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Recruitment, growth and population size structure of *Pollicipes pollicipes* in SW Portugal

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ABSTRACT

A general model for the life cycle of *Pollicipes pollicipes* in SW Portugal is proposed integrating results from a study on recruitment, growth and population size structure. A brief summary of literature concerning *Pollicipes* published since Margaret Barnes' review paper of 1996 is presented.

Recruitment of *P. pollicipes* on conspecifics (number of cyprids and juveniles with Rostro-Carinal length (RC) <0.6 mm per adult) was intense during summer and autumn, but inter-annual variation in the timing and duration of recruitment season was observed. Different indices of recruitment used in Iberian studies were compared. Spatial correlation between shores (~40 km apart) in SW Portugal suggests that cyprids of *P. pollicipes* are being affected by the same larval pool and physical transport processes operating at this scale. Recruitment of *P. pollicipes* in SW Portugal was higher on the low shore (~2.5 times) than on the high shore. Most recruits were attached to the lower half of the adult peduncle. The period of maximum attachment of juveniles (RC<12.5 mm) to conspecifics was summer and autumn (average of 15 juveniles per adult), while spring was the season with a lower number of juveniles growing on adults (average of 2 juveniles). Size of juveniles attached to conspecifics was rarely greater than 6 mm RC.

Individual annual growth rate of *P. pollicipes* that settled on a denuded surface was 15.7 mm RC (individuals ≤ 1 year old) which corresponds to a monthly increment of 1.3 mm RC in their first year of life.

Size structure analyses of *P. pollicipes* attached directly to primary substratum and/or to the base of conspecifics showed that barnacles at the low tide level reached a higher maximum size, indicating that growth at this level was faster than on the high shore. A higher temporal variability between these size-frequency distributions was detected in spring (March to May). In March, two cohorts (<1 year old, >1 year old) were identified. In May and August, it was difficult to identify individual different cohorts. From mid autumn to early spring, as a consequence of recruitment of barnacles to the primary substratum, it was again possible to identify two cohorts.

1. Introduction

Margaret Barnes (1996) published an extensive review on "Pedunculate cirripedes of the genus *Pollicipes*". Most of this review concerned the European *Pollicipes pollicipes* and the north eastern Pacific *P. polymerus* because very little was known about the tropical eastern Pacific *P. elegans*. More than ten years later, little has been published on *P. elegans* although several studies have been made on *P. pollicipes* (e.g. Kugele and Yule, 1996, 2000; Cruz and Hawkins, 1998; Cruz and Araújo, 1999; Molares and Freire, 2003; Macho et al., 2005; Bald et al., 2006; Borja et al., 2006a; Borja et al., 2006b), although much information remains in unpublished Ph.D. theses (e.g. Cruz, 2000; Pavón, 2003; Macho, 2006) (see Table 1). In this paper, we briefly review the literature on *Pollicipes* published after 1996 (Table 1), and present and re-analyse information regarding recruitment, growth and population size structure of *P. pollicipes* in SW Portugal originally presented in Cruz (2000).

P. pollicipes is a cirripede distributed in Western Europe and on the North African coasts of the eastern Atlantic from Brittany (France) to Senegal, being rare in the Mediterranean (Barnes, 1996). This species is abundant on very exposed rocky shores, ranging from the shallow subtidal to mid-intertidal zone.

Of all species of the genus *Pollicipes*, *P. pollicipes* is the most heavily exploited by man. In Spain and Portugal, it is highly prized as food (1 kg can cost up to 150 Euros in Iberian restaurants). *P. pollicipes* forms clumps of different sizes that are frequently damaged by human harvesting. Considering its vertical intertidal distribution, observations made on the Portuguese coast suggest that exploitation intensity is higher in the low shore than in the mid shore.

P. pollicipes is a simultaneous hermaphrodite, breeding more intensively from April to September on SW Portugal (Cruz and Hawkins, 1998). Brooding patterns differ between size classes and are similar

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Table 1
Studies about the genus Pollicipes published since the review by Barnes (1996). References are given in chronological order. IJ — international journal; Rep — report; PhD — PhD thesis; CP — conference proceedings; and BC — book chapter.

Reference	Subject	Location	Type of publication
Kugele and Yule (1996)	Larval morphology of *P. pollicipes*	Laboratorial conditions	IJ
Cruz and Hawkins (1998)	Reproduction of *P. pollcipes*	SW Portugal	IJ
Cruz and Araújo (1999)	Reproduction of *P. pollicipes*	SW Portugal	IJ
Jamieson et al. (1999)	Review on the biology of *P. polymerus*	W Canada	Rep
Lauzier (1999a)	Review on the biology of *P. polymerus*	W Canada	Rep
Lauzier (1999b)	Framework for *P. polymerus* fishery	W Canada	Rep
Cruz (2000)	Reproduction, recruitment, growth and size-structure of *P. pollicipes*	SW Portugal	PhD
Kugele and Yule (2000)	Active relocation of *P. pollicipes*	Laboratorial conditions	IJ
Jamieson et al. (2001)	Evaluation of community structure of *P. polymerus* beds	Vancouver Island, Canada	Rep
Lessard et al. (2003)	Fishery of *P. polymerus*	W Canada	CP
Marchinko and Palmer (2003)	Morphology, feeding of *P. polymerus*	Vancouver Island, Canada	IJ
Molares and Freire (2003)	Management of *P. pollicipes*	Galicia, Spain	IJ
Pavón (2003)	Reproduction, recruitment and population dynamics of *P. pollicipes*	Asturias, Spain	PhD
Borja et al. (2004)	Distribution of *P. pollicipes*	Basque Country, Spain	Rep
Castro (2004)	Exploitation of *P. pollicipes*	SW Portugal	PhD
Candeias (2005)	Feeding of *P. pollicipes* larvae	Laboratorial conditions	PhD
Macho et al. (2005)	Larval release of *P. pollicipes*	Galicia, Spain	IJ
Tapia (2005)	Larval distribution of *P. polymerus*	Southern and Baja California	PhD
Bald et al. (2006)	A system dynamics model for the management of *P. pollicipes*	Gaztelugatxe marine reserve, Spain	IJ
Borja et al. (2006a)	Relationship between wave-exposure and biomass of *P. pollicipes*	Gaztelugatxe marine reserve, Spain	IJ
Borja et al. (2006b)	Protection of *P. pollicipes* in a MPA	Gaztelugatxe marine reserve, Spain	IJ
Jesus (2006)	Management and exploitation of *P. pollicipes*	SW Portugal	BC
Macho (2006)	Reproduction, recruitment and larval distribution of *P. pollicipes*	Galicia, Spain	PhD
Quinteiro et al. (2007)	Genetics of *P. pollicipes*	Europe and west Africa	IJ
Campo et al. (2010)	Genetics of *P. pollicipes*	Europe and west Africa	IJ
Jacinto et al. (2010)	Fishery of *P. pollicipes* in a MPA	Nature reserve of Berlengas, Portugal	IJ

across tidal levels (Cruz and Araújo, 1999). Individuals apparently produce asynchronous broods and the estimates of the annual number of broods per individual vary from 1 to 4 (Cruz and Araújo, 1999).

Embryo development occurs inside the mantle cavity of adults until hatching of stage I nauplii. There are six naupliar stages and a cypris stage. The total embryo and larval development time of *P. pollicipes* in the laboratory under controlled conditions is about 1.5 to 2 months (Molares et al., 1994a; Molares et al., 1994b; Kugele and Yule, 1996).

1.1. Settlement and recruitment

Cyprids of *Pollicipes* settle heavily on conspecifics and so recruitment can be monitored with relative ease (Hoffman, 1989; Barnes, 1996). Size distributions of juvenile *P. polymerus* on adult peduncles were studied by Hoffman (1984) and he found that juveniles were not randomly distributed. There was a gradient from the smallest and most abundant near the growth zone (the narrow zone between capitulum and peduncle) to the largest and fewest located near the base of the peduncle. Cyprids or spat attached on the capitulum of an adult were rare. Hoffman (1984) suggested that juveniles could have a limited mobility that enables them to move in the direction of the primary substratum. Active relocation of juvenile *P. pollicipes* along the stalk was confirmed by Kugele and Yule (1993, 2000). According to these authors, the mechanism of relocation is the result of production of new tissue by the mitotically active basal region of the stalk (Chaffee and Lewis, 1988), which may be distorted by high haemolymph pressure into the direction of travel, and of secondary secretion of cement.

Besides conspecifics, recruitment on other surfaces (e.g., crevices and algal mats) has been observed in *P. polymerus* (Bernard, 1988). After six weeks, the great majority of these recruits had disappeared probably due to predation by crabs and polychaetes. Recruitment onto conspecifics helps to create a benign habitat with reduced physical and biological stresses (Bernard, 1988, Satchell and Farrell 1993, Barnes 1996). Differences in settlement and post-settlement mortality of *Pollicipes* on conspecifics versus other substrates have never been tested in the field.

Data on the temporal variability of recruitment of *P. pollicipes* on Iberian shores can be found in De la Hoz and Garcia (1993) (Asturias, Spain) and Molares (1994) (Galicia, Spain) and in unpublished theses (Cruz, 2000 — SW Portugal; Pavón, 2003 — Asturias, Spain; Macho 2006 — Galicia, Spain). However, different types of indices of recruitment were used in these studies: number of cyprids and juveniles of different sizes attached to adults (De la Hoz and Garcia, 1993; Cruz, 2000, Pavón, 2003); and percentage of adults with attached barnacles (Molares, 1994) or juveniles (Macho, 2006).

1.2. Growth and population size structure

Most studies of growth have been of *P. polymerus* (see review of Barnes, 1996) describing growth rates of a small number of marked individuals in certain habitats and conditions (e.g. Lewis and Chia, 1981; Page, 1986) or by following growth of barnacles that have recruited on cleared surfaces (e.g. Hoffman, 1989).

Several studies have demonstrated the potential for variability in rates of growth of barnacles as a function of intertidal location (e.g. Barnes and Powel, 1953). Sanford and Menge (2001) observed a dramatic variation of growth rates of intertidal barnacles (*Balanus glandula* and *Chthamalus dalli*) at a variety of spatial and temporal scales that appeared to be positively correlated with a complex set of oceanographic conditions, including wave exposure, abundance of planktonic food and water temperature.

Despite the economical importance of *P. pollicipes* in Iberia, essential information regarding the variability of growth rate of this species is still lacking.

Population size structure reflects recruitment, growth and mortality rates within a population. These processes are affected by several biological (e.g. larval supply, food, competition, predation and facilitation) and physical factors (e.g. desiccation stress, wave-exposure and sea water temperature). Page (1986) compared the population structure of *P. polymerus* at an intertidal rocky headland and at an offshore oil platform on one occasion, and found differences in the size-frequency distributions that were interpreted as a consequence of differential growth and survival rates between the two sites.