Influence of the General Circulation on Settlement of European Spiny Lobster Populations (*Palinurus elephas*) in the Balearic Islands

From: David Díaz, Raquel Goñi, Ben Stobart, Olga Reñones, Elisa Roldán, and Salud Deudero

Ocean currents can transport larvae of marine organisms over large distances. Populations are therefore demographically "open" and connected by larval dispersal (Planes et al. 2009). The rates, scale and spatial structure of larval exchange among local populations drive population replenishment, and therefore, have important implications for population dynamics and spatial management (e.g., marine protected areas; Cowen et al. 2006).

Recruitment of marine fish and invertebrate larvae is often highly variable, and identification of patterns is usually based on long-term settlement data which may provide insights into the biotic and abiotic variables influencing transport and survival (Acosta et al. 1997). However, it is impossible to empirically capture the full range of spatial and temporal variability resulting from oceanographic conditions and larval behavior. Thus, identifying the scale of marine larval dispersal remains one of the fundamental challenges of marine ecology and oceanography (Cowen et al. 2006).

Palinurid spiny lobsters have a complex life history, with a lengthy larval phase which can last from a few months to two years, and therefore is subject to widespread dispersal. Prevailing currents strongly affect larval transport and distribution in spiny lobster (Inoue & Sekiguchi, 2009). The puerulus postlarvae of many species settle in shallow nearshore nursery habitats, and the nearshore supply of postlarvae for certain palinurid species has been linked to large-scale oceanic processes (Acosta et al. 1997).

As part of a study of recruitment patterns of the spiny lobster *Palinurus elephas* in the Western Mediterranean, we have investigated spatial correlations between settlement indices and fishery production in various localities across the Northwestern Mediterranean region (Díaz, 2010). Preliminary results suggest that *P. elephas* has a metapopulation structure with a common larval pool (Díaz, 2010).

The dispersive larvae of *P. elephas* lasts only about five months (Goñi & Latrouite, 2005), but observations of *P.elephas* phyllosoma in the Western Mediterranean are very scarce

(Hunter, 1999) and none appeared in the series of planktonic surveys carried out around the Balearic Islands during 2002-2005 (Mallol et al. 2008). As a result, very little is known about *P. elephas* larval distribution, behavior and dispersal. As a way to overcome this, we assessed postlarval settlement in benthic habitats, which is a relative estimate of immigration rate and may be converted to an absolute estimate through measurements of flux across the water column (Lipcius et al. 1997).

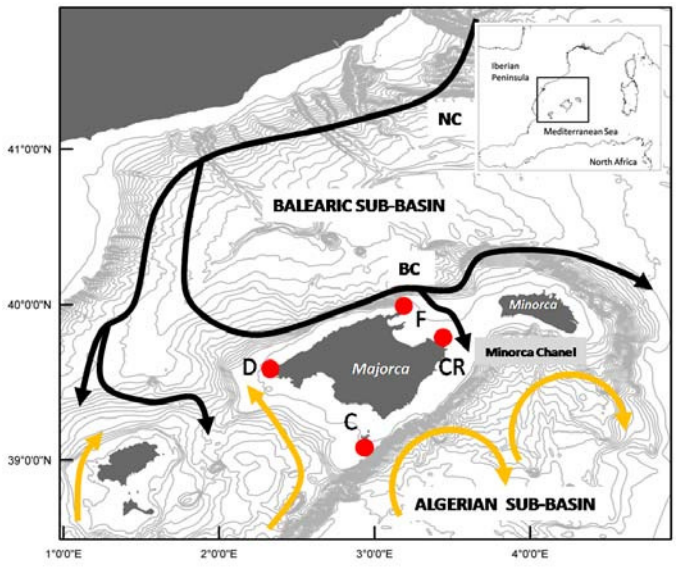

Figure 1. Map of the Balearic archipelago showing bathymetry (grey lines) and predominant currents. The Northern (NC) and Balearic Currents (BC) in black, and the branches of the Algerian Current in orange (Redrawn from Millot, 1999). Red dots mark the settlement sampling locations: northwest (Formentor, F), northeast (Cala Ratjada, CR), southwest (Dragonera, D) and southeast (Cabrera, C).

The Balearic Islands lobster fisheries are among the few still viable and productive in Western Mediterranean (Quetglas et al. 2004), with particularly rich fishing grounds located in the northern shores of Majorca Island and in the Minorca Channel (Figure 1). In contrast, along the southern shores of Majorca *P. elephas* occurs only sporadically and no targeted fisheries exist. Optimal *P. elephas* habitats for both settlers (empty date mussel *Lithophaga lithophaga* holes bored into limestone, Díaz et al. 2001) and adults (coralligenous substrates at 50-100 m depth, Goñi & Latrouite, 2005) abound throughout the Balearic islands. Thus, without habitat limitation for either settlement or adults as an explanation for the absence of spiny lobsters populations in the south of Majorca Island, we hypothesized that hydrodynamic patterns in the archipelago lead to differences in larval supply causing the observed spatial patterns of exploitable lobster abundance. To test this hypothesis we first ruled out the possibility that local populations were self-recruiting.

In previous studies of spiny lobsters self-recruitment was evaluated by analyzing the correlation between adult and post-settlement abundances (Lipcius et al. 1997). Here we examined correlations between adult populations (estimated throughout landings of nearby harbors) and settlement indices (with 1-year lag) among four locations around Majorca Island: northwest (Formentor), northeast (Cala Ratjada), southwest (Dragonera) and southeast (Cabrera) (Figure 1) and found no indication of self-recruitment (Table 1).

Table 1. Pearson's correlations coefficient (significance level $p < 0.05$) between settlement index and landing of spiny lobsters in the nearest fishing harbours from 2005- 2008 (1-year lag).

Locations	Coef Corr.	p-level
FORMENTOR	0.48	0.517
CALA RATJADA	0.72	0.715
DRAGONERA	0.46	0.542
CABRERA	0.45	0.553

To test the hypothesis that external larval supply from outside the area is one factor likely determining the distribution of adult lobsters around Majorca Island, we analyzed four years of settlement surveys carried out by scuba diving from 2005 to 2008 in the same four locations. We sampled four sites separated by < 500 meters in order to integrate spatial variability at each location. Inter-annual variation of settlement index (no. individuals / minute) was significantly different between the northern and southern locations ($F_{(3, 1196)} = 25.168$, $p<0.001$). On average settlement

densities were greater in the northern locations of Majorca Island while the southernmost location, Cabrera, had the lowest settlement counts (Figure 2). This pattern is consistent with the pattern of prevailing currents in the Balearic Islands (Figure 1). The southern side of Majorca Island is under the influence of the Algerian current that brings Atlantic water through the Strait of Gibraltar (Figure 1), while the Northern current, and its branch the Balearic current, bathe the northern shores of the Island. Thus the two sides of the island are influenced by currents of different origins, with the northern current presumably connecting the Balearic lobster populations with other traditionally productive grounds to the north and east of the Mediterranean basin.

Therefore we propose that in the Balearic Islands ocean circulation is a key factor determining spatial differences in larval supply and, as a consequence, of adult abundance. Hence, the presence of optimal settlement and adult habitats alone do not secure the presence of exploitable densities of *P. elephas*, although they are necessary for the existence of well establish populations. The influence of general circulation should be tested on a larger spatial scale. Expanding the settlement surveys to the south and east of the Western Mediterranean basin will be part of a future project.

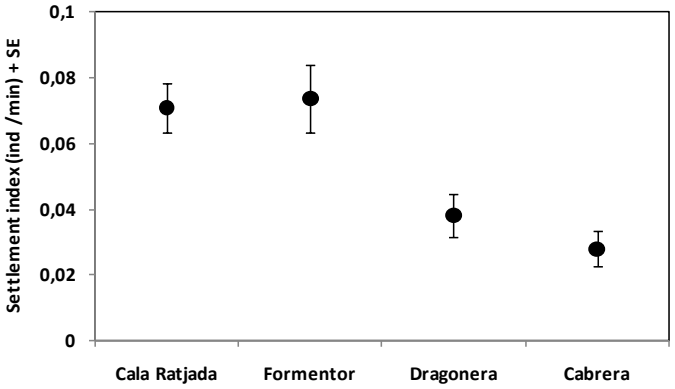

Figure 2. Mean *Palinurus elephas* settlement index (individuals/min) ± S.E. at four main sites on the Majorca Island. Data from the 2005 to 2008 surveys combined.

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David Díaz, Raquel Goñi, Ben Stobart, Olga Reñones, Elisa Roldán, and Salud Deudero*
Instituto Español de Oceanografía Centro Oceanográfico de Baleares
Muelle de Poniente s/n, 07015
Palma de Mallorca, SPAIN
**e-mail: david.diaz@ba.ieo.es*