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Hydrodynamism and its influence on the reproductive condition of the edible sea urchin *Paracentrotus lividus*

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ABSTRACT

Despite the large body of work published in the last two decades on the reproduction of the sea urchin *Paracentrotus lividus*, the reproductive aspects linked to hydrodynamic conditions and their influence on gonad production remain poorly understood. The present paper aims to evaluate the effect of hydrodynamism on the reproductive cycle of *P. lividus*. Variability in the gonadosomatic index (GSI) of *P. lividus* was estimated seasonally from 2007 to 2008 at two shallow sub-littoral flat basaltic areas at Ustica Island (Western Mediterranean). GSI was higher in the sites characterized by low hydrodynamism than in those with high hydrodynamism. Results also suggest a possible role for hydrodynamism in triggering processes of resource limitation (food shortage), probably by interfering with *P. lividus* feeding activity.

1. Introduction

The edible sea urchin *Paracentrotus lividus* (Lamarck, 1816) (Echinodermata: Echinoidea) is a common inhabitant of Mediterranean and North Atlantic shallow hard bottoms (Kempf, 1962; Boudouresque and Verlaque, 2001). With its distinctive, appetizing taste, *P. lividus* was already well known to the ancient Greeks and Romans, together with oysters, snails and other seafood (see Plinio and Archestrato di Gela). In recent decades, interest toward this species has increased, both economically and ecologically. *P. lividus* is commercially exploited in many European countries (Régis, 1987; Boudouresque and Verlaque, 2001; Gianguzza et al., 2006; Bertocci et al., 2012) and several authors acknowledge its paramount role in the transition from macroalgal beds to coralline barrens (Sala and Zabala, 1996; Bulleri et al., 1999; Bonaviri et al., 2011, 2012; Bertocci et al., 2012; Agnetta et al., in press).

P. lividus is a gonochoric species lacking sexual dimorphism (Gianguzza et al., 2009). Like other regular sea urchins, *P. lividus* gametogenesis involves energy storage (mainly as glycogen) in the gonads, transfer of accumulated energy from nutritive cells to gametogenic cells, storage of accumulated gametes, and broadcast spawning of sperm and eggs into the water column with external fertilization (Lawrence and Herrera, 2000). The reproductive cycle of *P. lividus* is annual, with three main phases: the growing phase (late autumn and winter) when gonads accumulate reserve material; the maturation phase (spring and early summer) in which gametogenesis and spawning take place; and the spent/regenerating phase in which relict gametes are resorbed by the nutritive phagocytes (Spirlet et al., 1998). There can be a single, intense spring spawning period, as described for populations from Mediterranean northeast Spain, Ireland, and Atlantic Northern France. In other cases, two spawning peaks are observed in early spring and autumn, in Ireland and in some Mediterranean populations (see Ouréns et al., 2011 and references therein).

The gonadal somatic index (GSI, the index of gonad mass relative to animal test diameter) is traditionally used in sea urchins to study the reproductive cycle, fluctuations in gonad size and spawning periods (Spirlet et al., 1998; Shpigel et al., 2004). Several studies of echinoid GSI have shown considerable variability at both spatial and temporal scales as a result of extrinsic factors such as

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food availability and quality, population density and other variables (Byrne, 1990; Fernandez and Boudouresque, 1997; Bayed et al., 2005; Brady and Scheibling, 2006). The bulk of the evidence suggests that sea urchins inhabiting plentiful food habitats, such as seagrasses, kelp beds and erect macro algae beds, show a high GSI due to the abundance of high quality food (Lawrence and Sammarco, 1982; Turòn et al., 1995; Sánchez-España et al., 2004; Agatsuma et al., 2005), while those inhabiting resource-limited habitats (such as coralline barrens) show a low GSI (Lozano et al., 1995; Turòn et al., 1995; Fernandez and Boudouresque, 1997). Yet other authors have recorded no significant effect of macroalgal assemblage structure on the reproductive conditions of the species (Chiantore et al., 2008; Agnetta et al., in press).

Moreover, *P. lividus* GSI is controlled by seasonal changes in photoperiod, water temperature and phytoplankton blooms (see Ouréns et al., 2011 and references therein).

Although many authors have studied *P. lividus* reproduction, very few have analyzed the effect of hydrodynamism on GSI and some results are contradictory. Lozano et al. (1995) showed that gonadal indices were higher at exposed sites, while Guettaf et al. (2000) and Sellem and Guillou (2007) found that *P. lividus* had higher GSI values at sheltered sites. These studies, however, confound (*sensu* Underwood, 1997) the potential effect of habitat and/or food availability across hydrodynamism.

The present study was aimed to evaluate the effect of hydrodynamism on the GSI of *P. lividus*, taking into consideration the seasonality of the reproductive cycle. In order to formally test the hypothesis that hydrodynamism affects *P. lividus* GSI, we considered two areas subject to different hydrodynamic conditions. Given that conspecific density and food availability can potentially affect urchins GSI via intraspecific competition, we took into account the density of *P. lividus* specimens, their diet (as gut content composition) and feeding condition (measured as chlorophyll-a in gut content). We also compared the benthic assemblage structure of the two considered areas.

2. Materials and methods

2.1. Study sites and hydrodynamic-force measurements

The study was carried out in the Marine Protected Area (MPA) of Ustica Island in the southern Tyrrhenian Sea (Western Mediterranean, 38°42′20″N–10°43′43″E), 60 km north of the Sicilian coast. The MPA, created in 1986, covers a total area of 16 000 ha and contains three zones with different degrees of protection. The no-take zone (zone A) covers 65 ha along the western part of the island, while the general reserve (zone B) and the take zone (zone C) share the remaining area equally (Fig. 1).

Variability in the GSI of *P. lividus* was estimated seasonally from 2007 to 2008 in two shallow sub-littoral flat basaltic areas with different exposure and hydrodynamic conditions: the western no-take zone A, characterized by high hydrodynamism (H area) and the southern take zone C, with low hydrodynamism (L area). Hydrodynamism was evaluated as Relative Exposure Index (RWE) according the Wave Exposure Model (WEMo) by Malhotra and Fonseca (2007), and significantly differed between the two areas (16 864.29 ± 2625.52 J/m^2 average RWE index ± ES in the H area and 829.51 ± 98.92 J/m^2 RWE index ± ES in the L area $F_{1,\,4.1} = 15.44$; $P = 0.0034$).

Two sites, were chosen in the H area (no-take zone A, sites H_1 and H_2) and two in the low hydrodynamism area (the take zone, sites L_1 and L_2) (Fig. 1).

Sites were approximately 600 m apart, with other important factors unchanged (depth, seascape). The seascape was a mosaic of *Cystoseira* patches (~1.5 m in diameter) interspersed with patches of encrusting coralline algae (Gianguzza et al., 2010).

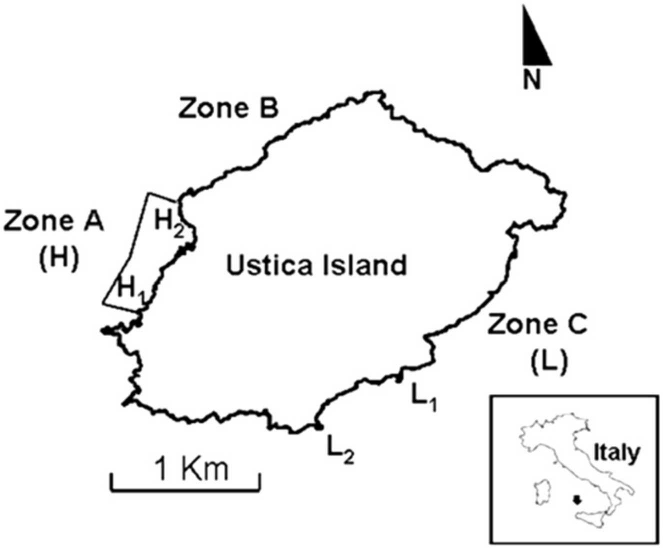

Fig. 1. MPA "Isola di Ustica". Sampling sites: H_1, H_2 (high hydrodynamism) and L_1, L_2 (low hydrodynamism).

The authors are well aware that the experimental design could be considered confounded because the area characterized by high hydrodynamism coincides with the no-take zone and the low hydrodynamism area with the take zone. However, it was not possible to replicate areas with different hydrodynamic conditions within the MPA zones. Given that protection can modulate the benthic assemblage and sea urchin density via trophic cascade (Bonaviri et al., 2011) and *P. lividus* GSI is affected by these variables, the benthic assemblage structure, density, diet (as gut content composition) and feeding condition (amount of chlorophyll-a in gut content) of *P. lividus*, according to Privitera et al. (2008), were compared across the two areas.

2.2. Benthic assemblages

Benthic assemblages have been characterized as follows: 16 randomly selected quadrats (20 × 20 cm) were photographed twice per season (Summer (S) June–September 2007, Autumn (A) October–December 2007, Winter (W) January–February 2008 and Spring (Sp) April–May 2008) in each site. Digital images were visually analyzed by superimposing a grid of 25 equal-sized small squares (each representing 4% of the total surface of each image). The percent cover of each taxon was quantified in all the small quadrats by assigning a score of between 0 (no presence) and 4 (total cover) to each taxon observed. Values from each small quadrat were added to obtain the final percentage of the entire quadrat (Dethier et al., 1993; Chiantore et al., 2008). The algae and animals recorded were grouped by following aprioristically the morpho-functional criteria presented by Steneck and Dethier (1994) and Jackson (1979) respectively (Table 1).

2.3. Density, diet, feeding conditions and GSI of *P. lividus*

P. lividus density was assessed in rocky reef habitats at about 4–6 m depth at the four study sites. Samplings were performed twice per season (Summer (S) June–September 2007, Autumn (A) October–December 2007, Winter (W) January–February 2008 and Spring (Sp) April–May 2008) on days with good sea-weather