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# Interaction between spawning habitat and coastally steered circulation regulate larval fish retention in a large shallow temperate bay

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Larval retention plays a fundamental role in the persistence of coastal fish assemblages. Here, we examine larval fish distribution and abundance patterns in Palma Bay, a large (~20 km) wind-driven microtidal bay in the southern coast of Mallorca (Spain, NW Mediterranean Sea). Larval fish assemblage structure in the bay were analyzed during July 2010 and interpreted in the context of the observed circulation patterns, adult habitat distribution and spawning traits. Acoustic Doppler Current Profiler (ADCP) observations showed the presence of retentive flow patterns in the middle of the bay enhancing local larval accumulation and self-recruitment. In consequence, larval abundances were higher in this central part of the bay (~40 m depth, mean abundance 607.6 ± 383 ind. 10 $m^{-2}$) than along the coastal fringe (<35 m 113.7 ± 91 ind. 10 $m^{-2}$). Also, a multivariate predictive approach based on Redundancy Analysis (RDA) revealed differences between the larval fish assemblages in areas inside the bay, constituted by small pelagic and benthopelagic taxa (gobids, *Chromis chromis* and *Serranus hepatus*) and offshore larvae, mostly from meso and large pelagic fish. These larval fish assemblages were structured according to depth variations and zooplankton abundance, and remained relatively unmixed because of the circulation patterns in the mouth of the bay that uncouple its dynamics from alongshelf circulation. Even larvae of typically pelagic species that spawn close to the coast (*Sardinella aurita*, *Auxis rochei*) were associated with the retentive effect of the bay. Our study highlights the important role of coastal bays in the regulation of coastal fish population dynamics and as hotspots for the maintenance of diversity in the Mediterranean Sea.

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## 1. Introduction

Bays, sounds, inlets and other semi-enclosed coastal geomorphological features are considered preferential areas for larval fish accumulation and retention, being important in the reproduction of local demersal species and of migrant pelagic fish that have evolved to hatch in favorable areas for growth and survival (e.g. Cushing, 1990). Retention of pelagic eggs and larvae in suitable areas for development may determine early life stage success, therefore influencing the rates of survivorship to adulthood and self-maintenance of the population (Bradbury et al., 2008). As a consequence, bays are regarded to play, through recruitment differences, a significant role in shaping the spatial distribution and population structure of organisms, as well as controlling the species diversity along the coast (e.g. Archambault and Bourget, 1999).

The spatial distribution of the larval fish populations are generally determined by a compound of factors such as spawning location of the adult, passive transport, behavior (mainly active swimming), predation and food availability (Stanley et al., 2012). During the egg and early larvae stages, the horizontal location of propagules is determined fundamentally by spawning location and physical transport processes. In many aspects, the importance of bays for larval development relies in the existence of weakened, stable and predictable marine dynamics. Likewise, the re-circulatory features within bays reduce advection and can entrap larvae reducing dispersal and favoring return to home habitat of

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coastal dwellers therefore strongly influencing the probability of survival of the early life stages of these organisms (e.g. Drake and Arias, 1991). The influence of terrestrial nutrient inputs through their watersheds can also be enhanced at bays sustaining increased coastal productivity (Newton et al., 2013). Moreover, reduced wave energy provides refuge and the larval settlement success is guaranteed by the quasi-continuous coastal habitat presence at relatively short distances and favorable swimming environment (Swearer et al., 1999). Moreover, these factors, including water exchange between the coastal water and the open ocean are strongly affected by their geometry and other boundary conditions.

In temperate seas, the study of early stages of fish in the coastal area has been traditionally approached in terms of statistical description of larval fish assemblages (herein LFAs) and their potential drivers (Sabatés et al., 2003; Azeiteiro et al., 2006; Borges et al., 2007; Basterretxea et al., 2013; Kent et al., 2013; Pattrick et al., 2013). Small-scale empirical information on LFA also exists for estuaries (e.g. Hoffmeyer et al., 2009; Kruger and Strydom, 2010), isolated oceanic islands (Macedo-Soares et al., 2012) and coastal lagoons (e.g. Pérez-Ruzafa et al., 2004). However, in temperate areas, the study of the early stages of fishes in the coastal area (and specifically the transport effects on LFA) has been studied less frequently, in part owing to the need for high resolution models. It has been studied for alongshore rocky nearshore LFAs (Roussel et al., 2010) but not in complex temperate areas, where small scale variability in topographic and oceanographic features (e.g. coastal gyres) may influence the metapopulation connectivity and dynamics (Di Franco and Guidetti, 2011; Garavelli et al., 2014; Rogers et al., 2014).

Larval fish assemblages of Mediterranean bays are typically composed of resident species such as gobids, labrids and sparids, preferentially spawning in spring and summer (Tsikliras et al., 2010; Álvarez et al., 2012). In these areas, ichthyoplankton diversity is generally high and bays are also regarded as important nursery areas for several marine organisms (Clark, 1992). Despite their ecological importance, the contribution of coastal embayments to the maintenance of early life stages of coastal resident fish is only poorly known. Palma Bay (Mallorca Island) is a rather productive coastal zone in the otherwise oligotrophic waters of the Western Mediterranean (Jordi et al., 2009a). Major circulation patterns in this coastal area can be explained in terms of the interaction between wind driven currents and oscillatory motions induced by the island-scale flow, which interact with topographic constrains that frequently generate submesoscale coastal gyres (Jordi et al., 2011). Reduced mean flows during summertime potentially favor retention both of eggs and larvae from fish assemblages inhabiting the bay (Hernández-Carrasco et al., 2013). Onshore surface transport induced by diurnal sea breeze which is intensified in the bay (Jordi et al., 2011), also represents a potential phenomenon affecting the recruitment of organisms spawned in nearby coastal areas and transported to the bay. The recognition of a double functional mechanism that both increases local recruitment but also incorporates larvae dispersed from other areas is a critical aspect for the understanding of the ecological role of bays in the persistence and connectivity of coastal fish populations (Stanley et al., 2012).

Previous works in this region anticipated, through numerical modeling, that Palma Bay is a highly retentive area in which maintenance of local fish populations could largely rely upon self-recruitment (Basterretxea et al., 2012); however, the mechanisms though which this retention takes place have not been addressed to date. Determining the role of bays in the reproductive cycle of various fish species, and the particular function of temperate microtidal coastal zones, is necessary to accurately define and quantify the mechanisms that promote larval retention. The hypothesis to be tested in the present work is that mechanisms regulating summer larval fish retention in a Mediterranean Bay can be attributed to an identifiable combination of biological and physical mechanisms.

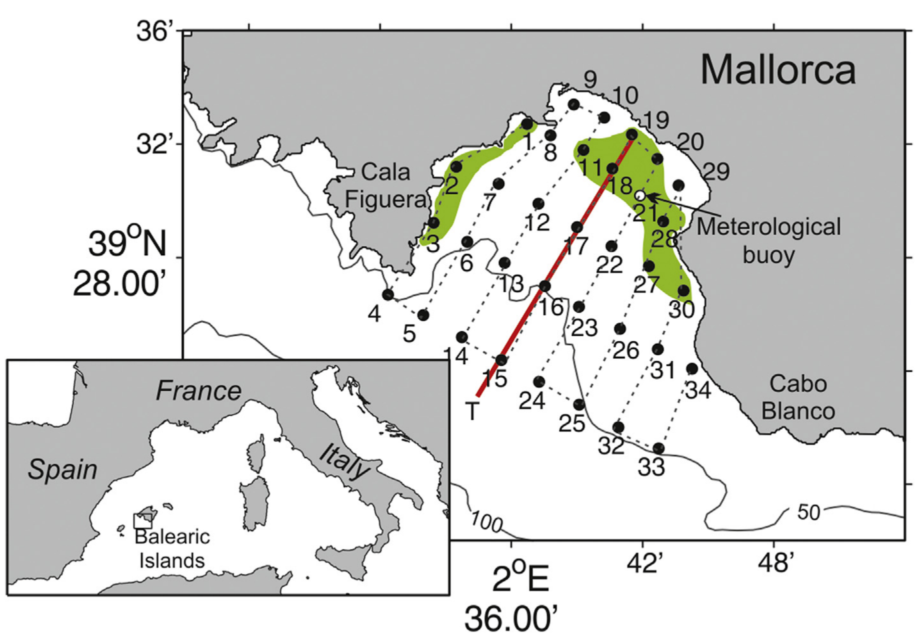


**Fig. 1.** Bathymetric map of the study area indicating the presence of seagrass covered bottoms (green) and zooplankton sampling points. CTD casts were obtained along T transect (5 stations, red line). The ADCP track is indicated by the dashed line. The position of the meteorological buoy is also indicated. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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