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Rapid Communication

Potential invasion of the Atlantic coast of South America by *Semimytilus algosus* (Gould, 1850)

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Abstract

The mytilid *Semimytilus algosus* (Gould, 1850) was collected from a fishing vessel after an in-water hull cleaning operation at Nuevo Gulf, north Patagonia, Argentina. This species is native to the Pacific coast of South America and had not been detected on the Atlantic coast of this continent. Histological slides from male and female portions of gonads of a subsample of specimens showed spawning activity. The gonad stages observed were: developing stage, ready to spawn, spawning, or had already spawned, suggesting the possibility of establishment of a breeding population in the area. The water temperatures, its seasonal range, and the habitats occupied by *S. algosus* in its native area are very similar to those present in Nuevo Gulf. The plasticity of this species, and its rapid invasion in other regions of the world, suggest that it could become a new invasive species in the Southwestern Atlantic in the near future. Targeted monitoring of the rocky shores of Nuevo Gulf is recommended to determine whether this non-native species is at an early stage of becoming established.

Key words: in-water hull cleaning, potential invasion, Argentina, Mytilidae

Introduction

It is widely accepted that many non-native marine species have been transported to new locations in the ballast tanks or attached to hulls of commercial ships (Ruiz and Carlton 2003). Authorities generally focus their attention on the management of ballast water and their associated sediments; however, the hull of vessels, and especially the sea chests, can be densely colonized by marine species, despite the use of antifouling paints (Gollasch 2002; Hopkins and Forrest 2008). Large cargo vessels (e.g. container vessels, >50 m length), bulk carriers, and oil tankers spend about 12–72 hours at each port and chances of being colonized by fouling species can be low. In contrast, smaller vessels, such as fishing ships, can spend weeks or even months at each harbor, which increase the opportunities to be colonized by fouling organisms (Brock et al. 1999; Coutts and Taylor 2004).

Speed and fuel consumption of ships are negatively affected when the hull is colonized by marine species. For this reason, most commercial ships have regular schedules for dry docking, cleaning, and application of antifouling paints (Davidson et al. 2008). Small vessels, however, often are cleaned manually *in situ* and rotating brushes and scrapers do not retain the defouled material; consequently, viable organisms, fragments, and propagules are thrown into the sea (Hopkins and Forrest 2008). Some countries have no regulations on hull-fouling management; hence, in-water hull cleaning is a common practice (but see the biosecurity regulations of New Zealand and Australia, Campbell 2008; Hopkins and Forrest 2008). In Argentina, small national and international fishing ships usually stop in gulfs, bays, and calm-water harbors for different requirements (medical care, food supplies, hull inspections, etc.) and for widely varying lengths of time. There are few regulations related to the prevention of establishment of marine invasive species in Argentina (see Boltovskoy et al. 2011), and all of them are related to the control and management of ballast water. Regulations about hull cleaning procedures are still under discussion. Within this context, samples of bivalves removed during in-water hull cleaning of a fishing ship in Puerto Madryn were obtained, all specimens were subsequently identified as the non-native *Semimytilus algosus* (Gould, 1850) and, as documented in this study, many specimens were reproductively active. This study reports the potential introduction of the bivalve *S. algosus* to the east coast of South America.

Methods

On 23 February 2013 a squid-fishing vessel arrived in Puerto Madryn harbor (42°14'30"S, 65°10'10"W), Argentina, for medical and food supplies. During its visit, an in-water hull cleaning procedure was performed by a local scuba diving company. The sea chests, colonized by unknown bivalves, were cleaned and some of the bivalves were discarded into the harbor. However, a sample of specimens was transported to the Centro Nacional Patagónico (Puerto Madryn, Argentina) for identification. Bivalves were received frozen and stored at -18°C.

The bivalves were identified using the appropriate taxonomic literature and were compared to the type material. To evaluate if the specimens were reproductively active, the sexual maturity and gonadic stages of a subsample were examined histologically. The shell lengths of 20 large specimens were measured with a digital caliper, then each individual was dissected and their gonads fixed for 3 hours in Bouin's solution. Fixed gonads were transferred to 70% ethanol, dehydrated in increasing ethanol concentrations, embedded in paraffin at 58°C, cut into 6-µm sections with a sliding microtome, and mounted on slides. The sections were then stained with hematoxylin and eosin, and examined under a light microscope. Photographs of the different gonadal stages observed were taken with a digital camera.

Gonadic maturity stages were classified by histological slides of the mantle tissues following Bigatti et al. (2005) for the mytilid *Perna viridis* (Linnaeus, 1758). These stages are: immature stage (gonads are not differentiated and follicles are not developed, therefore sex cannot be differentiated), growing stage (gamete development from the follicle walls, oogonia present in females and spermatocytes visible in males), ready to spawn stage (gonads ripe and gametes mature. In males mature spermatozoon attached to the follicle walls; in females: oocytes occupying the whole follicle), spawning stage (gametes detached from the follicle walls and released into the lumen of the follicles), spent stage (male and female follicles empty and some residual gametes present in the lumen), and resorption stage (atresic cells present in male and female follicles with gametes in the process of degradation).

Results

Taxonomic remarks of the potential invader

All of the specimens taken to the laboratory were identified as *Semimytilus algosus* (Mytilidae, Figure 1) based on the relevant taxonomic literature (Lamy 1931; 1936; Soot-Ryen 1955; Kensley and Penrith 1970) and comparison to the type material originally collected in Callao, Lima (Peru) and deposited at the Museum of Comparative Zoology (MCZ 216829, 154352), Harvard University, USA. Shell morphology of sampled specimens agreed with the diagnostic characters established for the species by Soot-Ryen (1955). These characters were: an elongate mytiliform shell; interiorly nacreous with anterior adductors present and posterior adductors and retractors continuous; hinge plate without teeth and resilial ridge compact; and external surface smooth with concentric and irregular rings from umbo to posterior edge. All specimens collected during this study were deposited at CENPAT General Invertebrate collection (CNP-INV 1783).

Gonadal stages

Shell length of the subsample of 20 specimens examined in detail ranged between 19.5–and 49.5 mm with a mean of 38.8 mm (SD=7.9). All of the specimens studied were mature: the male portion of the gonad was whitish and the female portion was grey-violet. Of the 20 bivalves examined, 14 had hermaphroditic gonads, one had male-only gonads, and five had female-only gonads. Based on the histological sections, these animals were reproductively active. Female gonad sections presented as 40% in growing stage, 10% ready to spawn, 31% spawning, 10% spent, and 9% in resorption (Figure 2 A-B). Sections of the male portion of the gonads presented as 38% in the growing stage, 29% ready to spawn, and 33% spawning (Figure 2 C-D).

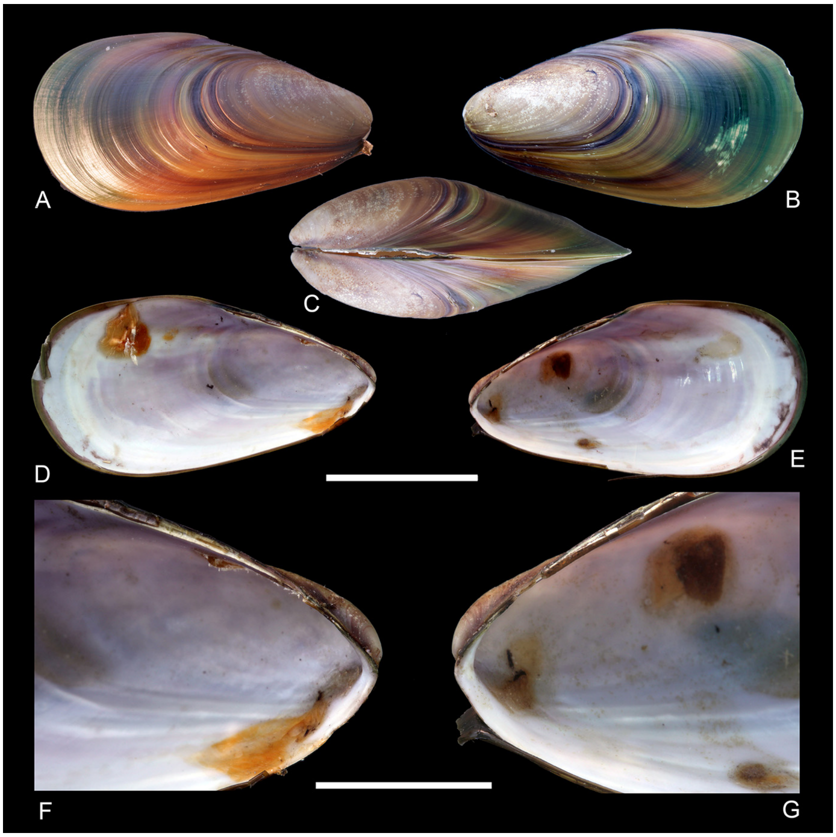

Figure 1. Specimens of *Semimytilus algosus* sampled from the fishing vessel. A-E: general aspect; F-G: detail of compact resilial ridge and hinge without tooth. Scale bar A-E: 2 cm, F-G: 1 cm. Photographs by JH Signorelli.

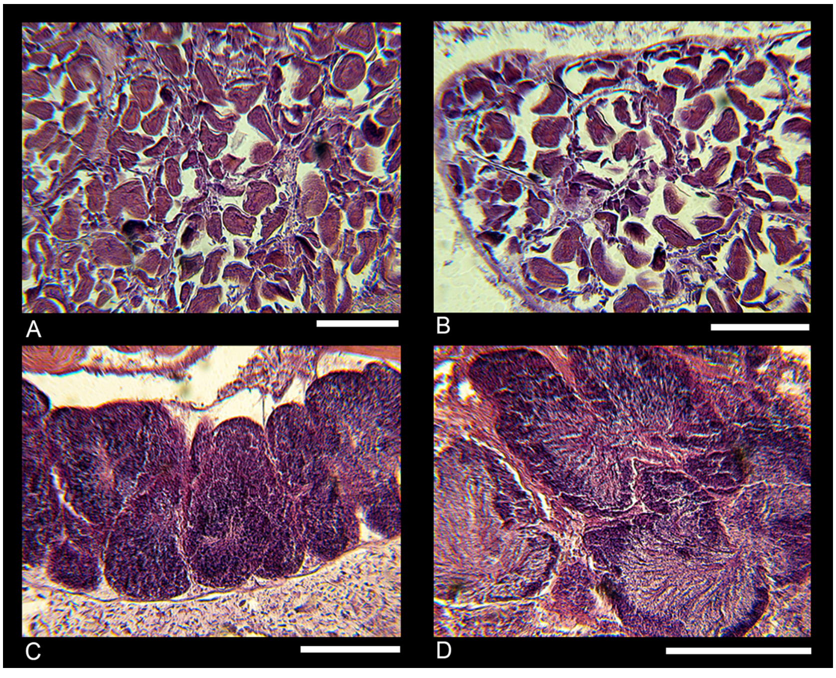

Figure 2. Gonadal stages of *Semimytilus algosus*. A: female ready to spawn. B: female spawning. C: male ready to spawn. D: male spawning. Scale bar: 200 µm. Photographs by G Bigatti.

Discussion

Semimytilus algosus is native to the Pacific coast of South America, and its distribution ranges from Manta, Ecuador (0°56'S, 80°92'W) to Gulf of Arauco, Chile (37°12'S, 73°20'W) (Osorio and Bahamonde 1968). It is recorded from the intertidal and subtidal rocky shores and as a fouling species in scallop aquaculture facilities (Pacheco and Garate 2005). This species is a common organism living on wave-exposed rocky shores along the Pacific coast (Tokeshi and Romero 1995; Navarrete et al. 2002). However, it is absent from the Atlantic coast of South America but that may well change if the animals detected in this study reproduced successfully.

The fishing vessel carrying *S. algosus* was anchored in Callao, Peru, for one month from October - November, 2012 and this was the last port-of-call. Callao is a breakwater harbor surrounded by sandy and rocky shores with a mean sea-surface water temperature in summer 2012 of 20–22°C and 16–19°C in winter (IMARPE 2014). At the southern limit distribution of the species in Chile, the sea-surface water temperature ranges from 9–11°C (Castro et al. 2000), while the temperature in Puerto Madryn varies between 9°C in winter to 20°C in summer (Servicio de Hidrografía Naval 2013). Although there are environmental differences between the source and possible recipient regions (nutrients, ocean currents, wave force, upwelling, among others Werlinger 2004; Falabella et al. 2009), the thermal range in Nuevo Gulf is similar to that observed in the native area. It is remarkable that *S. algosus* was able to recruit and grow on the vessel when it was anchored in Peru and then to survive the long trip to the Atlantic coast. Moreover, the sampled mussels were reproductively active, with some specimens ready to spawn and others spawning.

In its native range, *S. algosus* is reproductively active throughout the year, recruits are observed year round, and there is a reproductive peak during summer months (Navarrete et al. 2002; Belapatiño 2007). In its native environment, larval development is completed in about 27 days and pediveliger metamorphoses at a maximum size of 150 µm (Ramorino and Campos 1983; Garrido 1996). With a suitable thermal range, and rapid larval development, we think survival of this species on the Atlantic coast is highly likely.

Semimytilus algosus has already been introduced in to the western (Atlantic) coast of Africa. Specimens of Mytilidae from South Africa in the collection of the South African Museum were tentatively identified as *S. algosus* by Barnard (1964), a finding later confirmed by Kensley and Penrith (1970). However, this was not the first introduction to the African continent. The species *Modiola pseudocapensis* was described for the coast of Namibia (Lamy 1931) but subsequent authors (e.g. Kensley and Penrith 1980; Branch et al. 2010; Mead et al. 2011) referred this Namibian population as *S. algosus*. At present, non-native species are dominant species of some rocky shores on the west coast of South Africa: *S. algosus* has colonized the lower intertidal along 500 km of coastline; *Mytilus galloprovincialis* Lamarck, 1819 has invaded the mid-intertidal zone, and *Balanus glandula* Darwin, 1854 has colonized the high intertidal zone (de Greef et al. 2013). Of these, *B. glandula* is also an invasive species on the east coast of Argentina (Schwindt 2007).

Semimytilus algosus appears to have a great impact on the native rocky-shore community. Because this species is numerically dominant and forms dense beds, it excludes other species from subtidal areas of the wave-exposed shore (de Greef et al. 2013). At the present, the low intertidal rocky shores in Patagonia are dominated by the blue mussel *Mytilus* sp. and the ribbed mussel *Aulacomya atra* (Molina, 1782), and the establishment of *Semimytilus* would likely affect the ecological interactions within this habitat. With its smaller size and smaller interstitial spaces, *Semimytilus* might create new refuges for infaunal species not typically found in existing mussel beds (Sueiro et al. 2011). In addition, predator-prey interactions could change. For example, the sea urchin *Arbacia dufresnii* (Blainville 1825) is a generalist consumer and is very abundant in the subtidal (Penchaszadeh and Lawrence 1999) of Nuevo Gulf and it is unknown how its population might change in response to a new, smaller, prey species. The voracious, opportunist, sea slug *Pleurobranchaea inconspicua* Bergh, 1897, also is observed in high densities (Muniain et al. 2007) and other organisms such as the sea star *Anasterias antarctica* (Lütken, 1857), and crabs (including the invasive *Carcinus maenas* (Linnaeus, 1758)) are also potential predators of *S algosus* in low shore areas (Hidalgo et al. 2007; Gil and Zaixso 2008). With its small size compared to native mussels, abundances of some predators may actually increase as abundance of this novel prey (*S. algosus*) of suitable handling-size increases.

Semimytilus algosus has economic value in its native area. In Peru, this species is collected from the wild for human consumption and it is raised in limited quantities in some aquaculture sites in Chile (Gonzalez et al. 1980). In South Africa the economic effects of this non-native species have yet to be evaluated (de Greef et al. 2013). The development of fisheries for invasive species can be a good strategy for mitigation, and fisheries now exist for the invasive green mussel *Perna viridis* in Venezuela (pers.obs) and the exotic *Rapana venosa* (Valenciennes, 1846) in Uruguay (Carranza et al. 2013).

The results of this study have identified a problem with current in-water hull-cleaning practices. These operations are common in many regions, especially for small recreational vessels. However, some countries have placed restrictions on this method due to biosecurity risks (Forrest and Hopkins 2008). The absence of legislation addressing hull-cleaning practices in Argentina (Boltovskoy et al. 2011) increases the incentive for large commercial vessels to perform hull inspections and defouling practices outside their dry-docking schedule in, for example, the calm waters of Nuevo Gulf, Argentina. Although Patagonian ports are not the most important in Argentina in terms of shipping traffic, the number of exotic species is increasing (Schwindt et al. 2014) and some of them, like the aggressive kelp *Undaria pinnatifida* (Harvey) Suringar, likely were introduced as a fouling species and have changed the landscape and affected the native biodiversity in a negative way (Casas et al. 2004, Irigoyen et al. 2011). Thus, there is an urgent need to discuss and to legislate these risky activities. Given the results of this study, targeted monitoring of the rocky shores of Nuevo Gulf and adjacent areas is needed to determine whether *Semimytilus algosus* has colonized the study area, presumably at an early stage of the invasion when eradication might still be possible.

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References

Barnard KH (1964) Contributions to the knowledge of South African marine Mollusca, Part 5, Lamellibranchiata. *Annals of the South African Museum* 47 (3): 361–593

Belapatiño AO (2007) Variabilidad del asentamiento larval de mitílidos en bahía independencia, Pisco-Perú, durante el periodo. 1996–2003. Biology Degree Thesis. Universidad Nacional Mayor de San Marcos. Universidad del Perú, Perú, 67 pp

Bigatti G, Miloslavich P, Penchaszadeh PE (2005) Sexual differentiation and size at first maturity of the invasive mussel *Perna viridis* (Linnaeus, 1758) (Mollusca: Mytilidae) at La Restinga lagoon (Margarita Island, Venezuela). *American Malacological Bulletin* 20: 65–69

Boltovskoy D, Almada P, Correa N (2011) Biological invasions: assessment of threat from ballast-water discharge in Patagonian (Argentina) ports. *Environmental Science & Policy* 14: 578–583, http://dx.doi.org/10.1016/j.envsci.2011.03.007

Branch GM, Griffiths CL, Branch ML, Beckley LE (2010) Two oceans – a guide to the marine life of southern Africa. Cape Town: Struik Nature, 456 pp

Brock R, Bailey-Brock JH, Goody J (1999) A case study in the efficacy of freshwater immersion in controlling introduction of alien marine fouling communities: the USS. *Missouri Pacific Science* 53: 223–231

Campbell ML (2008) Organism impact assessment: risk analysis for post-incursion management. *ICES Journal of Marine Science* 65: 795–804, http://dx.doi.org/10.1093/icesjms/fsn083

Carranza A, Delgado EA, Martínez G (2013) Bases socio-ecológicas para el desarrollo de una pesquería artesanal de *Rapana venosa* en Maldonado, Uruguay. In: Aber A, Ferrari G, Porcile JF, Rodríguez E, Zerbino S (eds), Identificación de prioridades para la gestión nacional de las especies exóticas invasoras. Montevideo: UNESCO, pp 84–89

Casas G, Scrosati R, Piriz ML (2004) The invasive kelp *Undaria pinnatifida* (Phaeophyceae, Laminariales) reduces native seaweed diversity in Nuevo Gulf (Patagonia, Argentina). *Biological Invasions* 6: 411–416, http://dx.doi.org/10.1023/B:BINV.0000041555.29305.41

Castro LR, Salinas GR, Hernández EH (2000) Environmental influences on winter spawning of the anchoveta *Engraulis ringens* off central Chile. *Marine Ecology Progress Series* 197: 241–258, http://dx.doi.org/10.3354/meps197247

Coutts ADM, Taylor MD (2004) A preliminary investigation of biosecurity risks associated with biofouling on merchant vessels in New Zealand. *New Zealand Journal of Marine and Freshwater Research* 38: 215–229, http://dx.doi.org/10.1080/00288330.2004.9517232

Davidson IC, McCann LD, Fofonoff PW, Sytsma MD, Ruiz GM (2008) The potential for hull-mediated species transfers by obsolete ships on their final voyages. *Diversity and Distribution* 14: 518–529, http://dx.doi.org/10.1111/j.1472-4642.2008.00465.x

de Greef K, Griffiths CL, Zeeman Z (2013) Deja vu? A second mytilid mussel, *Semimytilus algosus*, invades South Africa's west coast. *African Journal of Marine Science* 35: 307–313, http://dx.doi.org/10.2989/1814232X.2013.829789

Falabella V, Campagna C, Croxall J (eds) (2009) Atlas del Mar Patagónico. Especies y espacios. Buenos Aires, Wildlife Conservation Society and BirdLife Internacional, 304 pp

Garrido O (1996) Biología comparada de la reproducción en moluscos bivalvos Mytilidae. Ph.D. Thesis, Universidad Austral de Chile, Valdivia, Chile

Gil DG, Zaixso HE (2008) Feeding ecology of the subantarctic sea star *Anasterias minuta* within tide pools in Patagonia, Argentina. *Revista de Biologia Tropical* 56: 311–328

Gollasch S (2002) The importance of ship hull fouling as a vector of species introductions into the North Sea. *Biofouling* 18: 105–121, http://dx.doi.org/10.1080/08927010290011361

Gonzalez J, Villagra J, Hinojosa M, Becerra R (1980) Potencialidad del cultivo en balsa de *Semimytilus algosus* (Gould) 1850, en la bahía de Concepción (Mollusca, Bivalvia, Mytilidae*). Boletim do Instituto Oceanografico, Sao Paulo* 29: 187–189, http://dx.doi.org/10.1590/S0373-55241980000200038

Hidalgo FJ, Silliman BR, Bazterrica MC, Bertness MD (2007) Predation on the rocky shores of Patagonia, Argentina. *Estuaries and Coasts* 30: 886–894

Hopkins GA, Forrest BM (2008) Management options for vessel hull fouling: an overview of risks posed by in-water cleaning. *ICES Journal of Marine Science* 65: 811–815, http://dx.doi.org/10.1093/icesjms/fsn026

IMARPE (2014) Instituto del Mar del Perú. http://www.imarpe.pe (Accessed 23 July 2014)

Irigoyen AJ, Eyras C, Parma A (2011) Alien algae *Undaria pinnatifida* causes habitat loss for rocky reef fishes in north Patagonia. *Biological Invasions* 13: 17–24, http://dx.doi.org/10.1007/s10530-010-9780-1

Kensley B, Penrith M (1970) New records of Mytilidae from the northern South West African coast. *Annals of the South African Museum* 57: 15–24, http://dx.doi.org/10.1007/s10530-010-9780-1

Lamy E (1931) Voyage de Mons. P. Lesne dans Afrique du Sud, 1928–1929. Mollusques marins. *Bulletin du Musee d'Histoire Naturelle de Paris* (2) 3: 304–307

Lamy E (1936/37) Revision des Mytilidae vivants du Museum d'Histoire Naturelle de Paris. *J. Conchyliol.* 80: 66–102, 107–212, 229–295 (1936); 307–363; 81, 5–71, 99–132, 169–197

Mead M, Carlton JT, Griffiths CL, Rius M (2011) Revealing the scale of marine bioinvasions in developing regions: a South African re-assessment. *Biological Invasions* 13: 1991–2008, http://dx.doi.org/10.1007/s10530-011-0016-9

Muniain C, Ardila NE, Cervera JL (2007) *Pleurobranchaea inconspicua* Bergh, 1897 (Opisthobranchia: Pleurobranchidae): Redescription and distribution from Argentina and Colombia. *Bonner zoologische Beiträge* 55: 291–300

Navarrete SA, Broitman B, Wieters EA, Finke GR, Venegas RM, Sotomayor A (2002) Recruitment of intertidal invertebrates in the southeast Pacific: Interannual variability and the 1997–1998 El Niño. *Limnology and Oceanography* 47: 791–802, http://dx.doi.org/10.4319/lo.2002.47.3.0791

Osorio C, Bahamonde N (1968) Moluscos bivalvos en pesquerías chilenas. *Biología Pesquera, Chile* 3: 69–128

Pacheco A, Garate A (2005) Bioincrustantes en estructuras de cultivo de *Argopecten purpuratus* en bahía Samanco, Perú. *Ecología Aplicada* 4 (1,2): 149–152

Ramorino L, Campos B (1983) Larvas y post larvas de Mytilidae de Chile (Mollusca: Bivalvia). *Revista Biología Marina, Chile* 19: 143–192

Ruiz GM, Carlton JT (eds) (2003) Invasive species: vectors and management strategies. Island Press, Washington, DC

Schwindt E (2007) The invasion of the acorn barnacle *Balanus glandula* in the south-western Atlantic 40 years later. *Journal of the Marine Biological Association of the UK* 87: 1219–1225, http://dx.doi.org/10.1017/S0025315407056895

Schwindt E, López Gappa J, Raffo MP, Tatián M, Bortolus A, Orensanz JM, Alonso G, Diez ME, Doti B, Genzano G, Lagger C, Lovrich G, Piriz ML, Méndez MM, Savoya V, Sueiro MC (2014) Marine fouling invasions in ports of Patagonia (Argentina) with implications for legislation and monitoring programs. *Marine Environmental Research* 99: 60–68, http://dx.doi.org/10.1016/j.marenvres.2014.06.006

Servicio de Hidrografía Naval (2013) Temperature data. http://www.hidro.gov.ar (Accessed 20 November 2013)

Soot-Ryen T (1955) A report on the family Mytilidae. *Allan Hancock Pacific Expedition* 20: 1–154

Sueiro MC, Bortolus A, Schwindt E (2011) Habitat complexity and community composition: Relationships between different ecosystem engineers and the associated macroinvertebrate assemblages. *Helgoland Marine Research* 65: 467–477, http://dx.doi.org/10.1007/s10152-010-0236-x

Tokeshi M, Romero L (1995) Filling a gap: dynamics of space occupancy on a mussel-dominated subtropical rocky shore. *Marine Ecology Progress Series* 119: 167–176, http://dx.doi.org/10.3354/meps119167

Werlinger C (ed) (2004) Biología marina y oceanografía: conceptos y procesos. Consejo Nacional del Libro y la Lectura. Universidad de Concepción. Trama Impresores S.A. Chile, 700 pp