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Body growth and mortality of the spiny lobster *Palinurus elephas* within and outside a small marine protected area

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ABSTRACT

Following the establishment of a small marine protected area (MPA) located off western Sardinia (Mediterranean Sea), a long-term survey was conducted on a spiny lobster (*Palinurus elephas*) population inhabiting the MPA and adjacent fishing grounds. Between 1998 and 2005, median carapace length increased by 1.9 mm year^{-1} both within and outside the MPA. On the contrary, body size dispersion (IQR) increased by 0.9 mm year^{-1} within the MPA and decreased by 0.6 mm year^{-1} outside. Mark-recapture data were used to develop and calibrate a body growth model explicitly accounting for sexual dimorphism and inter-individual variability. Median asymptotic carapace length was equal to 116 mm in females and 185 mm in males. Age frequency distributions, derived from size distributions through the body growth model, were used to estimate mortality rates inside (ca. 0.41 year^{-1}, natural mortality) and outside (ca. 0.78 year^{-1}, natural + fishing mortality) the MPA. Results provide new estimates of key life history traits for this species and suggest that the MPA is effective in protecting lobsters despite its small dimensions.

1. Introduction

A large proportion of marine stocks are currently overexploited, and fishing is considered one of the greatest threats affecting marine biodiversity and ecosystem functions and services (Pauly et al., 2002). Proper conservation measures and sustainable fishing practices can help maintain ecosystem health and related services to humans. From this perspective, marine protected areas (MPAs) have gained popularity in the last decades as a tool to ensure marine biodiversity conservation and replenishment of surrounding fishing grounds (Halpern, 2003; Stelzenmüller et al., 2007; Goñi et al., 2008). Long-term studies are fundamental to assess the effectiveness of protection measures (Russ et al., 2005). In fact, expected benefits of MPAs, including increase in stock abundance, average body size, and spillover of juveniles or reproductive adults may require several years to become evident (McClanahan et al., 2007). In addition, long-term studies provide valuable information to investigate demographic dynamics of protected stocks and derive mathematical models that can eventually be used to forecast the response of key species to different management policies.

Species with moderate mobility and subject to high levels of fishing mortality, such as most lobster species, have shown the strongest responses to protection (Micheli et al., 2004; Goñi et al., 2008). Lobsters, which have relatively small home ranges (Smith et al., 2001; Follesa et al., 2009) and are actively pursued because of their high commercial value (Goñi and Latrouite, 2005), may greatly benefit from the establishment of even small MPAs. Edgar and Barret (1999) documented an extraordinary increase (more than an order of magnitude) of rock lobster biomass after the implementation of the Maria Island reserve, in Tasmania. Lester et al. (2009) investigated the biological effects of no-take marine reserves on different taxonomic groups and showed that lobsters were among those that experienced the most significant benefits (in terms of biomass, density and body size increase) from protection. In this respect, the spiny lobster *Palinurus elephas* is a very representative model species. *P. elephas* is intensively exploited in the Mediterranean Sea and the north-eastern Atlantic (Goñi et al., 2003). It is traditionally targeted by artisan fisheries, but the change in fishing strategy (from traps to trammel nets) that took place between the 1960s and the 1970s has severely impacted lobster populations (Hunter, 1999; Goñi and Latrouite, 2005). Consequently, lobster catches have declined in most of the distribution range during recent decades (Goñi et al., 2003; Goñi and Latrouite, 2005). Despite its high commercial value, almost no long-term surveys have been carried out on *P. elephas*, with the remarkable exception of those conducted in the Columbretas islands marine reserve (southern Spain; Goñi et al., 2003, 2006, 2010) and in Su Pallosu MPA (western Italy; Follesa et al., 2007a, 2009). Also, few studies have investigated body growth patterns and none of them has explicitly accounted for inter-individual variability. However, key demographic processes,

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such as sexual maturation, fecundity and natural mortality, are size-dependent in a number of aquatic organisms (Caswell, 1989), and a reliable mathematical description of somatic growth is crucial for population analysis, stock assessment, and fishery management (Katsanevakis and Maravelias, 2008). In particular, suitable body growth models can be used to derive information on age structure from data on body size. This allows the estimation of mortality rates also in species lacking reliable age markers, like crustaceans.

In this work we analysed a data set on *P. elephas* obtained from an 11-year long mark-recapture experiment (1997–2007) conducted within and around Su Pallosu MPA, located off Sardinian coasts, in the western Mediterranean. The objective of the work was twofold: (1) to investigate body growth in *P. elephas* and develop a stochastic model explicitly accounting for inter-individual variability; (2) to assess the effectiveness of MPA protection, by comparing body size trends inside and outside the MPA since its establishment in 1998 and by estimating and comparing mortality rates within and outside the protection range.

2. Materials and methods

2.1. The species

P. elephas is distributed throughout the Mediterranean Sea and along the Atlantic coasts between Morocco and south Norway (Hunter, 1999). The lobster inhabits rocky bottoms from near shore to 70–200 m of depth (Goñi et al., 2006). It is a long-living (maximum estimated age up to 15 year), slow-growing species reproducing once a year between July and September (Goñi and Latrouite, 2005). Adult movement is restricted within ca. 2.5 km year^{-1} and is likely linked to reproduction and feeding, with older individuals showing higher site fidelity than juveniles (Goñi and Latrouite, 2005; Follesa et al., 2009). Fishing regulations include an annual 6-month closure from September to February and a minimum landing size that was recently increased from 80 to 90 mm carapace length (EC Regulation No. 1967/2006).

2.2. Study site and data collection

The study took place at Su Pallosu, a small MPA (ca. 4 km^2) located in western Sardinia, and adjacent fishing grounds, encompassing an area of ca. 5 km radius from the MPA centre (Fig. 1). Both the MPA and fishing grounds are comprised between the 50-m and 100-m isobaths and are characterized by similar coralligenous habitats. A monitoring programme including a long-term mark-recapture experiment was started in the region in 1997 (see Follesa et al., 2007a for further details), before commercial fishing was banned in 1998 (Regional Decree No. 766; 6-5-1998). The MPA was established to protect the stock from overexploitation and possibly enhance nearby catches through spillover. Local fishermen have been actively involved in capturing lobsters outside the MPA. To encourage fishermen collaboration, returned individuals were valued at double their commercial price (70–90 € kg^{-1} during the study period). Between 1998 and 2005, 3601 lobsters caught in the fishing grounds surrounding the MPA were bought from the fishermen.

Between 1997 and 2007, scientific surveys were carried out also within the MPA and 1675 lobsters were caught inside the area. Boats and fishing gears were the same as those operated by commercial fishermen, *i.e.* trammel nets 2.8-m high, with mesh sizes of 200 and 30 mm (inner and outer panels, respectively). Lobsters were sexed, measured (carapace length *L*, in mm), tagged with plastic T-bar-type tags inserted dorso-laterally between the first and second abdominal segment and eventually released in the centre of the MPA. A summary of the mark-recapture experiment is reported in Table 1. Recaptured lobsters (347 individuals) were measured to assess body growth and subsequently released in the MPA centre. Only individuals with time at liberty ≥1 year were considered for body growth analysis. This is a common practice in crustaceans showing periodic shedding and aims to exclude individuals captured just before a moult, avoiding a biased estimation of the growth rate (Ulmestrand and Eggert, 2001). The actual sample size used to estimate body growth was therefore reduced to 254 data matching this criterion (107 females and 147 males).

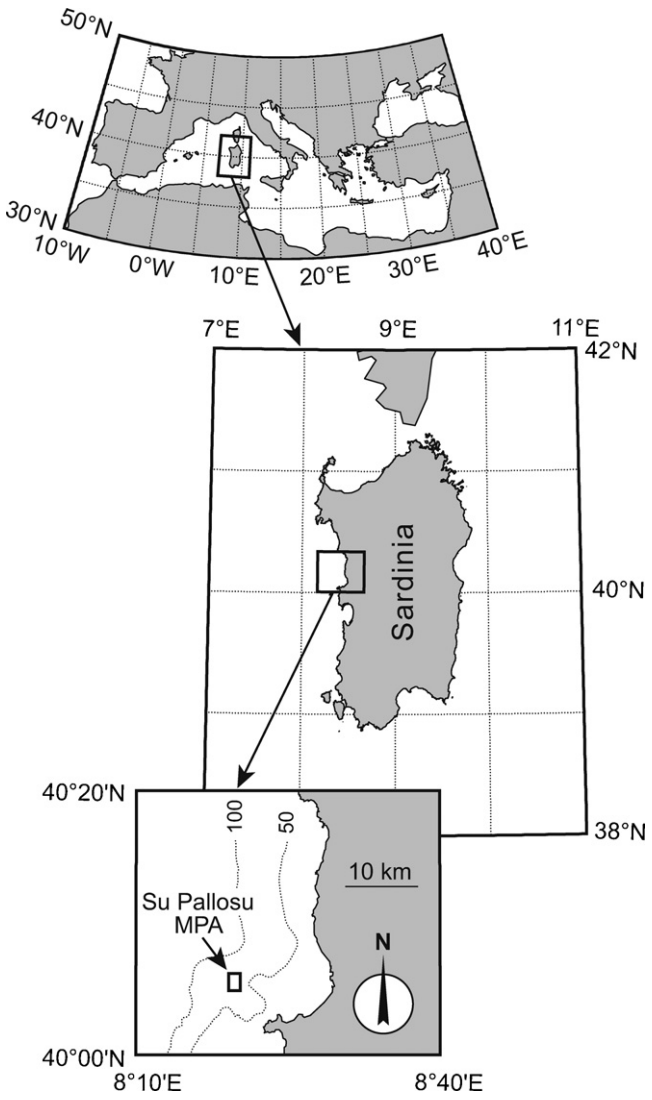

Fig. 1. Su Pallosu marine protected area.

Table 1
Summary of the mark-recapture experiment performed on *Palinurus elephas* inside and outside Su Pallosu MPA (Sardinia, Italy) between 1997 and 2007.

	Location of first capture	
	Inside	Outside
Captured	1675	3601
Marked	1157	3515
Not recaptured	1068	3257
Recaptured inside (1/2/3 times)	68/8/1	114/26/4
Recaptured outside (1/2/3/4 times)	21/4/0/1	144/21/2/0