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# Modelling seasonal variability of cephalopod abundances of three contrasting species from Western Mediterranean Sea

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## Summary
Cephalopod populations show wide temporal fluctuations in abundance, usually investigated at inter-annual scales. However, cephalopods are generally short-lived and single-seasonal breeders, with life cycles strongly linked to seasonal environmental variability. Therefore, population abundance critically depends on the success of breeding and recruitment when conditions are favorable. This adaptation of population dynamics is especially important in marked oligotrophic seas, such as the Mediterranean, where matching seasonal conditions is of paramount importance for marine species. We used monthly landings per unit effort (LPUEs) to explore the spatio-temporal variability in seasonal patterns of three cephalopod species (*Eledone cirrhosa*, *Illex coindetii* and *Octopus vulgaris*) from the Western Mediterranean Sea. Common seasonal trends were characterized, using a dimension reduction technique. These seasonal patterns were associated with local variability in the primary production and climate; presenting a spatial correlation scale between 69 - 193 km, at which population dynamics fluctuate in synchrony. Variability in the seasonal patterns over time showed pronounced seasonal trends in years with higher population densities. These results evidence that fluctuations in cephalopod populations respond to both spatio-temporal seasonal patterns at local scales, related to environmental variability and also to density-dependent control.

## Introduction
Cephalopods display wide inter-annual fluctuations in their populations, usually related to large environmental changes. However, cephalopods are also strongly linked to seasonal environmental fluctuations due to their short life span and single breeding followed by spawners death. Therefore, almost the entire population critically depends on the successful coupling of breeding and early life stages with a narrow window of favorable conditions. This population dynamics adaptation is especially important in marked oligotrophic environments such as the Mediterranean Sea, where productivity of lower trophic levels take place in short temporal and spatial scales. We explore spatio-temporal patterns of seasonality in three cephalopod species, the squid *Illex coindetii* and the octopuses *Eledone cirrhosa* and *Octopus vulgaris,* over the Western Mediterranean Sea. By using three different approaches we investigate: (1) the direct effects of environmental drivers in shaping common seasonal fluctuations from separate locations; (2) changes in seasonal patterns under contrasting regimes (high - low) of environmental conditions and population density; and (3) the spatial correlation scale at which populations fluctuate in synchrony.

## Materials and Methods
We used monthly landings per unit effort (LPUEs) of 30 ports located along the Spanish Mediterranean coast, including the Balearic Archipelago from 1998 to 2012. Remotely sensed monthly chlorophyll a (*Chl-a)* and a local climate index (LCI, details in Molinero *et al.*, 2005) were included as covariates. We used three complementary techniques. First, Dynamic Factor Analysis (DFA) was used to determine the common trends and environmental drivers that shape seasonal fluctuations in log(LPUE +1). Second, changes in the mean seasonal patterns over time were investigated applying Threshold General Additive Models (TGAMs). And third, spatio-temporal synchrony in LPUEs were explored with correlograms (Pearson's correlation r-coefficient for every pair of ports, plotted against the shortest distance separating them). An exponential fit were used to obtain spatial correlation scale.

## Results and discussion

Common seasonal trends were related to the location of the ports and the effects of covariates (Fig. 1). In the archipelago, same seasonal pattern was described in all species, with northern and southern locations affected by Chl-a and LCI respectively. However, different seasonal patterns were observed in the mainland region according to the location. For the octopus species, northern and southern locations were related to *Chl-a* seasonality, while central locations were associated with LCI due to probable influence of the Ebro River discharges on cephalopods (Lloret *et al.*, 2001; Quetglas *et al.*, 2011). The best TGAM resulted from allowing seasonal dynamics to change between contrasting regimes of population density. This suggests that in general, density-dependent control can modify the strength of density-independent (environmental) forcing, since seasonal patterns were pronounced under high-density scenarios (Fig. 2). Finally, spatial synchrony in seasonality seemed to be more related to local scale orography than to species characteristics. Similar spatial scales of correlation were found for both octopuses (~69km), and a value slightly higher for *I. coindetii* (76 ±14.4 km). However, the correlation scales were larger in the mainland (*E. cirrhosa*, 193.1 ±46.83km; *O. vulgaris*, 102.75 ±9.12km; *I. coindetii* 155.4 ±47.67km), but presenting lower degree of synchrony related to the maximum distance, probably due to the higher environmental heterogeneity observed along this region.

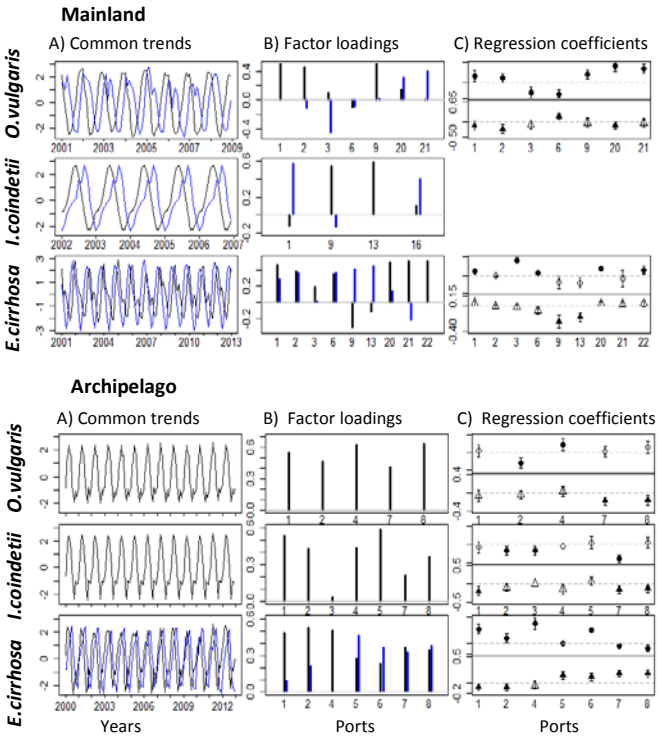


Fig. 1. Results of Dynamic Factor Analysis for LPUE time series. A) Common trends. B) Factor loadings. C) Regression coefficient of LPUE and the covariates included in the model, chlorophyll a concentration (circles) and local climate index (triangles), black symbols denote level of significance $p < 0.05$. Ports denoted by increasing numbers from North to South. All y-axis are unitless.

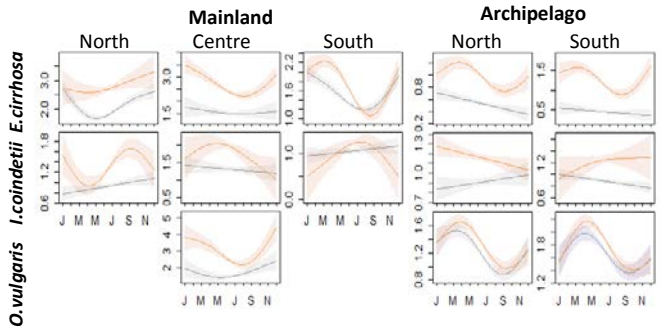


Fig. 2. Effects of month on LPUEs under low (gray) and high (red) population density regimes determined by TGAMs. X-axis denotes months, y-axis is unitless.

The combination of three different methodologies let us to assess cephalopod landings, showing a more comprehensible picture of seasonal patterns and its variability at spatial and temporal scales. The consistency of the results revealing geographical aggregation patterns in the three species evidences that common local environmental mechanisms control seasonality, constrained by population density-dependence and regional orography, as the main drivers shaping cephalopod seasonality patterns in the Western Mediterranean.

## References


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