually reported as bycatch of the Spanish drifting longline. Thereby, the surface drifting longline fisheries were considered as the significant origin of pelagic sharks landings reported. The Spanish surface longline fleet consists of approximately 151 vessels that fish on a year-round basis (BOE 59: 22308-22313; date 21/02/2014). Vessel length range from 12 to 27 m and fishing trips are often of short duration (one day to six days). A major description of these gears and fisheries are available in Camiñas *et al.* (2006), Báez *et al.* (2007a, b), García-Barcelona *et al.* (2010), and Báez *et al.* (2013b).

Alboran Sea showed the maximum value for the observed bycatches of pelagic sharks (61.5% of the observed catches of blue shark, shortfin mako shark, and thresher sharks reported by Megalofonou *et al.* 2005), while Balearic Islands area showed 1.7% of the observed catches of blue shark, shortfin mako shark, and thresher sharks reported by Megalofonou *et al.* (2005).

Monthly values of the NAO index and AO index during the study period were taken from the website (from 1997 to 2012) of the National Oceanic and Atmospheric Administration: http://www.cpc.noaa.gov/products/precip/CWlink/pna/nao_index.html and http://www.esrl.noaa.gov/psd/data/correlation/ao.data, respectively.

The atmospheric oscillations present strong inter-annual and intra-annual variability; there is a strong NAO/AO pattern only in winter, primarily from November to March (Hurrell 1995). Moreover, several studies have shown that changes in NAO/AO trends have a delayed effect on aquatic ecosystems due to ecosystem inertia (Báez *et al.*, 2013a). For this reason, I compared landing of pelagic sharks (blue shark, shortfin mako shark, and thresher sharks), *versus* to the average NAO and AO index in the previous year (NAO_{py} and AO_{py} hereafter), and during the winter prior to landing, *i.e.,* since November to December from the previous year (NAO_w and AO_w hereafter) (Table 1).

As a first step correlation between blue shark, shortfin mako shark, and thresher sharks landings from Balearic Sea and Alboran Sea was performed using Pearson correlation, having previously tested the normality of the variables using the Kolmogorov-Smirnov test of one sample (Sokal & Rohlf 1995). In a second step, linear and non-linear regressions was performed to test the responses of blue shark, shortfin mako shark, and thresher sharks landings from Balearic Sea and Alboran Sea *versus* the independent variables NAO_{py}, NAO_w, AO_{py} and AO_w. The best fit among was selected several significant regressions when different degrees of freedom were involved, in accordance with the highest F-value.

Results

A significant positive correlation was found between blue shark landings *versus* thresher sharks landings from Alboran Sea (r=0.851; df=10; p= 0.002), blue shark landings versus shortfin mako shark landings from Balearic Sea (r=0.579; df= 15; p= 0.024), and shortfin mako shark versus thresher sharks landings from Balearic Sea (r= 0.618; df= 13; p= 0.024).

There was a significant negative linear relationship between blue shark landings ($Blue_{bal}$) and shortfin mako shark ($Shortfin_{bal}$) from Balearic Sea versus AO_{py}, respectively, according to the functions (Figure 1 and 2):

$$Blue_{bal}= 22144.21 -66041.549*AO_{py} \quad (R^2= 0.333; F= 6.491; P= 0.024)$$

$$Shortfin_{bal}= 2980.765 -8158.739*AO_{py} \quad (R^2= 0.71; F= 31.796; P< 0.0001)$$

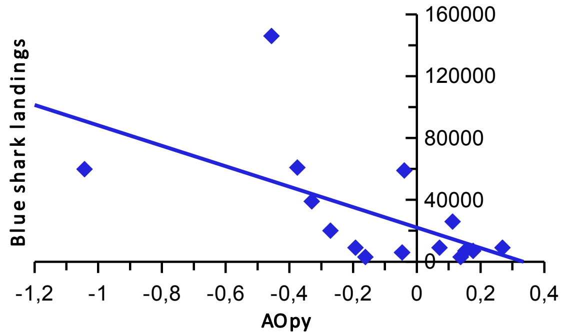

Figura 1. Relación lineal negativa entre descargas, en kg, de tiburón azul del mar Balear y la Oscilación Ártica en el año anterior (AO_{py}).

Figure 1. Negative linear relationship between blue shark landings, in kg, from Balearic Sea *versus* Arctic Oscillation in previous year (AO_{py}).

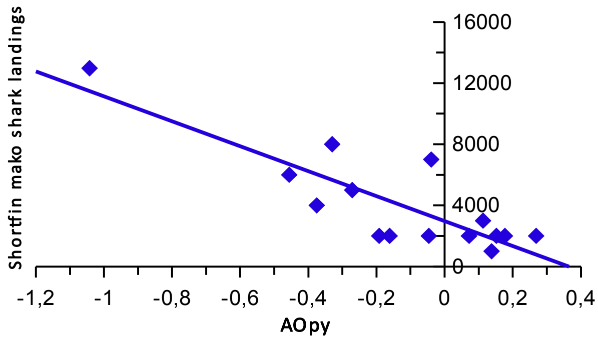

Figura 2. Relación lineal negativa entre descargas, en kg, de marrajo del mar Balear y la Oscilación Ártica en el año anterior (AO_{py}).

Figure 2. Negative linear relationship between shortfin mako shark landings, in kg, from Balearic Sea *versus* Arctic Oscillation in previous year (AO_{py}).

There was a significant positive exponential relationship between blue shark landings ($Blue_{alb}$) and thresher sharks landings ($Alopias_{alb}$) from Alboran Sea versus AO_w, respectively, according to the functions (Figure 3 and 4):

$$Blue_{alb}= 27615.827*Exp^{0.55*AOw} \quad (R^2= 0.342; F= 6.234; P= 0.028)$$

$$Alopias_{alb}= 2772.87* Exp^{1.129*AOw} \quad (R^2= 0.402; F= 5.371; P= 0.049)$$

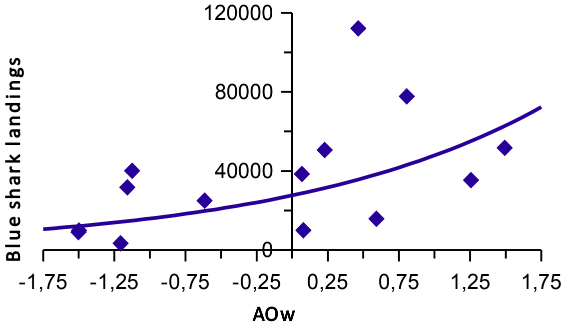

Figura 3. Relación exponencial positiva entre descargas, en kg, de tiburón azul del mar de Alborán y la Oscilación Ártica en invierno (AO_W).

Figure 3. Positive exponential relationship between blue shark landings in Kg from Alboran Sea *versus* Arctic Oscillation in winter (AO_w).

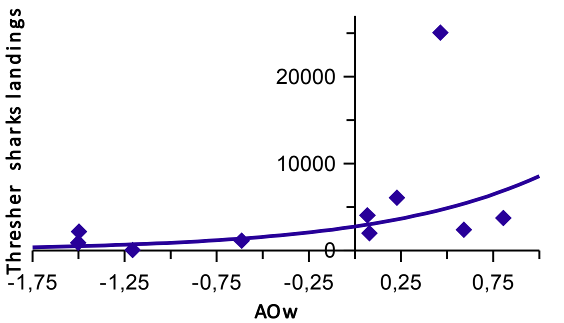

Figura 4. Relación exponencial positiva entre descargas, en kg, de tiburones zorros del mar de Alborán y la Oscilación Ártica en invierno (AO_W).

Figure 4. Positive exponential relationship between thresher sharks landings, in kg, from Alboran Sea *versus* Arctic Oscillation winter (AO_w).

Discussion

The results indicate that the local abundance of blue shark and thresher sharks landings could be mediated by the AO. The AO index can be positive or negative. It is widely known that during the negative AO there are weak Westerlies over northern Europe, and storms develop over the Mediterranean region (Ginati & Rosenfeld 2013). The hypothesis under study implies that the years with AO in negative phase, could increase supply of nutrients from the land to the sea in the area around the Balearic Sea. Given that several authors have shown that the Arctic Oscillation may be affected by the growing trend of global warming (Ginati & Rosenfeld 2013, Krichak *et al.* 2014), the results could mean that changes in the AO index towards a positive rate (as predicted by the Atmospheric General Circulation Models) could affect the local abundance of pelagic sharks from Balearic Sea and Alboran Sea.

On the one hand, this study is limited by the fact that the landings involved different fishing efforts. Moreover, *Alopias* sp. series is limited to 2010 year, because since this year its fishing is prohibited according to the Spanish legislation (BOE 240: 84098-84099; date 05/X/2009). On the other hand, the negative relationships observed between blue shark landings and shortfin mako shark landings from Balearic Sea *versus* AO_{py}, and positive relationships observed between blue shark landings and thresher sharks landings from Alboran Sea versus AO_w are very consistent, and they have to be taken in consideration. In this context, the two different databases used in this study (fisheries landings reported by Andalusian Regional Government, and FishStat Fisheries Data Analysis Software for Windows™) provide a useful tool, despite that they do not provide fishing effort.

There are two possible explanations in relation to these findings: i) negative AO phases increase in nutrients leads to an increase of productivity with a cascade effect on the entire food web of the area, increasing the number of prey of the swordfish, and thereby increase the fisheries effort in the area, or ii) negative AO phases increase in nutrients leads to an increase of productivity with a cascade effect on the entire food web of the area, increasing the number of prey of the pelagic sharks, begins a unidirectional flow of sharks individuals migrating to the Balearic Sea in detriment of near areas, such as the Alboran Sea.

Many studies indicate that the Spanish longline fleet is concentrated mainly around the Balearic Islands (Camiñas *et al.* 2006, Báez *et al.* 2007a, 2007b, García-Barcelona *et al.* 2010, Báez *et al.* 2013b). Thus, Alboran Sea was used by approximately 5% of the operative fleet; while Balearic Sea was used by approximately 80% of the operative fleet. Moreover, no correlation was found between landings of pelagic sharks (blue shark, shortfin mako shark, and thresher sharks) from Balearic Sea and Alboran Sea versus swordfish landings in both data sources.

The seasonality and migration pattern of blue shark have been studied by intensive tagging programs (for example, Fitzmaurice *et al.* 2005) or long-term electronic tagging experiments (for example, Vandeperre *et al.* 2014). These studies reported useful and real understanding on the migratory patterns of blue sharks, and how these patterns change across a blue shark´s life history. In this context, blue shark undertakes very long distance migrations which cover long distances on the high seas. Their migrations are very complex, relating to prey availability and breeding cycles, with segregation by sex and reproductive stage (IUCN Species Survival Commission’s Shark Specialist Group 2007).

Similarly, the shortfin mako shark is a very active fish that is highly migratory. Based on extensive tagging programs in the North Atlantic, it was observed that shortfin mako carry out extensive migrations of up to 4,542 km. However, transatlantic migrations are not common for this species. Thus, the migration is limited to vicinity thereof (Mejuto *et al.* 2005, Valeiras & Abad, 2006). Although, *A. superciliosus* and *A. vulpinus* are considered a highly migratory species, information about their movements are scarce (IUCN Species Survival Commission’s Shark Specialist Group 2007).

In this context, future tagging programs of pelagic sharks should be conducted to test the hypothesis put forward in this study, and to understand the possible effects that global warming may have on the pelagic shark populations in the Mediterranean Sea.

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