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Exploring long-term variability of *Nephrops norvegicus* landing per unit effort (LPUE) off North Galicia (NW Spain)

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ABSTRACT

Landings of *Nephrops norvegicus* from North Galicia (Northwest Spain) have decreased by 80% from 1975 to 2001. Variability in the landings per unit effort (LPUE) of this stock was investigated by using time series approach. The LPUE time series (1975–2001) exhibited a seasonal pattern. The seasonal decomposition of the LPUE showed a declining in the trend-cycle component from 1987 onwards.

Univariate and dynamic regression ARMA models were fitted to the LPUE time series. Population (proportion of males, proportion of ovigerous females and recruits) and environmental variables (temperature, salinity, nitrates and chlorophyll at 70 m depth, upwelling and sea surface temperature) were tested at different lags as explanatory variables. The proportion of males 4 years ago was the key factor explaining LPUE fluctuations.

1. Introduction

Norway lobster *Nephrops norvegicus* L. 1758 has a patchy distribution on the continental shelf and upper slope of the Northeast Atlantic and in the Mediterranean Sea (Bell et al., 2006; Farmer, 1975). This distribution is linked to the location of suitable habitats of muddy sediment in which adults construct burrows (Chapman, 1980). The life cycle of *Nephrops* consists of a 50 days pelagic larval phase (Johnson et al., 2013) and sedentary juvenile and adult stages.

More than 30 *Nephrops* stocks are considered in the Northeast Atlantic for assessment and management purposes (Bell et al., 2006; ICES, 2004). In the so-called North Galicia stock, Functional Unit 25, (Northwest Spain, Fig. 1) the Norway lobster is fished within a multiespecies trawl fishery together with bottom and demersal species, comprising mainly hake, anglerfish, megrim, horse mackerel and blue whiting (Castro et al., 2011; Fariña, 1989; Fernández et al., 1978). In this geographical area, characterized by episodic upwelling of North Atlantic Central Water during summer (Fraga, 1981; Ruiz Villarreal et al., 2012; Wooster et al., 1976), annual catches of *Nephrops* are relatively small compared with other Atlantic stocks, but this species is one of the most valuable of the bottom fishery. Since 1991, the North Galician *Nephrops* landings show a marked declining trend (Fariña and González Herraiz, 2003; ICES, 2013a), reaching at their lowest levels in the recent years (ICES, 2013a). The latest analytical assessment of this stock (ICES, 2006) identified a period of high fishing mortality between 1992 and 1997 and a strong decreased trend in the spawning stock biomass and recruitment since 1990. Since 2005 there is a recovery plan for hake and *Nephrops* in the area, mainly based in an annual 10% effort reduction and a temporal and spatial closure until the stocks were under security biological limits (EU, 2005), but *Nephrops* landings continue decreasing.

Variability in the abundance of *Nephrops* in trawl catches was in the past attributed to fishing (Thomas, 1965), but other factors were investigated later. Environmental and oceanographic variables such as primary production, chlorophyll and nutrient concentrations, salinity, upwelling, currents, and river discharge, have been largely shown to be influential in the life cycles and dynamics of marine ecosystems (Ligas et al., 2011). The nature of the mud sediments was considered to have a great effect on variations in the population LPUE of *Nephrops* (Chapman and Bailey, 1987; Chapman

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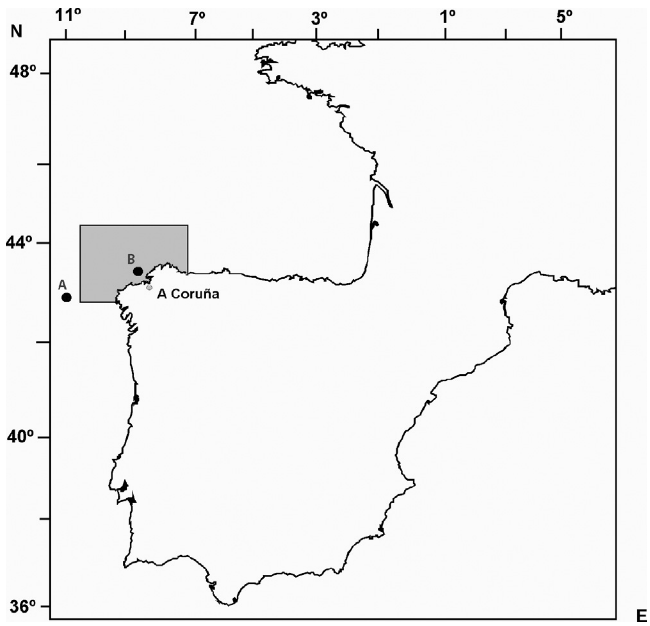

Fig. 1. Location of *Nephrops* grounds (shaded area) in North Galicia and position (dots A and B) where environmental variables were recorded.

and Howard, 1988; Tuck et al., 1997; Tully and Hillis, 1995), and the impact of temperature and hydrographic factors, mainly during the larval phase, has also been reported (Bailey et al., 1995; Dickey-Colas et al., 2000; González Herraiz et al., 2009; Hill et al., 1996). *Nephrops* is recorded at bottom temperatures between 6.4 and 17.3 °C and salinities between 31.8 and 38.8‰ and the suitability of different areas was derived using between others chlorophyll levels (as a proxy for productivity) (Johnson et al., 2013). The purpose of the present study is to model statistically the fluctuations in the *Nephrops* landings per unit effort (LPUE) from the North Galicia stock using time series approach, and to investigate the potential population and environmental factors related to these fluctuations.

2. Materials and methods

Since 1975 monthly *Nephrops* data from the North Galician fishery (landings and fishing effort) have been supplied by different ports authorities related with the fishery to the Instituto Español de Oceanografía (IEO). There are *Nephrops* data in other sources. In the European Union data base http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database, fisheries data are aggregated for Northeast Atlantic area since 1950. *Nephrops* data by ICES division since 1989 are also available in the ICES database http://www.ices.dk/marine-data/dataset-collections/Pages/Fish-catch-and-stock-assessment.aspx. Since 1997 there are data series on *Nephrops* landings collected from sales notes by the Galician regional authorities http://www.pescadegalicia.com/, but the fishing area is not reported in the sales notes. Therefore, the data collected by the IEO are the unique with enough resolution for being aggregated by Functional Unit and are not easily comparable with other source data. In fact the data used in this manuscript are the same that are employed in the ICES Working Groups of *Nephrops* assessment since 1976. The 1975–2001 data range was selected for this analysis: landings and LPUE since 2001 are so low that are considered not representative of the *Nephrops* fishery dynamic.

Monthly time series of independent variables were used for the development of the statistical models:

1) demographic population structure was obtained from the routine sampling programme of commercial landings developed by IEO including the following variables: (a) population sex ratio, as proportion of males over the total catch – MAL – (1980–2001); (b) proportion of ovigerous females over the total catch of females (1981–2001); and (c) recruit proxy (ICES, 2013b) (number of individuals lower than 30 mm carapace length (CL), 1979 and 1981–2001).
2) environmental variables: upwelling index and sea surface temperature (SST), (1996–2001) both corresponding to the Northwest Iberian Atlantic 43°N11°W (A in Fig. 1) (Lavín et al., 1991, 2000, 2002); and temperature, chlorophyll, salinity (1991–1999), and nitrates (1991–1998) from a permanent station routinely sampled in the shelf off A Coruña at 70 m depth (43°25′N8°26′W) (B in Fig. 1) (Casas et al., 1997).

All the population data both CPUE and sex ratio, percentage of ovigerous females and recruits come from the structural regular IEO sampling programme with samplers in the ports since 1975. In that period data have been monthly recorded with the same standard methodology, in the same way, with the same precision, reliability and frequency and sampling has been supervised by the same team. All data series correspond to fishing trips carried out in the same functional unit. Data were analyzed by using time series techniques. Firstly, to characterize the changing pattern of seasonality, the LPUE (y_t) was decomposed into a combined trend and cycle component (p_t), a seasonal component (s_t) and a short-term disturbance (u_t):

$$y_t = p_t + s_t + u_t \quad (1)$$

Census II Method (Makridakis et al., 1983) was used because of its simplicity and flexibility instead other complex procedures (Maravall, 1995).

Then, the relevance of population and environmental factors in relation with the trend of the LPUE was determined. For a better separation between univariate time dependence and the contribution of the explanatory variables, an ARMA (autoregressive and moving average) model was estimated to obtain the univariate dynamics. The model assumes homocedasticity in the original series and average stationarity, so it is necessary to make transformations if those are not the cases. The general expression of the model (Box et al., 1994) is:

$$\phi(L)\,\Phi\left(L^s\right) y_t = \mu + \theta(L)\,\Theta\left(L^s\right)\, a_t \quad (2)$$

where L is the lag operator defined by $L^j y_t = y_{t-j}$, $\phi(L)$, $\Phi(L^s)$, $\theta(L)$ and $\Theta(L^s)$ are polynomials in the lag operator, s is the seasonal periodicity (12 in monthly series), μ is a constant and a_t is normal white noise.

This simple model explains the current LPUE by its previous history and acts as a bench mark for more complex models, in the sense that any specification that considers explanatory factors should display a better fit than (2) to be validated. Next, turning to the dynamic regression model,

$$\phi*(L)\,\Phi*\left(L^s\right)\, y_t = \mu * + \upsilon(L)\, x_{t-k} + \theta*(L)\,\Theta*\left(L^s\right)\, e_t \quad (3)$$

where for simplicity only one input, x_t, with response delay k and dynamic effects on y_t represented by the lag polynomial $\nu(L)$ was considered. This dynamic regression assembles the dynamic contribution of the explanatory variables and the univariate time dependence.

Process for specification includes the estimate of single input regressions like (3), discarding the candidates that were not able to outperform the univariate model (2) and the combination of