# Effects of climate on Mediterranean fisheries: the Balearic Islands, Spain, as a case study

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Now a days nobody doubts that environmental fluctuations must be taken into account when analyzing fishing impacts on marine resources and ecosystems. In fact, the first trials to relate fluctuations of fishing catches with climate come from the 1950s, even earlier, but the successes were very limited. In any case, it is clear that fluctuations in landings cannot be exclusively explained by the fishing exploitation itself. Based on this premise, the Spanish Institute of Oceanography started a systematic sampling of landings from the Balearic Islands (western Mediterranean) during the late 1970s.

A fluctuation with a pronounced periodicity in the historical time series of hake (Merluccius merluccius) and red mullets (Mullus spp.) landings of the bottom trawl fleet from the Balearic Islands (western Mediterranean) was observed during the period 1980-1991 (Oliver, 1993). Posterior analyses of the population dynamics of these species revealed that such fluctuations might be related to underlying environmental factors because the reproductive success of marine organisms is highly dependent on oceanographic conditions.

**The influence of abiotic and biotic factors on the demersal ecosystems and resources**

Between 2003 and 2006, the multidisciplinary research "Influence of oceanographic structure and dinamics on DEmersal populations in waters of the BAlearic Islands" (IDEA) project (www.ba.ieo.es/idea) studied the influence of abiotic (oceanographic structure and dynamics) and biotic (trophic resources) factors on the demersal ecosystems and resources off the Balearic Islands. Special emphasis was given to the population dynamics of hake and red shrimp (Aristeus antennatus) owing to its ecological relevance on demersal communities and economic importance for fisheries.

Two different study strategies were applied to tackle these objectives: (i) a local-scale approach to analyse intra-annual (seasonal) variability through six oceanographic surveys and the scientific monitoring of the bottom trawl fleet; and (ii) a large-scale approach to investigate how the population dynamics of the target species was influenced by the inter-annual variability of the environmental conditions using climatic, meteorological and oceanographic indices.

The IDEA project allowed the development of models explaining how climatic conditions in the northwestern Mediterranean influence the hydrodynamics around the Balearic Islands, and the recruitment processes of hake and red shrimp (Massutí et al., 2008). In the case of hake, this environmental influence was related to the long term fishing pressure, which reduced the resilience of the population to adverse environmental conditions. Contrasting hydrodynamic scenarios were found on traditional fishing grounds situated on the north and south of the Archipelago, which could explain the differences observed in their trophic resources (zooplankton and suprabenthos), nekto-benthic assemblages and different life-history traits of hake, red shrimp and other deep water crustaceans. In addition, it was observed that environmental (modeled by meso- and macroscale climatic indexes) and/or biological (spawning population and body condition) factors affect the dynamics of hake and red shrimp populations and their accessibility to fishing exploitation (Massutí et al., 2008).

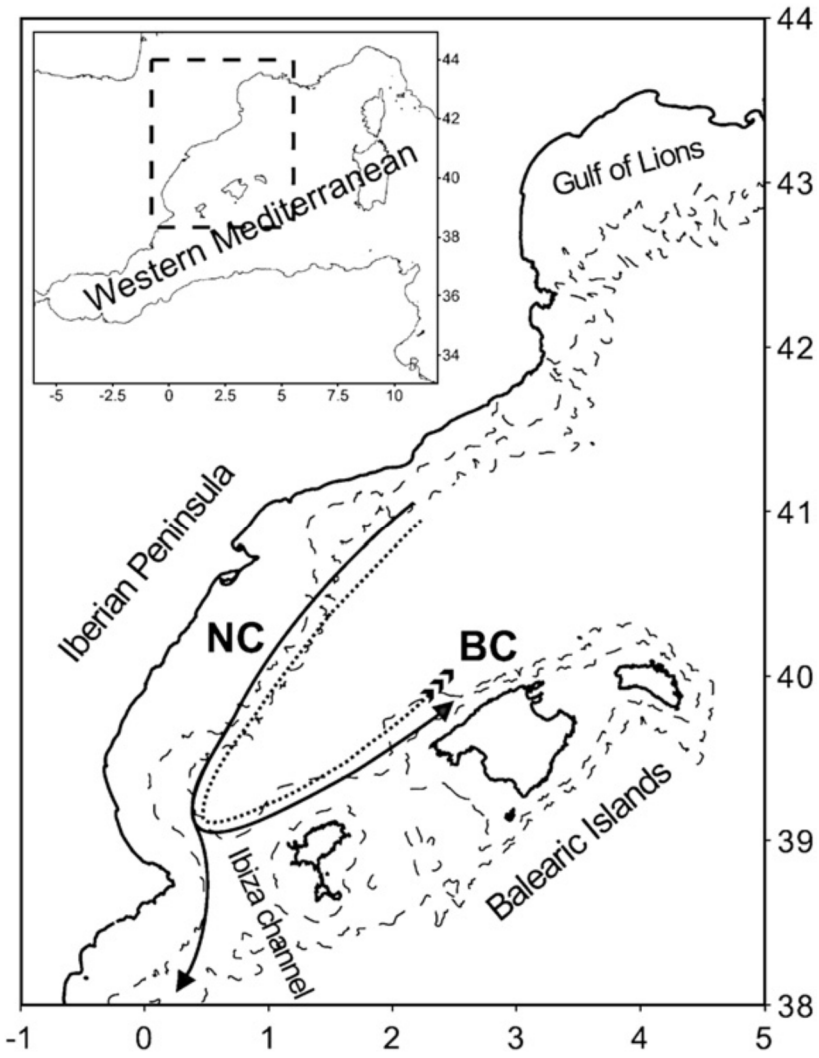
The project revealed that the macro and meso-scale climate regimes prevailing on the two contrasting oceanographic scenarios around the Balearic Islands affected the population dynamics of hake and red shrimp. This was especially true for recruitment, which was enhanced during periods of low global (North Atlantic Oscillation) and local (IDEA) indices.

During these periods, colder-than-normal winters generate high amounts of cold Western Mediterranean Intermediate Waters (WIW) in the Gulf of Lions, which flow southwards and reach the Balearic Islands channels in spring, increasing the productivity in the area (Figure 1).

This oceanographic scenario would also affect the distribution of hake, increasing its accessibility on trawl fleet fishing grounds. On the other hand, the abundance of red shrimp seems to be enhanced by high periods of a regional index (Mediterranean Oscillation), which increases the presence of the saline and warm Levantine Intermediate Waters (LIW) in the study area.

**Figure 1**

Location of the study area: the Balearic Islands, showing the 200 and 1000 m isobaths and a representation of the major slope currents in the region during spring–summer




*(NC: Northern Current; BC: Balearic Current), after mild (solid line) and cold (dashed line) winters.*

According to the Ecosystem Approach to Fisheries (EAF) the assessment and management of marine living resources must incorporate the complexity and global functioning of the ecosystems, their natural variations and the factors that control these changes, as well as the habitat and other components of the ecosystem and their interactions. This is related with the main conclusion of the IDEA project, which point to environmental changes and fishing pressure being key stressors to be taken into account when analyzing population dynamics of western Mediterranean demersal resources.

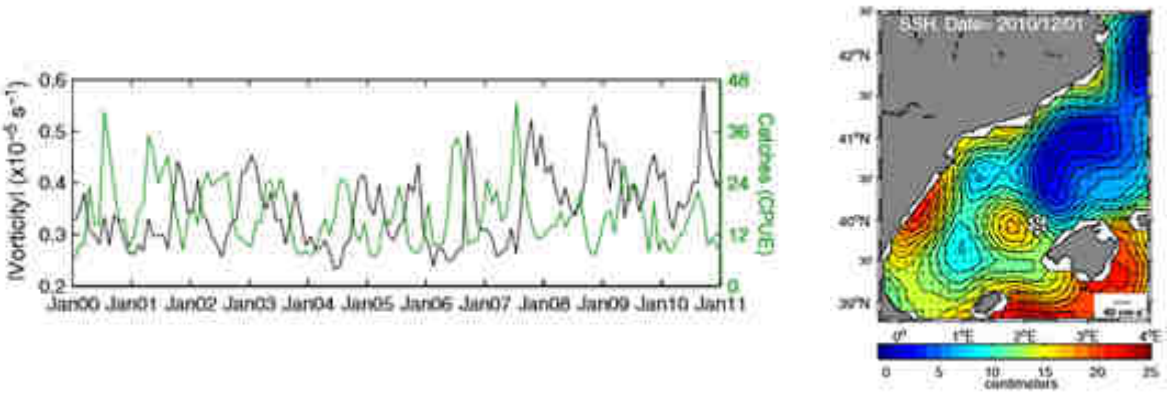
**Structure and dynamics of the bentho-pelagic slope ecosystems**

The IDEADOS project (www.ba.ieo.es/ideados/), developed between 2009 and 2012, was launched to investigate further on fisheries-climate interactions in the Balearic Islands (Massutí et al., 2014). This project aimed to determine the relationships between environmental conditions and the nekto-benthic slope communities in two areas with different geomorphologic and hydrodynamic characteristics: the Balearic (BsB) and Algerian (AsB) sub-basins, respectively.

Within the framework of this project, Amores et al. (2014) modeled the influence of the hydrodynamic conditions on the accessibility of red shrimp and other demersal species to the deep water trawl fishery off the Balearic Islands. Monthly catches per unit of effort (CPUE) of red shrimp and the mean ocean surface vorticity in its fishing grounds were compared between 2000 and 2010. A good correlation was found between the rises in the surrounding surface vorticity and the drops in the red shrimp CPUE (Figure 2). Such a correlation indicates that most of the surface vorticity episodes could reach the bottom, increasing the seabed velocities and producing sediment resuspension, which could affect the near bottom water turbidity. Red shrimp would respond to this increased turbidity, disappearing from the fishing grounds, probably moving downwards to deeper waters, and consequently decreasing their accessibility to fishing exploitation. This would explain the summer aggregations of red shrimp on north-western fishing grounds and its disappearance during the winter months when vorticity increases. Fishers are well aware of this dynamics, moving to those grounds in summer but leaving them in winter. Other by-cath species of the red shrimp fishery, having different behaviors and feeding habits, exhibited different responses to these events, but all of them were consistent with the increased bottom water turbidity.

**Figure 2**

Derivative time series of vorticity (black) and Aristeus antennatus CPUE's (green) on the left, and Sea Surface Height (SSH) image from 1 December 2010 showing an eddy in the region analyzed n the right. In the series of the vorticity derivative, the negative values have been fixed at 0, while the positive values of the derivative CPUE's series have been set at 0. From Amores et al. (2014).

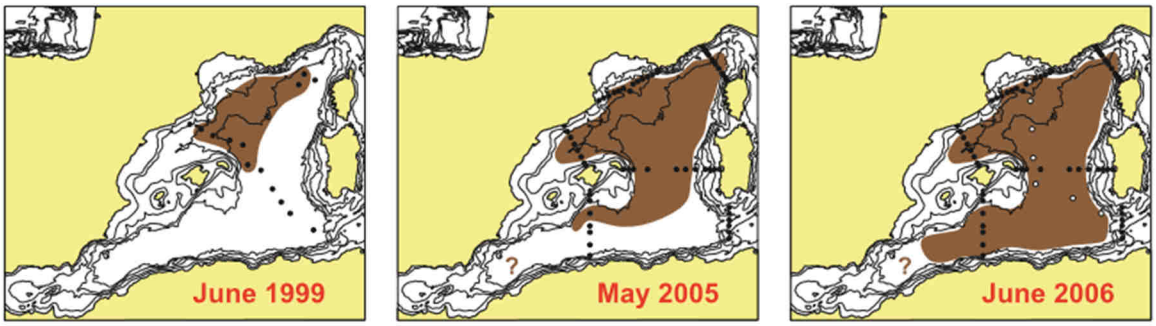


This vorticity effect off the Balearic Islands is similar, although lower in magnitude, to the one suggested by Company et al. (2008) on the down slope shelf dense water current events of the submarine canyons in the Catalan margin, which also affects the catchability of red shrimp. The analysis of CTD casts conducted from 1998 to 2011 has documented that cascading is a very important factor affecting not only red shimp grounds but also the entire western Mediterranean basin, through transporting suspended particulate matter from the coastal regions down to deep ecosystems (Puig et al., 2013). After the 1999 and 2005–2006 cascading events, the Western Mediterranean Deep Water (WMDW) was characterized by the presence of a thick bottom nepheloid layer (BNL), which corresponded in thickness with a thermohaline anomaly generated by the mixture of dense waters.

This BNL can be hundreds of meters thick and can reach peaks of suspended sediment concentrations close to the continental shelf. After winter 1999, the BNL spread over the north-western Mediterranean, while after winters 2005 and 2006 the BNL covered the entire western basin (Figure 3). Thickness and concentration of the BNL tend to diminish with time, but this trend is highly dependent on the volume of dense water generated. After winter 1999, the BNL signal vanished in one year, but after winters 2005 and 2006 it lasted for longer and the turbidity signal could still be distinguished in 2011. It highlights the fact that the WMDW can be periodically affected by the arrival of new dense waters loaded with suspended particles, mainly introduced by resuspension processes during major cascading events, being a key process that could ultimately affect deep-sea biogeochemical cycles in the western Mediterranean (Puig, 2013).

**Figure 3**

Maps showing the extension of the BNL in the western Mediterranean basin after deep cascading events




*Black dots represent the CTD locations (June 1999: TRANSMED and GEOTETHYS; May 2005: MEDOCC-05; June 2006: MEDOCC-06). Note that during the trans-Mediterranean cruise BOUM conducted in July 2008 (CTD locations illustrated with white dots), the BNL was still present in the entire basin. From Puig, P., et al. (2013)*

**Synergistic effects of climate and fishing on demersal assemblages and resources**

Accumulating evidence shows that fishing exploitation and environmental variables can synergistically affect the population dynamics of exploited populations (Perry et al., 2010; Planque et al., 2010). Such synchronic responses related to interactions between fishing impact and climate variability were reported for six exploited demersal species (elasmobranchs, hake, red mullets, octopus, squid and cuttlefish) in the Balearic Islands from 1965–2008 (Quetglas et al., 2013). Throughout this period, the fishing activity experienced a sharp increase in fishing effort, which caused all stocks to shift from an early period of underexploitation to a later period of overexploitation. This change altered the population resilience of the stocks and brought about an increase in the sensitivity of its dynamics to climate variability.

Landings increased exponentially when underexploited but displayed an oscillatory behavior once overexploited. Climatic indices, related to the Mediterranean mesoscale hydrography (IDEA index) and large-scale north Atlantic climatic variability (NOA), seemed to affect the species with broader age structure and longer lifespan, while the global-scale El Niño Southern Oscillation index (ENSO) positively influenced the population abundances of species with a narrow age structure and short lifespan. The species affected by ENSO preferentially inhabit the continental shelf, suggesting that Mediterranean shelf ecosystems are sensitive to the hydroclimatic variability linked to global climate.

A third project, ECLIPSAME (www.eclipsame.com), aimed to analyze the synergistic effects of climate and fishing on demersal assemblages and resources, through a comparative approach between marine ecosystems of the North-eastern Atlantic and the western Mediterranean. The overall goal of this project was twofold. First, it was tried to identify when changes occurring in marine ecosystems and their populations are caused by: a) climate; b) fishing impact; or c) a combination of both. Second, the existence of synchronous fluctuations between areas in the abundance of some key species of the ecosystem (e.g. elasmobranches and cephalopods), and exploited species (hake, red shrimp and red mullet, among others) was analyzed.

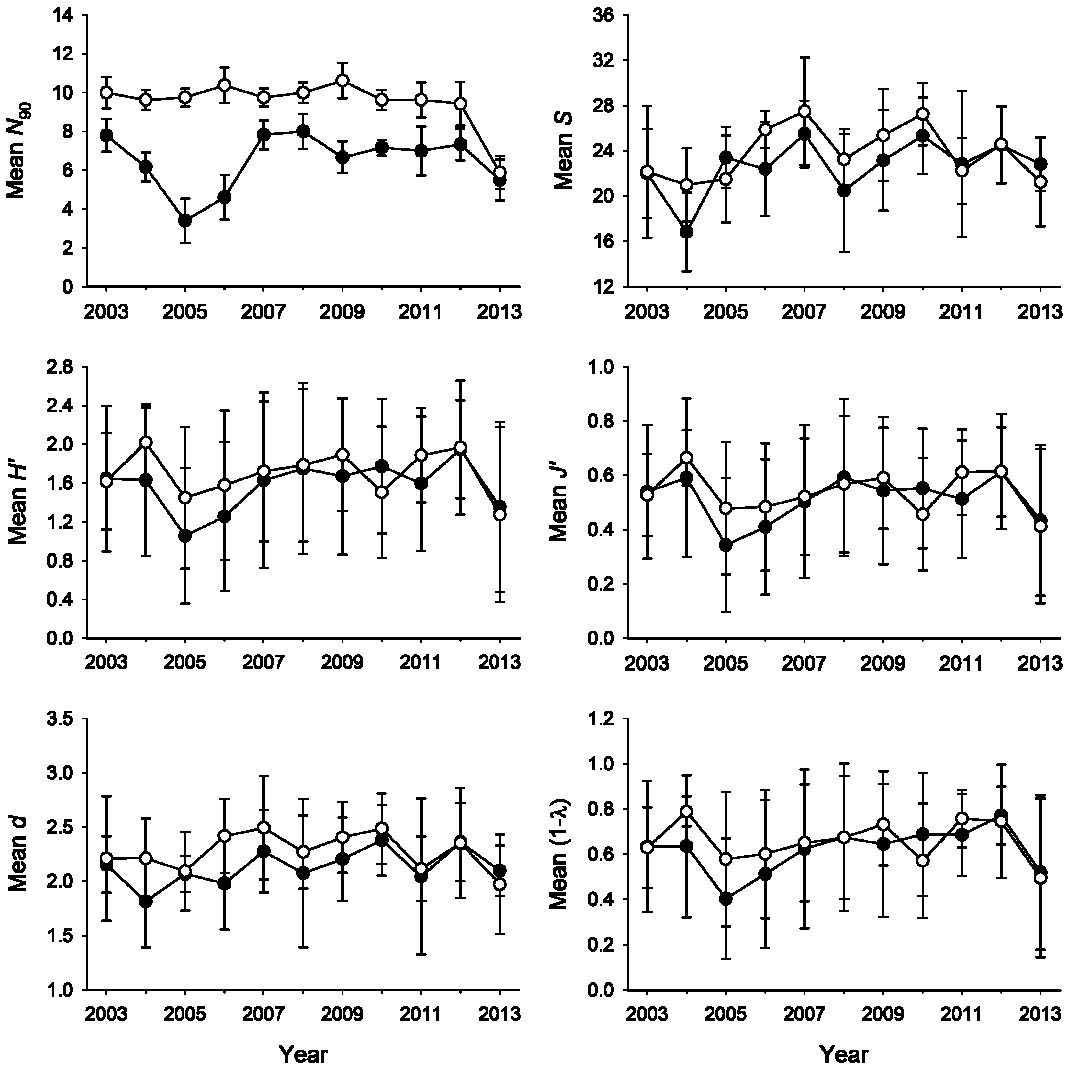
The project was structured around three main lines: 1) produce and make accessible to the scientific community a database assembling all the currently available information area one climate, oceanography, biology and fisheries for each study; 2) analyze the spatiotemporal evolution of climatic, oceanographic, fisheries, biological and ecological processes; and 3) model the synergistic effects of climate and fishing on populations, communities and marine ecosystems.

Results from this project revealed that cephalopod populations of the western Mediterranean mainly respond to ecological processes triggered by climatic variability and trophic drivers, such as chlorophyll concentration and prey densities. The same processes influenced both benthic and pelagic cephalopods, but exhibiting different sensitivities and time-lags in response to those factors, depending also on the different local environmental conditions dictated by ecological processes and trophic pathways across this region. These local scale differences as response to density independent variables (chlorophyll concentration) have also been observed in the body conditions of gadoid fishes, which can also be influenced by density-dependent (intra-specific competition) and the fishing pressure, and show different responses depending on the ontogeny (recruits, juveniles and adults). Fishing activity is an important driver of demersal assemblages, especially in the case of elasmobranches, which diversity and abundance along the western Mediterranean is clearly influenced by the bottom trawl fishery. These results also point to the fact that harvesting and environmental drivers, as well as life history strategies, should be taken into account for fishery management within the current context of global change in the western Mediterranean.

An important effort has also been made within the ECLIPSAME project to monitor the loss of biodiversity due to anthropogenic impacts in an accurate and comprehensible way. A new diversity index was developed (N90; Farriols et al., 2015), which showed higher sensitivity to fishing pressure than traditional diversity indices (species richness, Shannon-Wienner, Simpson, Pielou and Margalef). In addition, N90 also detects indirect fishing impacts by fluctuating in response to environmental variation in impacted areas, making it a good environmental indicator to detect synergies between climate and fishing impacts at a community level (Figure 4).

**Figure 4**

Annual mean values and standard deviation of the diversity indices analyzed for demersal fish assemblages during the period 2003–2013




*(N90; S: species richness; H': Shannon–Wienner; J': Pielou; d: Margalef; 1-λ: Simpson)*
*Black dots: high level of fishing impact; white dots: low level of fishing impact. From Farriols et al. (2015)*

## Conclusion

There remains a lot to know about the impact of climate change and the environmental variability on Mediterranean marine resources and ecosystems since there are many aspects that still need to be addressed. The results and modeling approaches of previous projects such as IDEA, IDEADOS and ECLIPSAME, are on the basis of the CLIFISH project ("Climatic variability and fisheries in the 21st century: Effects of global change on nektobenthic populations and communities"), a new project that will be developed between 2016 and 2018.

CLIFISH also involves a multidisciplinary research team, including experts on hydrodynamics and climate change scenarios, biodiversity and population dynamics, living resources and fisheries. In contrast to all previous projects, its main objective is to make predictions and projections of demersal exploited communities, their main species and fisheries at different time horizons and under different global change scenarios.

***Aknowledgment***

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## Bibliography / More information

- Amores, A., Rueda, L., Monserrat,S., Guijarro,B., Pasqual,C., Massutí, E. 2014. *Influence of the hydrodynamic conditions on the accessibility of Aristeus antennatus and other demersal species to the deep water trawl fishery off the Balearic Islands (western Medieterranean)*. Journal of Marine Systems 138, 203–210.

- Company, J.B., Puig, P., Sardà, F., Palanques, A., Latasa, M., Scharek, R., 2008. *Climate influence on deep sea populations*. PLoS ONE 3, e1431.

- Farriols, M.T., Ordines,F. , Hidalgo, M., Guijarro, B., Massutí, E. 2015. *N90index: A new approach to biodiversity based on similarity andsensitive to direct and indirect fishing impact*. Ecological Indicators 52 245–255.

- Massutí, E., Monserrat, S., Oliver, P., Moranta, J., Lopez-Jurado, J. L., Marcos,M., Hidalgo, M, Guijarro, B., Carbonell, A. and Pereda, P. 2008. *The influence of oceanographic scenarios on the population dynamics of demersal resources in the western Mediterranean: Hypothesis for hake and red shrimp off Balearic Islands*. Journal of Marine Systems 71, 421–438.

- Massutí, E., Olivar, M.P. and Monserrat, S. 2014. *Towards understanding the influence of environmental conditions on demersal resources and ecosystems in the western Mediterranean: Motivations, aims and methods of the IDEADOS project*. Journal of Marine Systems 138 (2014), 3-19.

- Oliver,P. 1993. Analysis of fluctuations observed in the trawl fleet landings of the Balearic Islands. Sci. Mar. 57 (2–3), 219–227.

- Perry, R. I., Cury, P., Brander, K., Jennings, S., Moellmann, C., and Planque, B. 2010. *Sensitivity of marine systems to climate and fishing: concepts, issues and management responses*. Journal of Marine Systems, 79: 427–435.

- Planque, B., Fromentin, J. M., Cury, P., Drinkwater, K. F., Jennings, S., Perry, R. I, and Kifani, S. 2010. *How does fishing alter marine populations and ecosystems sensitivity to climate?* Journal of Marine Systems, 79: 403–417.

- Puig, P., Durrieu de Madron, X., Salat J., Schroeder, K., Martín, J., Karageorgis, A.P., Palanques, A., Roullier, F., Lopez-Jurado, J.L., Emelianov, M., Moutin, T., Houper, L. 2013. *Thick bottom nepheloid layers in the western Mediterranean generated by deep dense shelf water cascading*, Progress in Oceanography, 111 1–23.

- Quetglas, A., Ordines, F., Hidalgo, M., Monserrat, S., Ruiz, S., Amores, A., Moranta, J., and Massutí, E. 2013. *Synchronous combined effects of fishing and climate within a demersal community*. ICES Journal of Marine Science 70(2), 319–328.