

ORIGINAL ARTICLE

Sewage-induced polychaete reefs in a SW Atlantic shore: rapid response to small-scale disturbance

Griselda V. Garaffo^{1,2}, María L. Jaubet^{1,2}, María de los Á. Sánchez^{1,2}, María S. Rivero¹, Eduardo A. Vallarino¹ & Rodolfo Elías¹

1 Departamento de Ciencias Marinas, Universidad Nacional de Mar del Plata, Mar del Plata, Argentina

2 Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Buenos Aires, Argentina

Keywords

Intertidal; polychaete reefs; sewage-impacted area; Southwest Atlantic; Spionidae.

Correspondence

Griselda V. Garaffo, Departamento de Ciencias Marinas, Universidad Nacional de Mar del Plata, Deán Funes 3350, B 7602 AYL Mar del Plata, Argentina.
E-mail: garaffo@mdp.edu.ar

Accepted: 29 August 2011

doi:10.1111/j.1439-0485.2011.00495.x

Abstract

The intertidal zone around Mar del Plata's sewage discharge (38° S, 57° W) is characterized by the presence of the non-indigenous spionid polychaete *Boccardia proboscidea*. This species has been classified as tolerant to moderate and high levels of organic contamination. During early stages of colonization this species can reach very high densities without suffering from interspecific competition, building biogenic structures such as reef. The aim of this work was to evaluate the recovery time of the reef to a small-scale experimental physical disturbance. Five independent rocks with *B. proboscidea* reefs on them were selected randomly and a small-scale disturbance was generated by corers (16 cm²). At the beginning of the experiment, six corers were collected in each reef to produce the disturbance. The original density of *B. proboscidea* in each reef was determined in these corers. The reefs with disturbed corer were sampled on successive days to assess the reef recovery time. The number of larvae, juveniles and adults was quantified. Polychaete reefs had very high densities before the disturbance (mean density: 1,021,250 ind m⁻²). *Boccardia proboscidea* reefs had a fast recovery rate after small-scale disturbance. Four days after disturbance the density reached about 50% of the original density and after 5 days the disturbed reefs could not be differentiated from the undisturbed reef. The initial recolonization of disturbed patches occurs as a result of migration which appears to be driven by larvae and juveniles. These reefs can not be seen as biodiversity hotspots and the presence of the species demonstrates great environmental deterioration.

Introduction

Humans influence marine ecosystems in different ways: for example, by removing, altering or destroying natural habitat, through organic enrichment, pollution, overfishing and selective harm to plant and animal populations (Vitousek *et al.* 1997; McIntyre 1999; Halpern *et al.* 2008). Among the anthropogenic activities, the sewage effluent discharges can affect the intertidal communities. In the long term this situation can affect the survival of individuals, changing the dynamics and structure of benthic communities and, consequently, the seasonality of the

ecosystem functional processes. On the other hand, invader species are favored in places and at times when stress is negatively affecting the existing biota, resulting in vacant niches available for colonization (Occhipinti-Ambrogi & Savini 2003). In turn, invaders can cause changes in disturbance regimes that profoundly alter the composition and successional trajectory of a community, and development of the ecosystem (Mack & D'Antonio 1998).

The intertidal zone around sewage discharges of Mar del Plata (38° S, 57° W) is characterized by the presence of the non-indigenous spionid *Boccardia proboscidea*, a gregarious polychaete species that uses sand to build its

tubes, which develop into biogenic structures. This species has been classified as tolerant and moderate to high levels of organic contamination due to sewage discharges (Dorsey 1982; Dorsey *et al.* 1983). This species has been proposed as a good indicator of organic pollution in Southeast Australia because it is restricted to areas under direct influence of sewage discharges (Petch 1989). The increase of organic contamination near the sewage discharge area of Mar del Plata has resulted in a massive development of the tube-dwelling spionid *B. proboscidea*. Originally, all intertidal areas of hard substrate in the area were characterized by dense mussel beds of the small mytilid *Brachidontes rodriguezii* (up to 5 cm of length) (Scelzo *et al.* 1996) including areas moderately affected by sewage impact (Vallarino *et al.* 2002). The mussel beds that develop in sewage-impacted areas on abrasion platforms could facilitate the settlement of *B. proboscidea* and mussels could then be excluded by this polychaete. In fact, this spionid is characterized by the capability of a rapid development of dense populations and, consequently, of typical biogenic structures such as reefs (according to the definition given by Holt *et al.* 1998). These reefs are of variable sizes, from 1 to 5 m² and up to 30 cm height, and occur in different forms that can evolve into a continuous platform, as is typical in impacted area. These structures are characterized by a high density of specimens, up to 650,000 ind m⁻², and by a great stability and compactness that can support a person walking over them (Jaubet *et al.* 2011).

In general, these reefs are considered a symptom of environmental deterioration, covering between 0 and 25% of non-impacted intertidal sites and almost 100% of impacted sites (Jaubet *et al.* 2011).

Boccardia proboscidea occurs naturally around Japan and along the west coast of North America, from British Columbia to Southern California, with unconfirmed records extending the distribution even further south (Hartman 1940; Woodwick 1963; Fauchald 1977; Petch 1995; Sato-Okoshi 2000), but it has also been introduced in Hawaii (Bailey-Brock 2000), Australia (Blake & Kudenov 1978; Petch 1989; Leonart 2001; Hewitt *et al.* 2004; Sato-Okoshi *et al.* 2008), New Zealand (Read 2004), South Africa (Robinson *et al.* 2005; Simon *et al.* 2010) and perhaps the Iberian Peninsula (Martínez *et al.* 2006). In its native range, *B. proboscidea* occupies a wide ecological niche, burrowing into soft rock and in crevices, among encrusting algae and in muddy and sandy sediments (Hartman 1940; Woodwick 1963; Gibson *et al.* 1999). However, reefs of this tube-dwelling polychaete were only recorded in sewage-impacted intertidal areas of Mar del Plata (Argentina) (Jaubet *et al.* 2011).

Early studies carried out in this area showed the ephemeral nature of these reefs, as their destruction and

regeneration occurred in just a few weeks (Jaubet *et al.* 2011). However, they survived the storm effect (autumn–winter 2009, personal observation) and have become permanent structures. This suggests that these organisms have a high recovery rate and have the potential to recover from disturbance. The aims of this work were to analyze the response of *B. proboscidea* reefs to a small-scale experimental physical disturbance and to evaluate the recovery time of the disturbed reefs.

Material and Methods

Study area

The coast of the Buenos Aires Province in the zone of Mar del Plata city (38° S–57° W) is dominated by sandy beaches interrupted only by quartzite outcrops and abrasion platforms (geological formation of consolidated loess, limestone or caliche). These horizontal platforms are present in a great part of the Province, and constitute a biotope of particular ecological characteristics. The present study was carried out on one of these platforms, which surrounds the sewage effluent of Mar del Plata city and it is affected by intertidal sewage discharges. The sewer normally dumps 2.8 m³ s⁻¹ of untreated wastes (during autumn, winter and spring seasons), and 3.5 m³ s⁻¹ during summer months due to the arrival of millions of tourists (Scagliola *et al.* 2006).

Sample collection

The experiment was carried out in an area affected by intertidal sewage discharges and located about 1,000 m south of the sewage effluent of Mar del Plata city (Figs 1 and 2) in November 2009. Five independent reefs of *Boccardia proboscidea* were selected randomly and a small-scale disturbance was generated by corers (16 cm²). At the beginning of the experiment T₀ on 16 November 2009, six corers were collected in each reef to produce the disturbance; the days following the beginning of the disturbance are indicated in Fig. 3. To assess the reef recovery process, one corer was collected in each selected reef for each sampling day, taking into account the number of consecutive days with low tide for conducting the surveys (approximately a week). To assess the density (ind m⁻²) of *B. proboscidea* before the disturbance (original density) only one corer, from each reef, was used, according to the methodology proposed by Jaubet *et al.* (2011). To estimate the density of *B. proboscidea* over time, the corers, sampled each day (T₁, T₂, etc.) in the selected reefs, were analyzed (Fig. 3). The sampling of corers was carried out until it was impossible to distinguish, visually, disturbed areas from undisturbed ones on each reef.

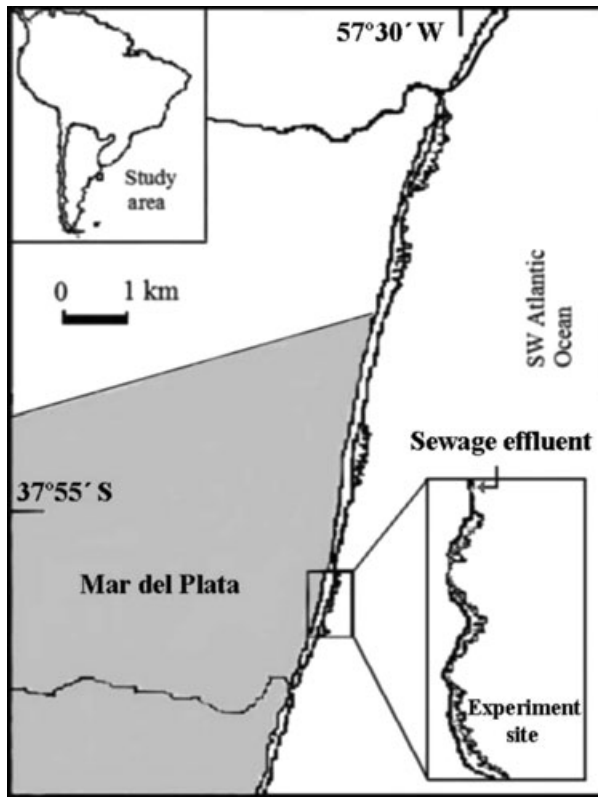


Fig. 1. Sampling site around Mar del Plata city sewage discharge.



Fig. 2. The sewage-impacted area (Impacted site) almost completely covered by *Boccardia proboscidea* reefs.

The samples were fixed in a 10% formaldehyde solution with seawater until laboratory analysis. These samples were sieved through a 1-mm mesh and the specimens of *B. proboscidea* retained were counted. In addition, for each sample larvae, juveniles and adults of *B. proboscidea* were analyzed and quantified. Age classes

were assigned according to Gibson (1997). Females produce broods containing both planktotrophic larvae and nurse-egg-ingesting (adelphophagic) offspring that hatch as advanced larvae only or as benthic juveniles (Blake & Kudenov 1981). Larvae and juvenile of polychaetes can be very similar morphologically and they can only be differentiated by the number of chaetigers. In this study, individuals with ≤ 16 chaetigers were classified as larvae, those with 17–45 chaetigers as juvenile and those larger than 45 chaetigers as adults.

Data Analysis

To evaluate the recovery density of *B. proboscidea* in the disturbed reefs with respect to original density, Friedman's ANOVA was used. In this analysis, each reef was considered as a block, the successive days were considered as the treatments (Time), and the variable was the proportion of original density (before disturbance). To assess the effects of two factors (Time and Age classes) on number of individuals of *B. proboscidea* during recovery, factorial randomized complete block design was used. One replicate of each combination of factors was located in each block. In this case, 'reef' was used as blocking variable (Quinn & Keough 2001). Homogeneity of variances and normality were assessed using Levene and Shapiro-Wilk's tests, respectively. Any data not conforming to either of these two assumptions were transformed using an appropriate transformation (Zar 1999).

A frequency table with two classification variables (Time and Age) was constructed and a Chi-squared test was conducted to see whether the percentages of adults, juveniles and larvae change significantly with time – from original reefs (before disturbance) to the end of the experiment.

Results

The analyzed reefs were characterized by high densities of *Boccardia proboscidea* before the disturbance occurred (maximum density: 1,465,000; minimum density: 848,750) (Table 1). On 18 November the sampling was not carried out due to unsuitable environmental conditions (tidal). Five days after the disturbance, disturbed areas were not visually distinguishable from undisturbed areas, so the experiment was suspended because disturbed areas could not be found. Four days after disturbance (T_4), the reef density reached about 50% of the original density (Fig. 4).

The proportion of density of *B. proboscidea* with respect to original density showed different values during the time after disturbance (Friedman ANOVA, $n = 5$, $df = 3$, $P = 0.0134$).

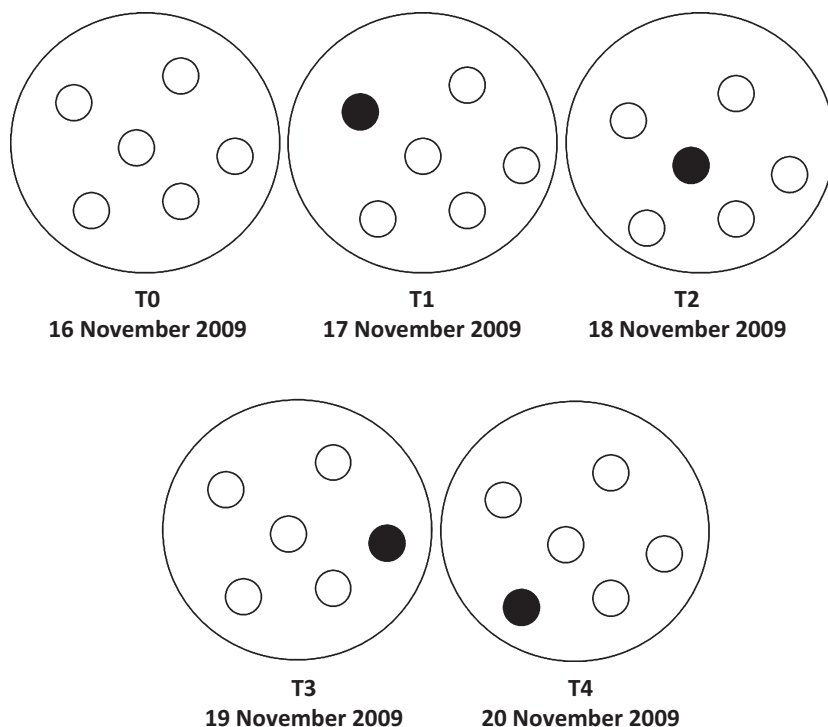


Fig. 3. Hypothetical sampling scheme for a *Boccardia proboscidea* reef, applied to each of five selected reefs. The disturbances generated by corers from the beginning of the experiment (T_0) and in each consecutive day (from T_1 to T_4) are indicated by the white circles. The corers sampled to estimate the density of *B. proboscidea* in each consecutive day are indicated in black.

Table 1. Original density of *Boccardia proboscidea* calculated in each selected reef.

Reef	Density (ind m^{-2})
Reef 1	896,250
Reef 2	1,008,750
Reef 3	887,500
Reef 4	848,750
Reef 5	1,465,000

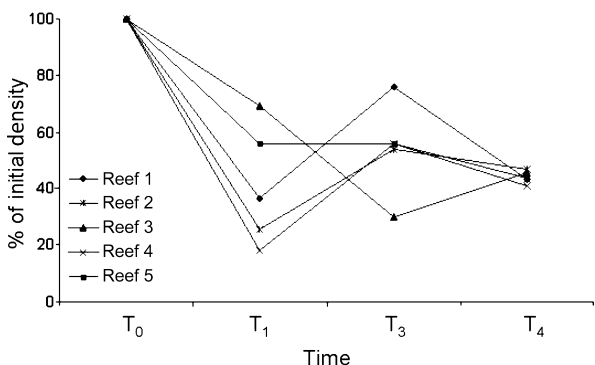


Fig. 4. The change in density of *Boccardia proboscidea* as a percentage of initial density with time.

The factorial randomized complete blocks ANOVA showed that time had a significant effect on the number of individuals of *B. proboscidea* ($F_{3,24} = 6.248$, $P = 0.008$) but there were no significant differences between different age classes ($F_{2,24} = 2.960$, $P = 0.109$). Nevertheless, the

number of juveniles increased from the beginning to the end of the experiment (Fig. 5).

The percentages of adults, juveniles and larvae changed significantly from the beginning of the experiment (T_0) to the end (T_4) (Chi-squared test, $P < 0.001$). The proportion of adults decreased with increasing time after the disturbance. At the beginning of the experiment (before disturbance) adults constituted approximately 60% of the total individuals and juveniles up to 30%. Larvae were present but in a low proportion (6%). During the experiment the proportion of adults decreased, whereas the opposite pattern was found for the proportion of juveniles and larvae, which increased from the beginning to the end of the experiment. At the end of the experiment (T_4) the percentage of larvae had shifted from 6 to 21%, and that of adults from 60 to 25% (Fig. 6).

Discussion

This study shows that *Boccardia proboscidea* reefs have a fast recovery rate after small-scale disturbance. Four days after the disturbance, the reef density reached about 50% of the original density and in the 5th day the disturbed areas were not visually distinguishable from undisturbed areas. An increase in larvae and juveniles were recorded since the first day after the disturbance. Probably the initial recolonization of disturbed patches occurred as a result of migration. Nevertheless, we observed a differential migration process after disturbance, first mediated by

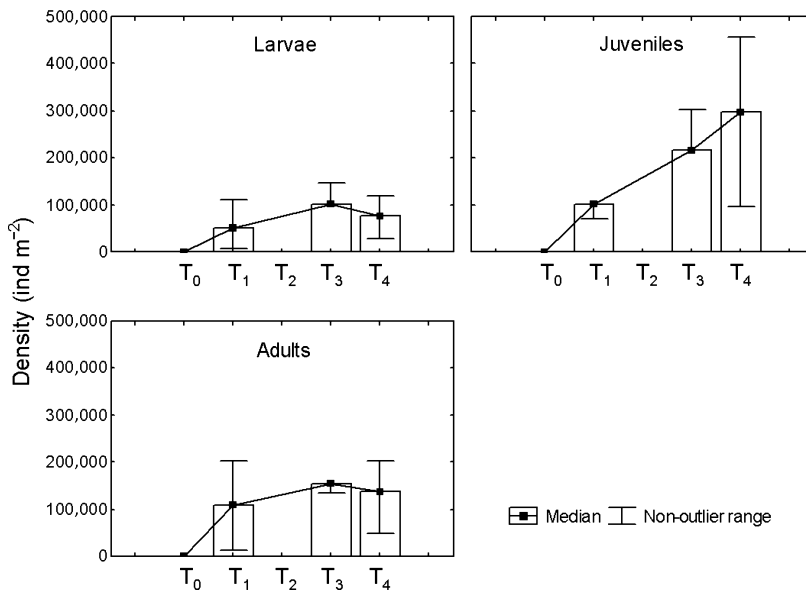


Fig. 5. Density of individuals of each age class of *Boccardia proboscidea* along the time.

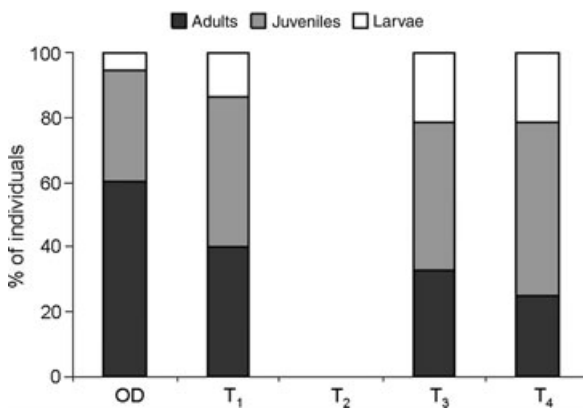


Fig. 6. Percentage of individuals of each age class of *Boccardia proboscidea* along the time; original density (OD) corresponding at time before disturbance.

adults, juveniles and larvae in the original proportions, but just after, larvae and juveniles became more abundant than adults. In fact, surrounding polychaetes of *B. proboscidea* fall into the crevices created by the experiment, and although individuals of all age classes migrate/fall into the disturbed space, the migration appears to be driven by larvae and juveniles.

The analysis of recovery rate of these reefs showed that the reefs are permanent structures. The dynamics and stability of these reefs could be directly enhanced by continuous sewage enrichment, allowing the full development of a reef in a very short time. The reef formation occurs after the stormy season (autumn–winter according to Manolidis & Alvarez 1994), *i.e.* during spring–summer. In fact, spring time is favorable due to warm temperatures and food provision is guaranteed by continuous sewage flows.

In intertidal communities, the small-scale disturbances tend to be biologically mediated and include pits created by predation (Levin 1984; Oliver *et al.* 1985; Hall *et al.* 1990, 1991; Savidge & Taghon 1988) and by sediment modification by macroinfauna (Woodin 1985; Brey 1991; Hall *et al.* 1991). These disturbances create free space at different stages of recovery and allow larval colonization by invertebrate fauna. In this study, after disturbances on *B. proboscidea* reefs only conspecific colonization occurred. The high *B. proboscidea* recruitment, mediated by organic pollution, probably helped to prevent early recruitment by other potential colonizers, such as *Brachiodontes rodriguezii* (R. Elías & E.A. Vallarino unpublished data). Other opportunistic polychaete species, belonging to the same family, show similar strategies, such as the tube-building spionid *Pygospio elegans*. On the intertidal sandflat Drum Sands, Firth of Forth, Scotland, this species forms dense aggregations. The long-term maintenance of their patches ensures a local source of colonists following larger scale disturbances within the area, consequently the effects of larger scale disturbances are potentially minimized (Bolam & Fernandes 2002).

In the intertidal zone around Mar del Plata, a moderate storm occurred during December 2008. As a result of this event, polychaete reefs disappeared almost completely from impacted sites. However, in January 2009, reefs were present again in impacted sites (Jaubet *et al.* 2011). This suggests that *B. proboscidea* responded to the disturbance generated by the storm, increasing larval recruitment.

In general, reef structures can be seen as biodiversity hotspots where species diversity deeply contrasts with that of surrounding sediments (Dubois *et al.* 2002). Therefore, biogenic reefs have an important role for the ecological

functioning of the habitats and areas in which they are found (Callaway *et al.* 2010). Tube-building polychaetes such as *Sabellaria alveolata*, *Serpula vermicularis* and *Ficopomatus enigmaticus* develop biogenic reefs (Obenat & Pezzani 1994; Fornos *et al.* 1997; Obenat 2002; Dubois *et al.* 2002; Poloczanska *et al.* 2004; Schwindt *et al.* 2004). The tubes of these worms provide complex structural habitats for attachment of sessile organisms (Dubois *et al.* 2006) and a refuge or a food source for vagile vertebrates and invertebrates (Bruschetti *et al.* 2009). However, an opposite pattern was found in sewage-impacted intertidal areas around Mar del Plata. *Boccardia proboscidea* reach unprecedented high densities without suffering interspecific competition. Around sewage-impacted areas in Australia this species could reach about 164,000 ind m⁻² (Dorsey 1982), far less than the approximately 1,000,000 ind m⁻² in Mar del Plata. Another derived phenomenon of the high densities and high rate of colonization is the competitive exclusion of any other invertebrate species from the area. Only a few algae could coexist within the *B. proboscidea* reef (Santiago 2009). Consequently, *B. proboscidea* has become the dominant species of the intertidal community in this SW Atlantic shore affected by sewage impact (Jaubet *et al.* 2011).

These reefs can therefore not be seen as biodiversity hotspots and their presence demonstrate the great environmental deterioration. Moreover, if sewage-induced enrichment continues or increases, the presence of the polychaete reefs could be a common feature of the organically impacted shore of the Southwest Atlantic (Jaubet *et al.* 2011).

Conclusions

This study shows that *Boccardia proboscidea* reefs have a fast recovery rate after small-scale disturbances. The initial recolonization of disturbed areas occurred as a result of migration which appears to be driven by larvae and juveniles. *Boccardia proboscidea* reached unprecedented high densities without suffering interspecific competition, becoming the dominant species of organically impacted intertidal community on this SW Atlantic shore. The dynamics and the persistence of these reefs could be directly enhanced by continuous sewage enrichment, allowing the full development of a reef in a very short time. These reefs can not be seen as biodiversity hotspots and their presence reflect great environmental deterioration.

Acknowledgements

We offer thanks for Dr. Vasily Radashevsky who spends time working in Mar del Plata, identifying *Boccardia* species

and teaching us a lot. M. L. Jaubet, M. A. Sánchez and G. V. Garaffo were supported by a Ph.D. Fellowship from Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) of Argentina. We thank the anonymous referees for their contributions, which greatly improved the quality of this manuscript.

References

- Bailey-Brock J.H. (2000) A new record of the polychaete *Boccardia proboscidea* (Family Spionidae), imported to Hawaii with oysters. *Pacific Science*, **54**, 27–30.
- Blake J.A., Kudenov J.D. (1978) The Spionidae (Polychaeta) from southeastern Australia and adjacent areas with a revision of the genera. *Memoirs of the National Museum Victoria*, **39**, 171–280.
- Blake J.A., Kudenov J.D. (1981) Larval development, larval nutrition and growth for two *Boccardia* species (Polychaeta: Spionidae) from Victoria, Australia. *Marine Ecology Progress Series*, **6**, 175–182.
- Bolam S.G., Fernandes T.F. (2002) Dense aggregations of tube-building polychaetes: response to small-scale disturbances. *Journal of Experimental Marine Biology and Ecology*, **269**, 197–222.
- Brey T. (1991) Interactions in soft-bottom benthic communities: quantitative aspects of behaviour in the surface deposit feeders *Pygospio elegans* (Polychaeta) and *Macoma balthica* (Bivalvia). *Helgoland Marine Research*, **45**, 301–316.
- Bruschetti M., Bazterrica C., Luppi T., Iribarne O. (2009) An invasive intertidal reef-forming polychaete affect habitat use and feeding behavior of migratory and locals birds in a SW Atlantic coastal lagoon. *Journal of Experimental Marine Biology and Ecology*, **375**, 76–83.
- Callaway R., Desroy N., Dubois S.F., Fournier J., Frost M., Godet L., Hendrick V.J., Rabaut M. (2010) Ephemeral bio-engineers or reef-building Polychaetes: how stable are aggregations of the tube worm *Lanice conchilega* (Pallas, 1766)? *Integrative and Comparative Biology*, **50**, 237–250.
- Dorsey J.H. (1982) Intertidal community offshore from the Werribee sewage-treatment farm: an opportunistic infaunal assemblage. *Australian Journal of Marine and Freshwater Research*, **33**, 45–54.
- Dorsey J.H., Green K.D., Rowe R.C. (1983) Effects of sewage disposal on the polychaetous Annelids at San Clemente Island, California. In: Soule D.F., Walsh D. (Eds), *Waste Disposal in the Oceans. Minimizing Impact, Maximizing Benefits*. Southern California Academy of Sciences, Wersview Press, Boulder, Colorado, **13**: 209–233.
- Dubois S., Retiere C., Olivier F. (2002) Biodiversity associated with *Sabellaria alveolata* (Polychaeta: Sabelliidae) reefs: effects of human disturbances. *Journal of the Marine Biological Association of the United Kingdom*, **82**, 817–826.
- Dubois S., Commito J.A., Olivier F., Retiere C. (2006) Effects of epibionts on *Sabellaria alveolata* (L.) biogenic reefs and

- their associated fauna in the Bay of Mont Saint-Michel. *Estuarine, Coastal and Shelf Science*, **68**, 635–646.
- Fauchald K. (1977) Polychaetes from intertidal areas in Panama, with review of previous shallow-water records. *Smithsonian Contributions to Zoology*, **221**, 1–81.
- Fornos J.J., Forteza V., Martínez Taberner A. (1997) Modern polychaete reefs in Western Mediterranean lagoons: *Ficopomatus enigmaticus* (Fauvel) in the Albufera of Menorca, Balearic Islands. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **128**, 175–186.
- Gibson G. (1997) Variable development in the spionid *Boccardia proboscidea* (Polychaeta) is linked to nurse egg production and larval trophic mode. *Invertebrate Biology*, **116**, 213–226.
- Gibson G., Paterson I.G., Taylor H., Woolridge B. (1999) Molecular and morphological evidence of a single species, *Boccardia proboscidea* (Polychaeta: Spionidae), with multiple development modes. *Marine Biology*, **134**, 743–751.
- Hall S.J., Raffaelli D.G., Basford D.J., Robertson M.R. (1990) The importance of flatfish predation and disturbance on marine benthos: an experiment with dab *Limanda limanda* (L.). *Journal of Experimental Marine Biology and Ecology*, **136**, 65–76.
- Hall S.J., Basford D.J., Robertson M.R., Raffaelli D.G., Tuck I. (1991) Patterns of recolonisation and the importance of pit digging by the crab *Cancer pagurus* in a subtidal sand habitat. *Marine Ecology Progress Series*, **72**, 93–102.
- Halpern B.S., Walbridge S., Selkoe K.A., Kappel C.V., Micheli F., D'Agrosa C., Bruno J.F., Casey K.S., Ebert C., Fox H.E., Fujita R., Heinemann D., Lenihan H.S., Madin E.M.P., Perry M.T., Selig E.R., Spalding M., Steneck R., Watson R. (2008) A global map of human impact on marine ecosystems. *Science*, **319**, 948–952.
- Hartman O. (1940) *Boccardia proboscidea*, a new species of spionid worm from California. *Journal of the Washington Academy of Sciences*, **30**, 382–387.
- Hewitt C.L., Campbell M.L., Thresher R.E., Martin R.B., Boyd S., Cohen B.F., Currie D.R., Gomon M.F., Keough M.J., Lewis J.A., Lockett M.M., Mays N., McArthur M.A., O'Hara T.D., Poore G.C.B., Ross D.J., Storey M.J., Watson J.E., Wilson R.S. (2004) Introduced and cryptogenic species in Port Phillip Bay, Victoria, Australia. *Marine Biology*, **144**, 183–202.
- Holt T.J., Rees E.I., Hawkins S.J., Seed R. (1998) An overview of dynamic and sensitivity characteristics for conservation management of marine SACs. *Scottish Association for Marine Science (UK Marine SACs Project)*, **9**, 1–170.
- Jaubet M.L., Sánchez M.A., Rivero M.S., Garaffo G.V., Vallarino E.A., Elías R. (2011) Intertidal biogenic reefs built by the polychaete *Boccardia proboscidea* in sewage-impacted areas of Argentina, SW Atlantic. *Marine Ecology: An Evolutionary Perspective*, **32**, 188–197.
- Levin L.A. (1984) Life history and dispersal patterns in a dense infaunal polychaete assemblage: community structure and response to disturbance. *Ecology*, **65**, 1185–1200.
- Leonart M. (2001) Australian abalone mudworms: avoidance and identification. A farm manual. <http://www.frdc.com.au/subprograms/aas/download/mudworm.a.farm.manual.pdf> [accessed on 6 December 2010].
- Mack M.C., D'Antonio C.M. (1998) Impacts of biological invasions on disturbance regimes. *Trends in Ecology and Evolution*, **13**, 195–198.
- Manolidis N., Alvarez J.A. (1994) Grandes tormentas en la zona costera marplatense entre 1980–1992. *Centro Oceanográfico Buenos Aires, Serie Ciencia y Técnica*, **5**, 1–33.
- Martínez J., Adarraga I., López E. (2006) Nuevos datos del género *Boccardia carazzi*, 1893 (Polychaeta: Spionidae) para la península Ibérica y el océano Atlántico. *Boletín del Instituto Español de Oceanografía*, **22**, 53–54.
- McIntyre A.D. (1999) Conservation in the sea – looking ahead. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **9**, 633–637.
- Obenat S. (2002) Estudios ecológicos de *Ficopomatus enigmaticus* (Polychaeta: Serpulidae) en la laguna Mar Chiquita, Buenos Aires, Argentina. Doctoral thesis, Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Mar del Plata: 159 pp.
- Obenat S.M., Pezzani S.E. (1994) Life cycle and population structure of the polychaete *Ficopomatus enigmaticus* (Serpulidae) in Mar Chiquita Coastal Lagoon, Argentina. *Estuaries*, **17**, 263–270.
- Occhipinti-Ambrogi A., Savini D. (2003) Biological invasions as a component of global change in stressed marine ecosystems. *Marine Pollution Bulletin*, **46**, 542–551.
- Oliver J.S., Kvilek R.G., Slattery P.N. (1985) Walrus feeding disturbance: scavenging habits and recolonization of the Bering Sea benthos. *Journal of Experimental Marine Biology and Ecology*, **91**, 233–246.
- Petch D.A. (1989) *Variation in the spionid polychaete Boccardia proboscidea*. Ph.D. thesis. University of Melbourne: 136 pp.
- Petch D.A. (1995) Morphological variation in the spionid polychaete *Boccardia proboscidea*. *Proceedings of the Royal Society of Victoria*, **107**, 25–30.
- Poloczanska E.S., Hughes D.J., Burrows M.T. (2004) Underwater television observations of *Serpula vermicularis* (L.) reefs and associated mobile fauna in Loch Creran, Scotland. *Estuarine, Coastal and Shelf Science*, **61**, 425–435.
- Quinn G., Keough M. (2001) *Experimental Design and Data Analysis for Biologists*. Cambridge University Press, Cambridge: 629 pp.
- Read G.B. (2004) Guide to New Zealand shell polychaetes. <http://biocollections.org/pub/worms/nz/Polychaeta/Shell-Poly/NZShellsPolychaeta.htm> [accessed on 8 December 2010].
- Robinson T.B., Griffiths C.L., McQuaid C.D., Ruis M. (2005) Marine alien species of South Africa – status and impacts. *African Journal of Marine Science*, **27**, 297–306.
- Santiago L. (2009) Distribución espacial y temporal de las macroalgas intermareales en áreas naturales e impactadas de Mar del Plata: su valor como bioindicadores de contaminación

- orgánica. Thesis, Universidad Nacional de Mar del Plata, 44 pp.
- Sato-Okoshi W. (2000) Polydoridae species (Polychaeta: Spionidae) in Japan, with descriptions of morphology, ecology and burrow structure. 2. Non-boring species. *Journal of the Marine Biological Association of the United Kingdom*, **80**, 443–456.
- Sato-Okoshi W., Okoshi K., Shaw J. (2008) Polydoridae species (Polychaeta: Spionidae) in south-western Australian waters with special reference to *Polydora uncinata* and *Boccardia knoxi*. *Journal of the Marine Biological Association of the United Kingdom*, **88**, 491–502.
- Savidge W.B., Taghon G.L. (1988) Passive and active components of colonisation following two types of disturbance on intertidal sandflats. *Journal of Experimental Marine Biology and Ecology*, **115**, 137–155.
- Scagliola M., Furchi P., von Haefen G., Comino A.P., Moschione E., Gonzalez R., Gayoso G., Caldararo A., Cerdá G., Vergara S., Genga G., Elías R., Vallarino E.A. (2006) *Sewage outfall project of Mar del Plata city (Argentina): an effective intervention to achieve quality objectives on the marine environment*. 4th International Conference on Marine Waste Water Disposal and Marine Environment, MWWD, Antalya, 6–10 November .
- Scelzo M.A., Elías R., Vallarino E.A., Charrier M., Lucero N. (1996) Variación estacional de la estructura comunitaria y de la fauna acompañante del bivalvo *Brachidontes rodriguezii* (D'Orb., 1846) desarrollada en sustratos artificiales (Mar del Plata, Argentina). *Neritica*, **10**, 87–102.
- Schwindt E., De Francesco C.G., Iribarne O.O. (2004) Individual and reef growth of the introduced reef-building polychaete *Ficopomatus enigmaticus* in a south-western Atlantic coastal lagoon. *Journal of the Marine Biological Association of the United Kingdom*, **84**, 987–993.
- Simon C.A., Worsfold T.M., Lange L., Sterley J. (2010) The genus *Boccardia* (Polychaeta: Spionidae) associated with mollusc shells on the south coast of South Africa. *Journal of the Marine Biological Association of the United Kingdom*, **90**, 585–598.
- Vallarino E.A., Rivero M.S., Gravina M.C., Elías R. (2002) The community-level response to sewage impact in intertidal mussel beds of the Southwestern Atlantic, and the use of the Shannon index to assess pollution. *Revista de Biología Marina y Oceanografía*, **37**, 25–33.
- Vitousek P.M., Aber J.D., Howarth R.W., Likens G.E., Matson P.A., Schindler D.W., Schlesinger W.H., Tilman D.G. (1997) Human alteration of the global nitrogen cycle: sources and consequences. *Ecological Applications*, **7**, 737–750.
- Woodin S.A. (1985) Effects of defecation by arenicolid polychaete adults on spionid polychaete juveniles in field experiments: selective settlement or differential mortality? *Journal of Experimental Marine Biology and Ecology*, **87**, 119–132.
- Woodwick K. (1963) Comparison of *Boccardia columbiana* Berkeley and *Boccardia proboscidea* Hartman (Annelida, Polychaeta). *Bulletin of Southern California Academy of Science*, **62**, 132–139.
- Zar J.H. (1999) *Biostatistical Analysis*, (4th edn). Prentice-Hall: Upper Saddle River, NJ: 662 pp.