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First record of *Lepas* spp. (Cirripedia: Thoracica: Lepadiformes) attached to pumice from the Cordón-Caulle eruption along the central-South Chilean coast

GONZALO VÁZQUEZ-PRADA[1], EDUARDO JARAMILLO[1], GONZALO MORALES[1] AND RICARDO SILVA[2]

[1]Facultad de Ciencias, Instituto de Ciencias Ambientales y Evolutivas, Universidad Austral de Chile, Valdivia, Chile, [2]Facultad de Medicina, Universidad Austral de Chile, Valdivia, Chile

An early and massive settlement of Lepas australis *and* Lepas pectinata *attached to pumice from a recent volcanic eruption is described for the first time. The last 2010 earthquake of central Chile generated stress changes on the magma pathway and this reaction induced the Cordón-Caulle Volcanic Complex eruption on 4 June 2011. Only four months later, a great amount of pumice showing a massive settlement of goose barnacles (*Lepas *spp.) was drift-carried to the Chilean coast. Our results suggest that the larval attachment structures of* Lepas australis *and* L. pectinata *have a high capacity for adhering to the pumice surface, using it as an important dispersion vector.*

Keywords: Cirripedia, goose barnacle, volcanic subsidies, Chile, South Pacific Ocean

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INTRODUCTION

Lepas australis (Darwin, 1852) and *Lepas pectinata* (Spengler, 1793), commonly known as goose barnacles, are members of the family Lepadidae Darwin, 1852 (Crustacea: Cirripedia). Goose barnacles are pelagic and have been found attached to all types of floating structures, both biotic and abiotic, such as buoys, plastic boats, petroleum lumps, macroalgae, marine mammal remains, seals and birds (Darwin, 1852; Bishop, 1951; MacIntyre, 1966; Fine, 1970; Horn *et al.*, 1970; Arnaud, 1973; Tsikhon-Lukanina *et al.*, 1986; Conway *et al.*, 1990; Young, 1990; Aznar *et al.*, 1994; Arnbom & Lundberg, 1995; Minchin, 1996; Barnes *et al.*, 2004; Hinojosa *et al.*, 2006; Setsaas & Bester, 2006; Reisinger & Bester, 2010) as well as pumice (Newman & Ross, 1971; Donovan, 1999; Bryan *et al.*, 2004), and are sometimes ingested by certain birds, incorporating *Lepas* spp. in their diets (Simpson, 1965). *Lepas australis* has a circumpolar subantarctic distribution, with its presence diminishing to 33°S (Hinojosa *et al.*, 2006), whereas *L. pectinata* is known from both hemispheres (Conway *et al.*, 1990; Young, 1990; Aliani & Molcard, 2003; Jones, 2003, 2004; Hinojosa *et al.*, 2006). *Lepas pectinata* is more abundant in central Chile than *L. australis* and shows a preference for *Sargassum* species as a substrate in the northern hemisphere (Fine, 1970; Conway *et al.*, 1990; Hinojosa *et al.*, 2006).

The 2010 Mw 8.8 Maule earthquake of central Chile induced the Cordón-Caulle Volcanic Complex (CCVC) eruption on 4 June 2011, due to stress changes produced on the magma pathway (Bonali *et al.*, 2013). It generated an immense amount of pumice that was transported to the adjoining watersheds of the Bueno and Puyehue Rivers, in Chilean North Patagonia, i.e. the 'X Los Lagos Region' (Figure 1), as well as to other watersheds of Argentina (Castro & Schipper, 2011). Pumice is a distinctive feature of silicic eruptions (Eichelberger *et al.*, 1986). These two Chilean basins carry their waters to the Pacific Ocean. The surface ocean currents, present in the Bueno River mouth, flow in a north-south to north direction, parallel to the Humboldt Current. Pumice that had been stranded on the beaches had a massive settlement of cirripedes. Previous studies affirmed the importance of ocean conditions related to the modulation of the distribution of *Lepas* species along the Chilean coast (Hinojosa *et al.*, 2006) but the direct mechanisms that affect these distribution patterns are unknown. Four months after the volcanic eruption of 2011, pumice with an immense number of *Lepas* individuals attached was found stranded on the Valdivian coast (XIV Los Ríos Region, Chile). The purpose of this study was to characterize this observed settlement, including the average size of the scutum of the barnacles, the number of individuals per each piece of pumice and the pumice percentage of the total settlement presented on the pumice surface stranded on the Valdivian coast beaches and those found in the VIII Bío Bío Region.

MATERIALS AND METHODS

No specific permits were required for the described intertidal field studies. The sandy beaches we studied in Chile are

Corresponding author:
G. Vázquez-Prada
Email: gvpcruz@hotmail.com

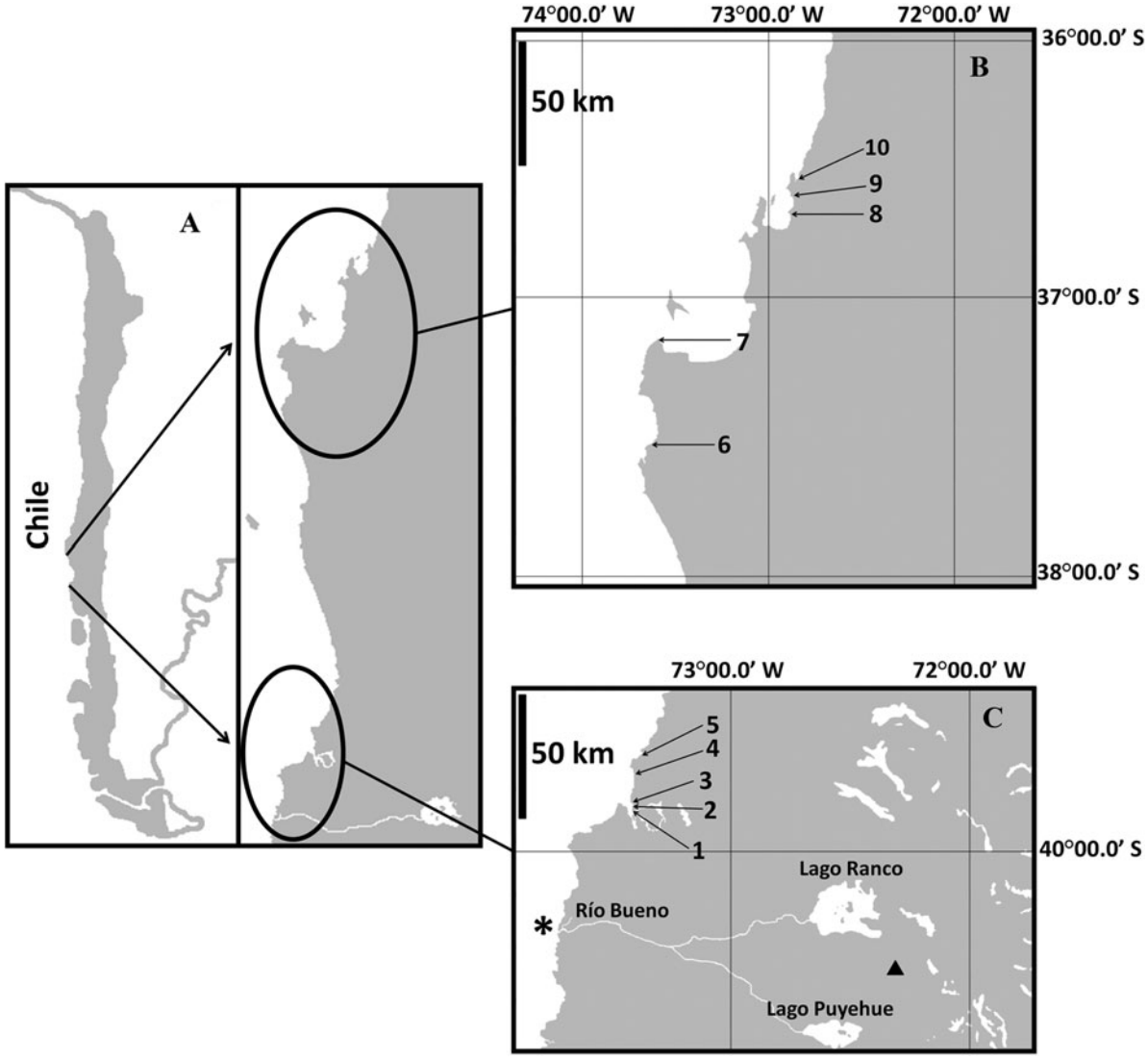

Fig. 1. Study area: (A) North Patagonia and South Pacific Chilean coast, Chile; (B) study coastal areas located between 36°20′S and 37°70′S (i.e. VIII Bío Bío Region), 6: Lebu, 7: Punta Lavapié, 8: Bellavista, 9: Cocholgue y 10: Dichato; (C) study beaches located between 39°48′S and 39°40′S (i.e. XIV Los Ríos Region), 1: San Ignacio, 2: Loncoyén, 3: Centenilla, 4: Curiñanco, 5: Pilolcura; *, shows the Bueno River mouth.

unrestricted to public access and use, and are not privately owned or designated as protected areas (reserves or parks). No protected or endangered species were involved in this study.

Four months after the CCVC eruption, cirripedes found attached to the pumice were analysed and the species *Lepas australis* and *Lepas pectinata* were identified following the criteria used by Hinojosa *et al.* (2006). After observing the settlement, we proceeded to sample five beaches in Los Ríos and Bío Bío Regions, respectively (Figure 1). Ten sampling grids of 35 × 35 cm and 9 × 9 cells were placed randomly per beach within the area of pumice stranded in the intertidal zone, and a picture of each grid was captured. At the same time, the width of the band of the surface stranded pumice (Figure 2) was measured per beach. The percentage of area occupied by the presence of pumice with *Lepas* species was estimated as the number of cells with *Lepas* species attached to the pumice per total of cells with pumice (×100) using Adobe® Photoshop® CS5 software.

A representative sample of volcanic fractions with *Lepas* species from San Ignacio, Loncoyén, Centenilla, Curiñanco and Pilolcura (i.e. beaches of the Los Ríos Region) were deposited in alcohol solution. Identical sampling was carried out at Lebu, Punta Lavapié, Bellavista, Cocholhue and Dichato beaches, in the Bío Bío Region (Figure 1). However *Lepas* species were not found on these beaches, excepting Punta Lavapié, where the number of arthropods was not representative. Also, *Lepas* species found on Curiñanco Beach were less abundant than the other Valdivian beaches, but this sample was taken into consideration. The samples were examined with a Motic SMZ-168 stereo microscope with 10 × magnification. Thirty-five pieces of pumice with *Lepas* attached were analysed per each beach. The number of *Lepas* per pumice was taken into account and the length of their scutum was measured. A descriptive statistical analysis was performance using SigmaPlot®10.0 Software for each variable and beach. Finally, species were studied with scanning electron microscopy MEB (LEO 420), following the techniques used by previous researchers on the morphology of *Lepas* species (Blomsterberg *et al.*, 2004). The attachment positions of the larval structures, as well as details of the peduncles, were photographed (Figure 6).

Fig. 2. Pumice stranded on Curiñanco Beach.

RESULTS

Lepas australis and *Lepas pectinata* were observed attached to floating pumice (Figure 3). A high percentage of stranded pumice with *Lepas* species settlement was found in the intertidal zone (Figure 4). The number of observed individuals varied from 1 to 35 per pumice for *L. australis* with the latter figure corresponding to one piece of pumice found on Centenilla Beach. *Lepas pectinata* was much less abundant, with only 20 individuals observed versus approximately 1200 individuals of *L. australis*, all from the XIV Los Ríos Region. When both species were observed, they were attached to the same pumice, i.e. they were sharing substrate (Figure 3). Size ranges of the scutum were between 1.1–7.5 mm for *L. australis* and 1.1–3.5 mm for *L. pectinata*. No differences were observed between scutal sizes from the beaches of the Los Ríos Region (Figure 5). However, the average scutal sizes were lower on the beaches from the Bío Bío Region (i.e. Punta Lavapié) than those of the southern region. The larvae of both species occurred in the sample of the Los Ríos Region and were photographed by MEB (Figure 6). Attachment sites chosen by the larvae could also be observed and these corresponded with the holes on the irregular pumice surface (Figure 6).

Morphological characters observed by MEB agree with the observations by Blomsterberg *et al.* (2004) in their morphological study of *Lepas*.

DISCUSSION

Our results suggest that the nauplii of *Lepas australis* and *Lepas pectinata* have had a high capacity to attach early and

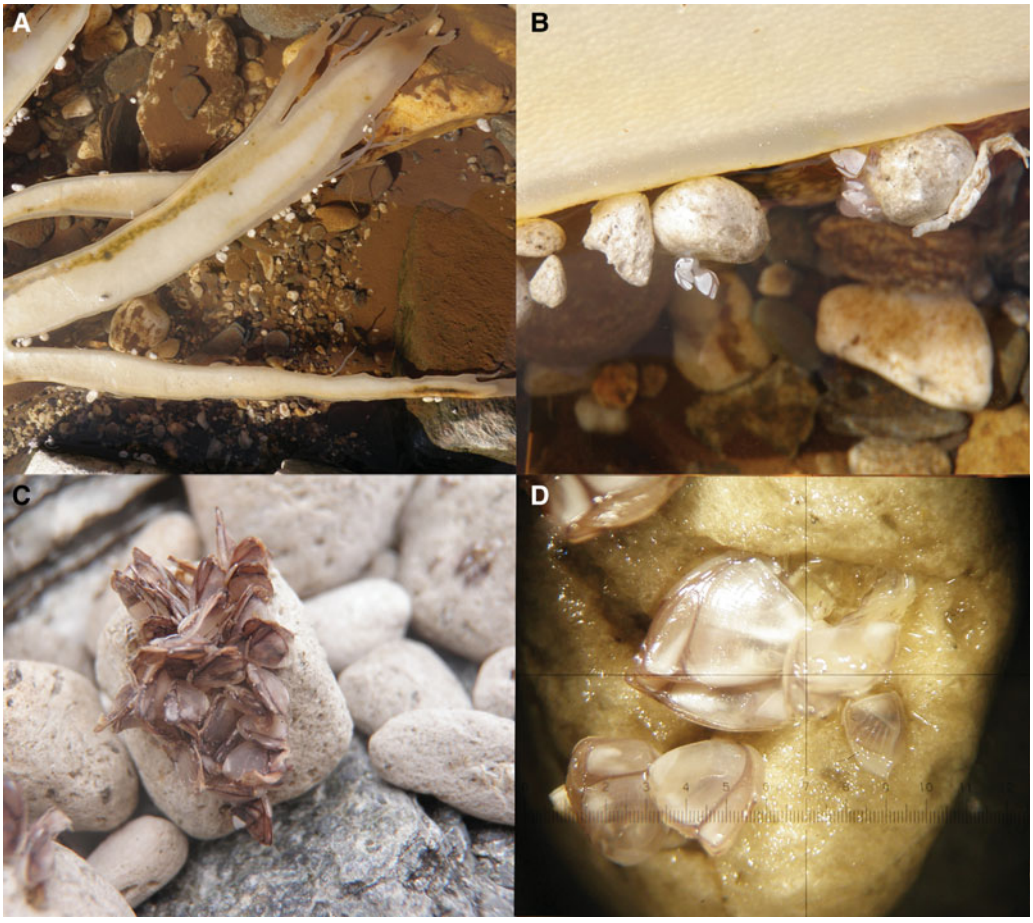

Fig. 3. *Lepas* species attached to pumice: (A) floating pumice stranded on the shore; (B) *Lepas* species attached to floating pumice; (C) *Lepas* species attached to pumice stranded on the intertidal zone; (D) *Lepas australis* and *Lepas pectinata* attached to the same pumice observed with a Motic SMZ-168 stereo microscope standardized at 10 × magnification.

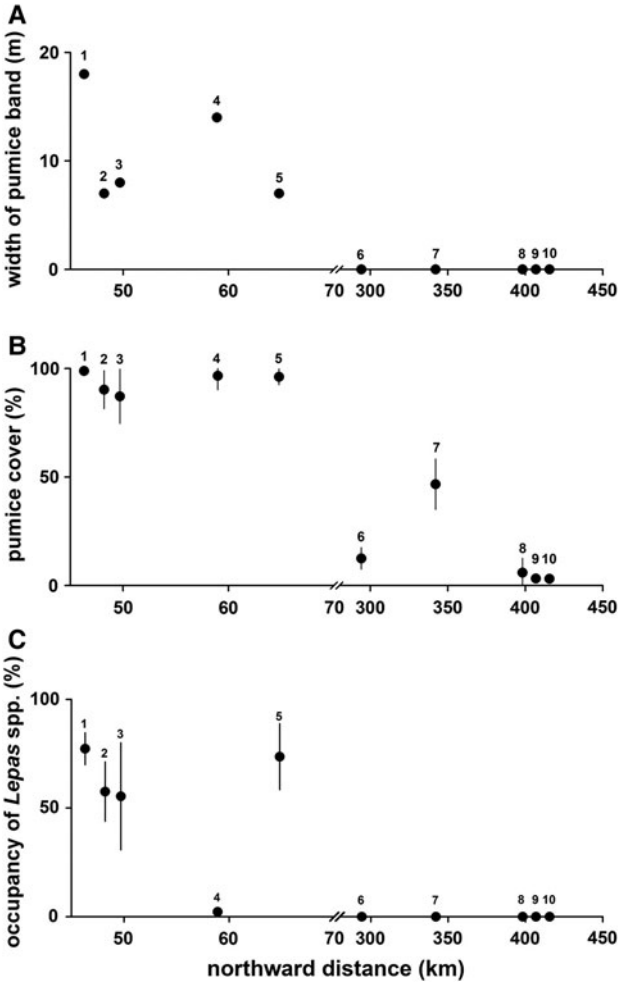

Fig. 4. Characterization of the surface of pumice deposited on beach shore: (A) bandwidth; (B) % area coverage of the shore with pumice; (C) % area with *Lepas australis* attached. Vertical bars represent the standard deviation of each parameter.

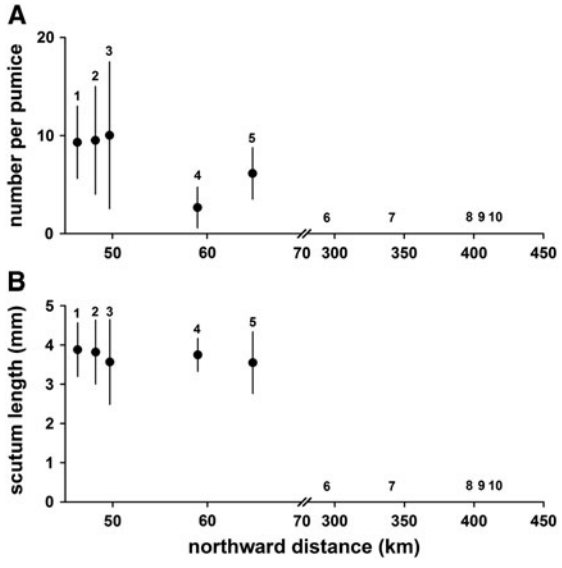

Fig. 5. (A) Representation of the number of individuals attached per pumice by distance to the mouth of the Bueno River; (B) scutal length of *Lepas australis* attached to pumice found on the shore of XIV Los Rios Region Beaches. Vertical bars represent the standard deviation of each parameter.

rapidly via their larval attachment structures to pumice that had arrived in the Pacific Ocean via the Bueno River mouth. *Lepas australis* individuals were more numerous than those of *L. pectinata* and extreme numbers of them could be observed on the shores. This result suggests there was no overlap between the species in this settlement. It directly implies that these organisms can use this floating substrate for attachment as a vector for dispersion, as many authors have reported for other regions of the southern hemisphere (Simpson, 1965; Newman & Ross, 1971; Bryan *et al.*, 2004), although these authors only observed a small number of samples.

The small size of the large number of individuals observed in this fortuitous settlement (Figure 5) indicates that the deposition of the pumice on beaches due to the action of ocean surface currents prevented them from reaching adulthood. No analysis of the development of their gonads was performed and thus no information on the reproductive capacity of individuals is available. The low number of individuals found on Curiñanco Beach could be explained by the strong waves on this exposed beach (Duarte *et al.*, 2009), which could favour the friction between the pieces of pumice with presence of *Lepas* species, or inhibit the attachment of them to the pumice. The small number of pieces of pumice and barnacles found on the beaches of the VIII Bío Bío Region could be explained by the effects of continental uplift that resulted from the earthquake of 27 February 2010. These changes in intertidal beach structures after the Maule earthquake have been constant during 2010 and 2011 (Jaramillo, 2011; Vargas *et al.*, 2011; Jaramillo *et al.*, 2012a, b). The finding of juveniles suggests that the larvae had taken little time to find the volcanic substrate and complete their development to adults after the pumice had arrived in the Pacific Ocean, which is consistent with that described by MacIntyre (1966). It would be interesting to analyse the origin of the larvae attached to the pumice to corroborate the observations of Scheltema (1971), which affirmed the possibility of the larvae of benthic organisms moving long distances, and the observations of Helmuth *et al.* (1994) on larval dispersal of subantarctic benthic organisms by kelp rafting. In turn, this information would serve for comparison with the results of Barnes *et al.* (2004), which suggest that it is unlikely that they will find their development site in a few weeks; however, in this case, these pieces of pumice were floating on the ocean surface for less than four months and the larvae age is unknown. Volcanic activity in this area has been recorded from the Cenozoic (Vergara & Munizaga, 1974) and thus it can be argued that these species of barnacles could have used this natural vector for several millennia to move from low subantarctic latitudes, following the ocean currents to warm water, and agreeing with the proposal by Donovan (1999) for *Lepas anatifera* in the Caribbean Sea. Barnes *et al.* (2004) reported stalked barnacles attached to different organisms from the Antarctic region. Herein, we report the first record of *Lepas* species attached to pumice for the Chilean coast, where past volcanic activity is well known (Illies, 1970; Vergara & Munizaga, 1974; Lavenu & Cembrano, 1999; Pino, 2003). The destructive nature of volcanic eruptions can be contrasted with the increased supply of available substrates for utilization by the larval attachment structures of stalked barnacles, serving as an important dispersal vector for these organisms.

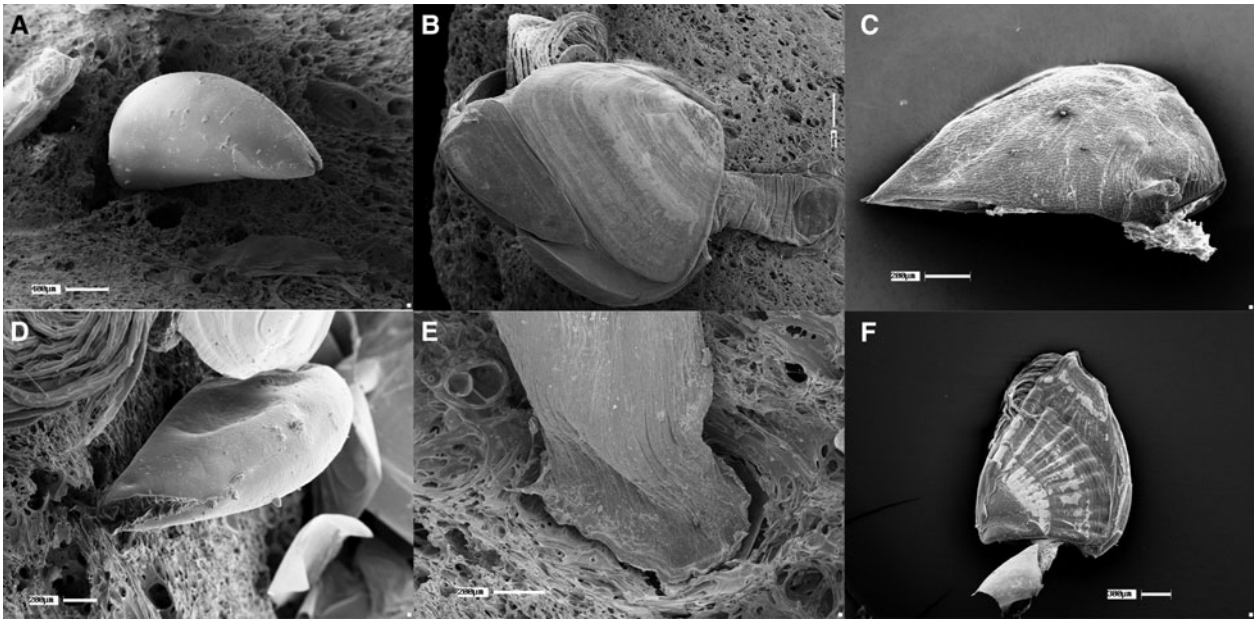

Fig. 6. MEB images: (A) *Lepas australis* nauplius larva attached to pumice; (B) *L. australis* individual attached to pumice; (C) nauplius larva of *Lepas pectinata*; (D) *L. australis* larva sharing substrate with metamorphic individuals of same species; (E) detail of the peduncle structure of *L. australis*; (F) *Lepas pectinata*.

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Correspondence should be addressed to:
G. Vázquez-Prada
Facultad de Ciencias
Instituto de Ciencias Ambientales y Evolutivas
Universidad Austral de Chile, Valdivia, Chile
email: gvpcruz@hotmail.com