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Modelling the influence of environmental and weather factors on the density of the invasive polychaete *Boccardia proboscidea*

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Abstract

The inter-tidal zone around sewage discharges in a Southwest Atlantic shore (Mar del Plata, Argentina) is currently colonized by extensive inter-tidal reefs of the invasive spionid *Boccardia proboscidea*. Understanding the links between both human and natural disturbances and the massive development of non-indigenous species will help prevent marine bioinvasions, which are already favoured by global oceanic trade. We present herein predictive models for variations in the density of *B. proboscidea* around sewage discharges of Mar del Plata, using environmental (pH, turbidity, temperature, salinity and total organic matter content), weather (wind direction and storm records), spatial (sites) and temporal (season and year) variables. Density variations were modelled by generalized linear models, and model averaging (multimodel inference) was used to obtain predicted values. The highest predicted values of *B. proboscidea* density occurred at sites to the south of the sewage effluent in spring. These sites are more affected by urban effluent discharges and they showed increased *B. proboscidea* density when the north wind was predominant. In addition, *B. proboscidea* density values were higher in sites with 20–22 °C (seawater temperature), high total organic matter content in sediments and low salinity. The averaged model was only a good 'predictive model' for sites to the north of the outfall, but was useful as an 'explanatory model' in all sites. Such predictions may help to back up conservation and management policies and decisions.

Introduction

A healthy, pristine community is a natural impediment to bioinvasion; where and when this contrasting force is lacking, an alien species may successfully outcompete native ones (Occhipinti-Ambrogi & Savini 2003; Darrigan & Damborenea 2006). Anthropogenic disturbance is a risk factor that may promote the establishment of non-indigenous species (Piola & Johnston 2008). For this reason, the invasion of alien species may be facilitated in stressed environments. Seaweeds and reef-forming alien species can change the architecture of the invaded habitat by altering the physical and/or chemical properties of the substrate (Wallentinus & Nyberg 2007). Such modifications may affect growth rates, species' interactions and overall ecosystem functioning.

Inter-tidal bottoms around the sewage outfall of Mar del Plata, Argentina (38° S, 57° W), are currently monopolized by the invasive spionid *Boccardia proboscidea*, a gregarious tube-building polychaete that uses sand to build extensive sandy reefs (Jaubet *et al.* 2011, 2013; Garaffo *et al.* 2012). The introduction of *Bo. proboscidea* probably occurred several years ago without ecological consequences, co-existing with the other spionid species

(*Boccardia* spp.) and mussels (*Brachidontes rodriguezii*) in the inter-tidal community (Jaubet *et al.* 2013). However, an increase in sewage contamination then induced a demographic explosion in areas under the influence of inter-tidal sewage discharge (Jaubet *et al.* 2011; Jaubet 2013). The massive accumulation of polychaete tubes covering the entire sewage-impacted area produced profound changes in the inter-tidal community of epilithic mussel beds.

All local inter-tidal bottoms, including sites moderately affected by sewage impact (Vallarino *et al.* 2002), were previously colonized by dense mussel beds of the small mytilid *Brachidontes rodriguezii* (Scelzo *et al.* 1996). More recently, *Boccardia proboscidea* reefs have smothered and excluded the mussel beds in sewage impacted sites (Jaubet *et al.* 2013). *Boccardia proboscidea* can be considered a local ecosystem engineer because by building its three-dimensional habitat it displaces most of the native flora and fauna (Jaubet *et al.* 2013). Ecosystem engineers are expected to increase species diversity (Jones *et al.* 1997a, b). This positive effect is contingent upon the abundance of the ecosystem engineer and if the engineered habitat becomes dominant, species richness will decline (Jones *et al.*1994; Wright *et al.* 2004). Thus, invasive species that are ecosystem engineers are expected to have strong impacts owing to their high abundances and novel disturbances (Crooks 2002).

Boccardia proboscidea was described from the west coast of North America (California), from British Columbia to Baja California (Hartman 1940). Its current distribution also includes Japan (Sato-Okoshi 2000), Hawaii (Bailey-Brock 2000), Australia (Blake & Kudenov 1978; Petch 1989; Lleonart 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 all of these areas, it is considered an introduced species (Kamel *et al.* 2010; Çinar 2013). *Boccardia proboscidea* burrows into soft rock and in crevices, amongst encrusting algae and in muddy and sandy sediments (Hartman 1940; Woodwick 1963; Gibson *et al.* 1999). Its reef-building strategy is only known for sewage-impacted inter-tidal areas in Mar del Plata, Argentina (Jaubet *et al.* 2011, 2013).

Understanding the links between both human and natural disturbances and the massive development of invasive species will help prevent marine bioinvasions, which are already favoured by global oceanic trade. Invasion ecology urgently requires predictive methodologies that can forecast the ecological impacts of existing, emerging and potential invasive species (Dick *et al.* 2014). Predictive models can be a powerful tool for assessing areas of high relative density of an invasive species, and for determining the factors that influence their distribution. Generalized linear models (GLMs) constitute a more flexible family of regression models, which allow other distributions for the response variable and non-constant variance functions to be modelled (Guisan & Zimmermann 2000). If data abundance originates for instance from counts of individuals, GLMs with a Poisson or a negative binomial distribution should preferably be used (Vincent & Haworth 1983; Nicholls 1989), rather than regression applied to a log-transformation of the response variable (log-linear models).

Herein we present predictive models for the density of *Bo. proboscidea* in the inter-tidal zone around sewage discharges of Mar del Plata, Argentina, using environmental (pH, turbidity, temperature, salinity and total organic matter content), weather (wind direction and storm records), spatial (sites) and temporal (season and year) variables. It was hypothesized that the density of *Bo. proboscidea* is related to variables that indicate organic pollution. For this reason, it was expected that the density of *Bo. proboscidea* would be positively related to organic matter content and turbidity, and negatively related to pH and salinity. Beaches that receive more impact of sewage discharge plume are more exposed to organic pollution. Consequently, wind direction and the occurrence of storms should influence *Bo. proboscidea* density. Finally, it was expected that the sites closest to the effluent would have higher densities of *Bo. proboscidea*.

Material and Methods

Study area

The coast of Buenos Aires Province is dominated by sandy beaches; however, around Mar del Plata city there are quartzite outcrops and almost horizontal inter-tidal abrasion platforms (geological formation of consolidated loess, limestone, stony rocks or caliche). The sewage outfall of Mar del Plata city is located 9 km north of the city centre (N°11 route, km 507). This inter-tidal urban effluent discharges 241,920 m^3 of untreated sewage daily during the winter (flow average rate of 2.8 $m^3 \cdot s^{-1}$) and 302,400 m^3 daily during the summer (average of 3.5 $m^3 \cdot s^{-1}$) into the coastal waters (Scagliola *et al.* 2006).

Sampling design and field and lab procedures

The study was carried out from January 2008 to December 2009 at four sampling sites on inter-tidal abrasion platforms: Site 1, 9000 m to the north of the outfall; Site 2, 8000 m to the north; Site 3, 200 m south of the outfall; and Site 4, 1000 m to the south (Fig. 1). Each site encompassed an area of 1500 m^2 and was classified

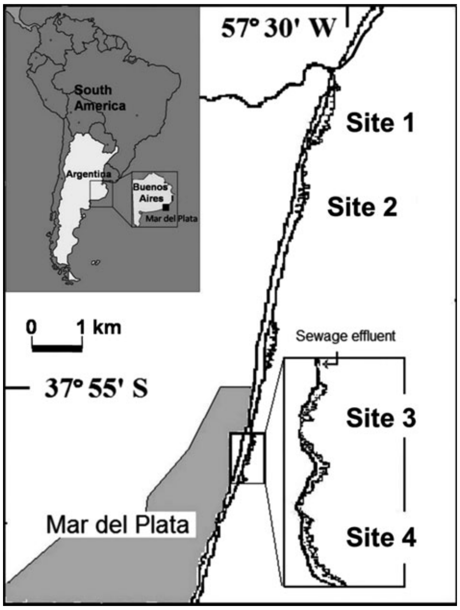

Fig. 1. Locations of the four sites sampled around the sewage discharge point of the city of Mar del Plata, Argentina. The position of the sewage effluent is shown.

as: (i) to the north of the outfall (North) or (ii) to the south of the outfall (South). The sites to the south of the outfall are more affected by urban effluent discharges (Elías *et al.* 2009; Jaubet *et al.* 2011, 2013; Sánchez *et al.* 2013). Surveys were conducted at each site and sampling was performed seasonally. However, during the austral spring of 2008 and austral summer of 2009, two surveys were conducted in each season. In each site 12 sampling units were randomly taken from independent inter-tidal rocks by mean of a 10-cm corer (78 cm^2). The corer was buried in the community matrix up to the substrate. The samples were preserved in a solution of 7% neutralized formalin in seawater. In the laboratory, each sampling unit was sieved through a 0.5-mm mesh and all *B. Proboscidea* individuals were identified, counted and preserved in 70% ethanol solution.

Selected environmental variables (pH, turbidity, salinity and temperature of the seawater) were measured *in situ* with aU 10 Horiba equipment. The percentage of total organic matter (TOM) in the marine sediments was determined by the calcinations method (Byers *et al.* 1978).

Wind direction can influence the sewage discharge plume direction. The beaches that receive more impact of the sewage discharge plume will be more exposed to organic pollution. For this reason, the prevailing wind during the month preceding the sampling date was considered as a variable. For this, the number of days with a particular type of wind was quantified and then the prevailing wind was calculated. The prevailing wind was classified into three types: North (N), East (E) and West (W). Preliminary analysis showed that the E and W winds did not influence the density of *Bo. proboscidea* differentially at the different sampling sites. However, when the prevailing wind was from the northern sector, polychaete densities increased south of the effluent. For this reason, the presence of a north wind (Nw: yes or no) in the preceding month of sampling date was used as a predictive variable. Wind data were provided by the 'Servicio Meteorológico Nacional' (National Weather Service).

Another dichotomous variable was also generated: storm record in the month preceding the date of sampling (Storm: yes or no). The storm records were provided by Licenciada Nilda Manolidis (Universidad Nacional de Mar del Plata).

Data analysis

Generalized linear models (Dobson 2002) were used to assess variations in the density of *Boccardia proboscidea* in relation to environmental and weather variables. The response variable was the density of *Bo. proboscidea*, given as number of individuals per square metre (ind.$\cdot$m^{-2}). The explanatory variables, chosen based on their hypothesized biological relevance, were Season (summer, autumn, winter and spring), Site (north and south of sewage effluent), Year (2008 and 2009), Temperature (Temp), Total organic matter content (TOM), pH, Turbidity (Turb), predominant north wind (Nw: yes or no), Storm (yes or no), Temp^2, pH^2 and all interactions amongst them. The R-project and MASS packages in the R environment (Venables & Ripley 2002; R Core Team 2013) were used for data analyses. The models were fitted assuming a negative binomial error distribution with a log-link function because of the existence of overdispersion (McCullagh & Nelder 1989). The dispersion parameter was estimated to confirm that overdispersion was no longer present.

The best model was selected using the Akaike information criterion (AIC; Akaike 1973). Models with a difference in AIC (ΔAIC) < 2 were considered to have equivalent support from the data (Burnham & Anderson 2002). ΔAIC and Akaike weights (w_i) were calculated for each model. When more than one model had substantial support, model averaging (a form of multimodel inference) was used (Burnham & Anderson 2002). Part of multimodel inference includes ranking the fitted models from the best to the worst based on the AIC, and then scaling to obtain the relative plausibility of each fitted model by a weight of evidence (in this case w_i) relative to the selected best model (lowest AIC). Then, a weighted estimate of the predicted value, weighting the predictions by w_i, is computed. For this reason, this method allows formal statistical inference from all models in the set. The model fit and the selection of predictive variables deemed to be important often reflect the selection process more than biological relevance (MacNally 2000). In the present study, the fit and complexity of the models were evaluated in successive steps to avoid overfitting until a model with sufficient predictive power was obtained.

Model evaluation

The predictive performance of the models was evaluated using an independent data set collected on 20 May 2013 (n = 40). To assess whether the selected models reflect not only the pattern in the data from which they were derived but also succeed in capturing a biological relationship between the environmental and weather variables and the density of *Boccardia proboscidea*, the averaged model was applied to this data set. The observed and predicted data were compared using a *t*-test for paired samples.

Results

The density of *Boccardia proboscidea* (n = 479) varied from 0 to 708,250 ind.·m^{-2} (mean = 38,271 ind.·m^{-2}). Table 1 shows the models with ΔAIC < 2. The model with the lowest AIC value shows that the density of *Bo. proboscidea* was significantly related to TOM, Temp, Season, Site and the interaction between Site and Season. However, this model was clearly not the best as $w_i = 0.216$, which is a very low value. A model can be considered the best when w_i is ~1, and so the averaged model was calculated. Following model averaging, the highest predicted values of density of *Bo. proboscidea* occurred at sites to the south of the sewage effluent and during spring (Fig. 2). The sites to the south of the effluent showed increased density of *Bo. proboscidea* when the north wind was predominant (Fig. 3). In addition, *Bo. proboscidea* showed higher density values between 20 and 22 °C (Fig. 4) and in sites with high TOM and low salinity (Figs 5 and 6). A trend regarding the occurrence of storms was found; sites to the south of the outfall showed a lower density of *Bo. proboscidea* if there was a storm record for the previous month. By contrast, at sites to the north of the outfall *Bo. proboscidea* density was slightly higher after a storm.

Table 1. Models with a difference in Akaike information criterion (ΔAIC) < 2. All were generalized linear models with a binomial negative error structure and log-link function, relating environmental and weather variables to the density of *Boccardia proboscidea*.

model	AIC	ΔAIC	w_i
(Site:Season)+TOM+Temp+Site+Season	8383.7	0	0.216
(Site:Season)+TOM+Temp+Sal+Site+Season	8384	0.3	0.186
(Site:Season)+(Site:Nw)+TOM+Temp+Site+Season+Nw	8384.2	0.5	0.168
(Site:Season)+Temp+Site+Season	8384.8	1.1	0.124
(Site:Season)+TOM+Temp+Storm+Site+Season	8385	1.3	0.113
(Site:Season)+(Site:Nw)+TOM+Temp+Sal+Site+Season+Nw	8385.3	1.6	0.097
(Site:Season)+(Site:Nw)+TOM+Temp+Storm+Site+Season+Nw	8385.3	1.6	0.097

w_i = Akaike weight; TOM = total organic matter content; Temp = temperature; Sal = salinity; Nw = North wind.
The symbol ':' means an interaction between variables.

The evaluation showed that the averaged model worked well in predicting trends in the changes in density of *B. proboscidea* with respect to the studied variables. However, the independent data set showed higher values of density of *Bo. proboscidea* than predicted by the averaged model for sites to the south of the outfall and for the temperature values (Figs 2–6). The observed and predicted values for sites to the north of the outfall were not significantly different (P = 0.53). However, the observed values were significantly higher than those predicted by the model (P < 0.01) for the sites to the south of the outfall. Therefore, only the density of *Bo. proboscidea* in the sites to the north of the outfall could be predicted by the averaged model.

Discussion

Ours is the first modelling of the density of the invasive polychaete *Boccardia proboscidea* in the inter-tidal zone of Mar del Plata in relation to environmental and weather variables. The density of this species was modelled using GLMs in order to determine variables driving its density in the area and then model averaging (a form of multimodel inference) was performed. This approach has practical advantages: when a model averaged estimator can be used, it appears to have better precision and reduced bias compared with an estimator from the selected 'best' model (Burnham & Anderson 2002). Model evaluations as performed here are critical steps frequently omitted from modelling studies.

The evaluation showed that the averaged model worked well in predicting trends in the changes in density of *Bo. proboscidea* with respect to the studied variables. However, only the density of *Bo. proboscidea* in the sites to the north of the outfall could be predicted by the averaged model. The predicted values for the sites to the south of the outfall were significantly lower than observed values.

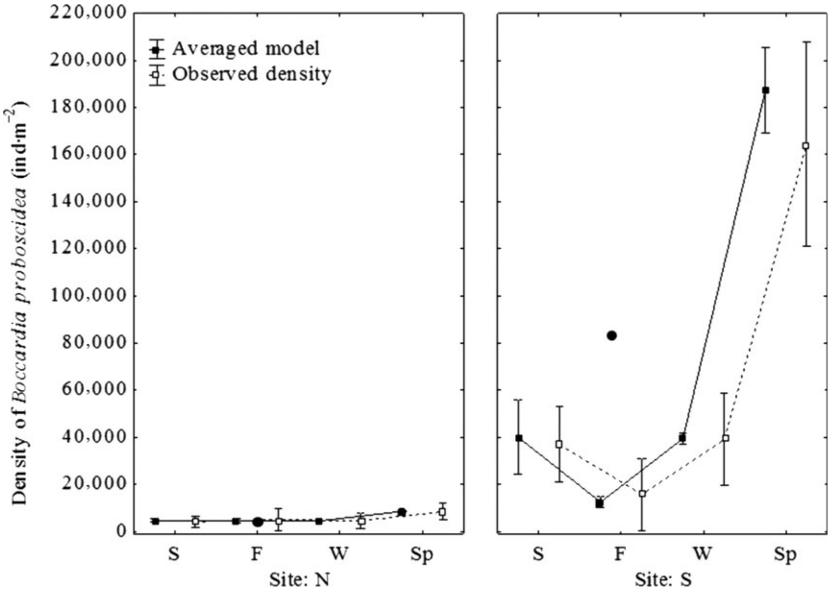

Fig. 2. The mean density of *Boccardia proboscidea* predicted by our averaged model and the mean observed density in every season for the sites north (N) and south (S) of the sewage outfall. Bars indicate 95% confidence intervals. Black circles indicate the mean observed density of *Bo. proboscidea* from the independent data set. The letters on the *x*-axis correspond to: S, summer; A, autumn; W, winter; and Sp, spring.

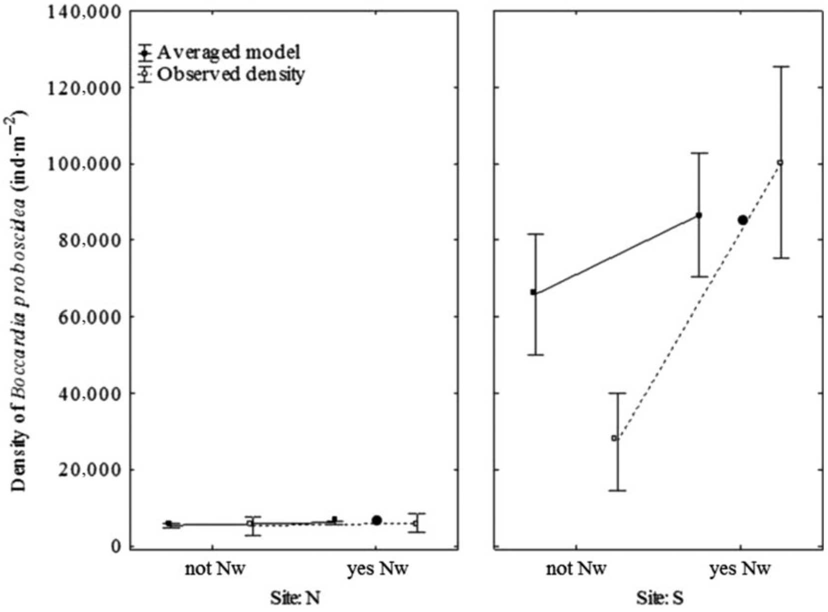

Fig. 3. The mean density of *Boccardia proboscidea* predicted by our averaged model and the mean observed density for the sites north (N) and south (S) of the sewage outfall according to whether or not the north wind (Nw) predominated. Bars indicate 95% confidence intervals. Black circles indicate the mean observed density of *Bo. proboscidea* from the independent data set.

In the Southwest Atlantic *Bo. proboscidea* reached densities never found in any other natural or sewage-impacted place (Jaubet 2013). In Australia, *Bo. proboscidea* reached densities up to 164,000 ind.·m^{-2} in areas of secondary treated sewage discharges (Dorsey 1982). The high densities of *Bo. proboscidea* found in the Southwest Atlantic (Mar del Plata) in the present study are linked to the increase of organic matter in the environment associated with the discharge of the untreated sewage effluent. The increase in organic matter acts as an environmental trigger and so the populations of this opportunistic species grow and spread over the inter-tidal benthic community.

Densities of *Bo. proboscidea* were higher at the sites to the south of the sewage effluent than at the sites located to the north. This was an expected pattern owing to the proximity of these sites (south) to the point of sewage discharge. At the same time, considering only the sites located south of the effluent, a significant increase in density was found in the spring. A similar pattern (increase in density in the spring) was found on abalone farms in South Africa (Simon & Booth 2007), although the increase was not so large. Weather conditions are a possible explanation for the pattern found here. Storms are rare in Mar del Plata in October and November (spring),

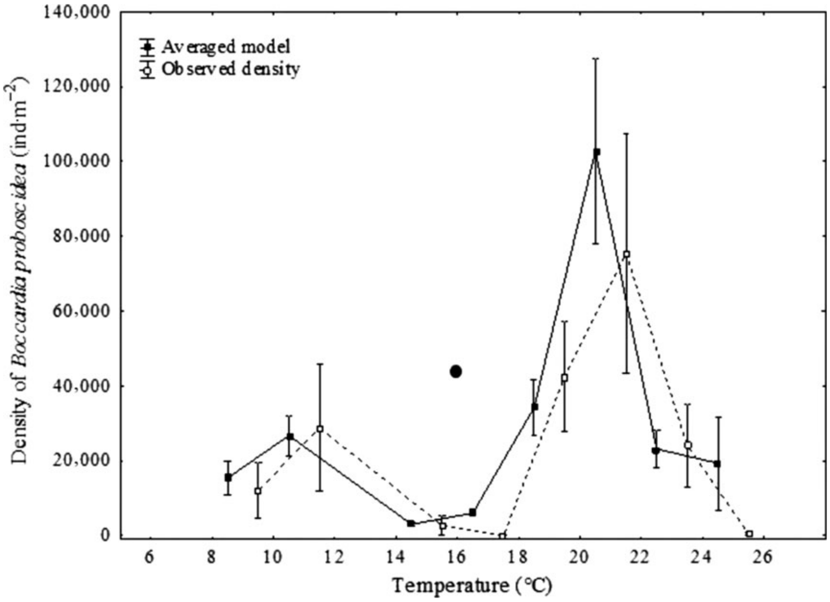

Fig. 4. The mean density of *Boccardia proboscidea* predicted by our averaged model and the mean observed density for seawater temperature. Bars indicate 95% confidence intervals. Black circles indicate the mean observed density of *Bo. proboscidea* from the independent data set.

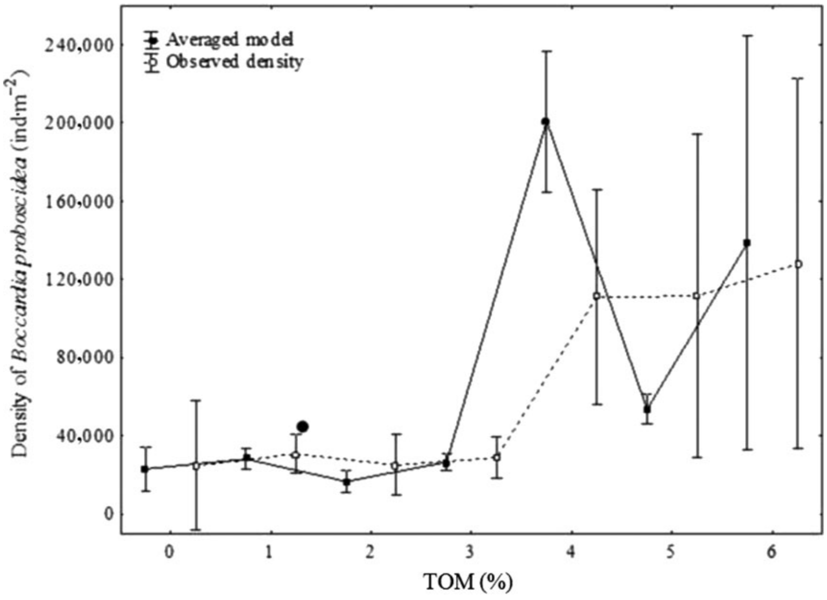

Fig. 5. The mean density of *Boccardia proboscidea* predicted by our averaged model and the mean observed density for total organic matter content (TOM). Bars indicate 95% confidence intervals. Black circles indicate the mean observed density of *Bo. proboscidea* from the independent data set.

whereas autumn and winter are characterized by severe south–southeast storms (Manolidis & Alvarez 1994). Owing to the orientation of the coast (south–north), these storms strike the shore almost perpendicularly, producing great movements of sand (Isla & Aliotta 1999; Isla *et al.* 2001). These storms are capable of totally or partially destroying the *B. proboscidea* reefs, which would result in a decrease in the density of the species in the area. The dynamics of the benthic environment can therefore be explained by acute sewage impacts during spring–summer, followed by southeasterly storms in autumn–winter that would improve environment health. Storms are important in the structuring of the inter-tidal mussel beds (Seed & Suchaneck 1992), and may also be important in the settlement and maintenance of the polychaete reefs.

Densities of *Bo. proboscidea* were lower at the sites to the south of the outfall after storms and the opposite pattern was found in sites to the north of the outfall. As mentioned above, the reefs can be partially or totally destroyed by the storms. The drift generated by the storm and the longshore current from south to north could transport *Bo. proboscidea* individuals (including larvae, juveniles and eggs) to the sites to the north of the outfall.

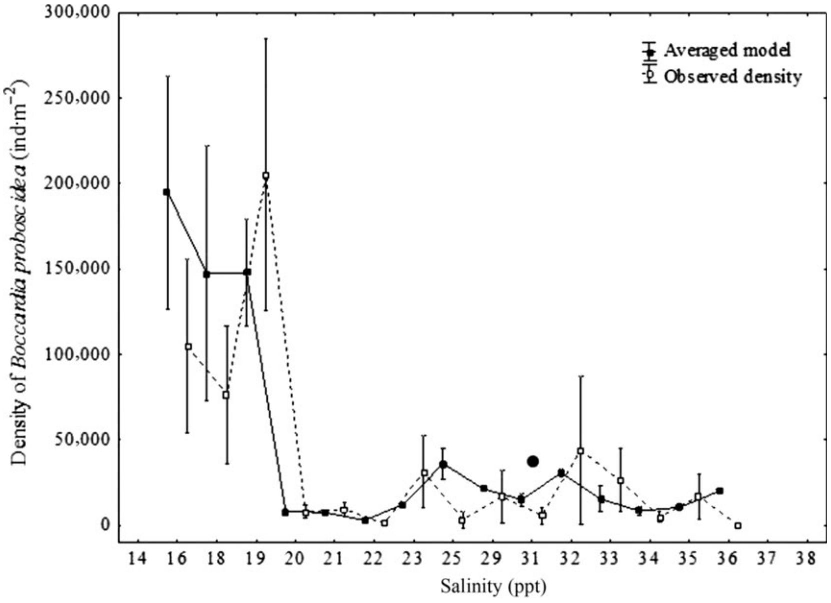

Fig. 6. The mean density of *Boccardia proboscidea* predicted by our averaged model and the observed mean density for salinity. Bars indicate 95% confidence intervals. Black circles indicate the observed mean density of *Bo. proboscidea* from the independent data set.

Therefore, storms may produce a source–sink effect on the formation of reefs of *Bo. proboscidea*, whereby sites south of the effluent act as a source and the sites to the north as a sink.

Another factor that influenced the density of *Bo. proboscidea* was the north wind. The sites to the south of the effluent showed increased densities of *Bo. proboscidea* when the north wind was predominant. North winds produce that effluent plume set down on the south coast (Isla *et al.* 1998). The combination of increased sewage volume and a north wind produces an increase in the area affected by organic contamination mediated by sewage discharge (Elías *et al.* 2006, 2009). This increment of sewage flow conduct to higher supply of organic matter on the sites located to the south of the effluent. This increased supply of organic matter allows polychaetes have abundant food available and colonize quickly available space.

Boccardia proboscidea is tolerant of environments with salinities ranging from strictly marine to brackish water; the presence of this species in high-tide pools at the eastern end of San Francisco Bay (around Berkeley, California) indicates that they tolerate high salt (Hartman 1941). In the present study, the highest densities of *Bo. proboscidea* were found in sites with low salinity values associated with the proximity to the discharge of sewage effluent. With respect to water temperature, a peak in the density of *Bo. proboscidea* was found between 20 and 22 °C. This would be related to water temperature that characterize to spring because the highest values of *Bo. proboscidea* density were recorded during this season.

It is difficult to predict the density of *Bo. proboscidea* at the sites to the south of the effluent. These sites are the most affected by organic pollution. In addition, there are several anthropogenic factors that influence them and cause unpredictable fluctuations in the population of *Bo. proboscidea* and the community in general. One of these factors is the irregular functioning of the pre-treatment plant; this plant must be stopped at least twice a year for maintenance and the effect on the inter-tidal benthic community has been shown to be severe, increasing the impacted area (Elías *et al.* 2009). In addition, the organism responsible for the sewage disposal (Obras Sanitarias S.E.) adds chlorine to the raw sewage discharge in order to lower faecal indicators on bathing beaches (Comino *et al.* 2010, 2011). The chlorinated water and its by-products are released directly by the shore, affecting the inter-tidal community for several kilometres (Jaubet 2013).

Conclusions

We have shown that long-term continuous monitoring is necessary to understand and predict the population fluctuations of the invasive *Boccardia proboscidea* at a sewage-contaminated area in Mar del Plata, Argentina. Our averaged model was only a good ‘predictive model’ for sites to the north of the sewage outfall, but was useful as an ‘explanatory model’ for all sites. Such predictions may help to back up future conservation and management policies and decisions.

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References

Akaike H. (1973) Information theory and an extension of maximum likelihood principle. In: Petran B.N., Csàaki F. (Eds), *International Symposium on Information Theory*. Akadèemiai Kiadi, Budapest: 267–281.

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 of Victoria*, **39**, 171–280.

Burnham K.P., Anderson D.R. (2002) *Model Selection and Multimodel Inference*, 2nd edn. Springer-Verlag, New York, NY:488 pp.

Byers S., Mills C., Stewart P. (1978) Comparison of methods of determining organic carbon in marine sediments, with suggestions for a standard method. *Hydrobiologia*, **58**, 43–47.

Çinar M.E. (2013) Alien polychaeta species worldwide. *Journal of the Marine Biological Association of the United Kingdom*, **93**, 1257–1278.

Comino A.P., Scagliola M., Ge Z., Frick W. (2010) Integrated coastal management strategy of Mar del Plata city and the use of Virtual Beach as a management tool. In: Proceedings of MWWD 2010, the 6th International Conference on Marine Waste Water Disposal and Marine Environment (www.mwwd.org), Langkawi, Malaysia, 25–29 October, 2010, p 50–51.

Comino A.P., Scagliola M., Frick W., Ge Z. (2011) The use of Virtual Beach empirical model for Mar del Plata beaches as a management tool. International Bibliografía Symposium on Outfall Systems, Mar del Plata. http://www.osmgp.gov.ar/ symposium2011/Papers/48_Comino.pdf [accessed 21 December 2012].

Crooks J.A. (2002) Characterizing ecosystem-level consequences of biological invasions: the role of ecosystem engineers. *Oikos*, **97**, 153–166.

Darrigan G., Damborenea C. (2006) Bio-invasiones. In: EDULP. (Ed.) *Bio-Invasión del mejillón dorado en el continente Americano*. Edulp, La Plata, Argentina: 220 pp.

Dick J.T.A., Mhairi E.A., Jeschke J.M., Ricciardi A., MacIsaac H.J., Robinson T.B., Kumschick S., Wey O.L.F., Dunn A.M., Hatcher M.J., Paterson R.A., Farnsworth K.D., Richardson D.M. (2014) Advancing impact prediction and hypothesis testing in invasion ecology using a comparative functional response approach. *Biological Invasions*, **16**, 735–753.

Dobson A.J. (2002) *An Introduction to Generalized Linear Models*. Chapman and Hall/CRC, Boca Raton, FL: 221 pp.

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.

Elías R., Rivero M.S., Palacios J.R., Vallarino E.A. (2006) Sewage-induced disturbance on Polychaetes inhabiting intertidal mussel beds of *Brachidontes rodriguezii* off Mar del Plata (Southwestern Atlantic, Argentina). In: Sarda R., San Martin G., Lopez E., Martin D., George D. (Eds), *Scientific Advances on Polychaete Research*. *Scientia Marina*, **70**, 187–196.

Elías R., Sánchez M.A., Jaubet M.L., Rivero M.S., Vallarino E.A. (2009) Do treatment sewage plants really work? The intertidal mussels community of the Southwestern Atlantic shore (38° S, 57° W) as a case study. *Revista de Biología Marina y Oceanografía*, **44**, 357–368.

Garaffo G.V., Jaubet M.L., Sánchez M.A., Rivero M.S., Vallarino E.A., Elías R. (2012) Sewage-induced polychaete reefs in a SW Atlantic shore: rapid response to small scale disturbance. *Marine Ecology*, **33**, 272–279.

Gibson G., Paterson I., Taylor H., Woolridge B. (1999) Molecular and morphological evidence of a single species, *Boccardia proboscidea* (Polychaeta) with multiple development modes. *Marine Biology*, **134**, 743–751.

Guisan A., Zimmermann N.E. (2000) Predictive habitat distribution models in ecology. *Ecological Modelling*, **135**, 147–186.

Hartman O. (1940) *Boccardia proboscidea*, a new species of spionid worm from California. *Journal of the Washington Academy of Sciences*, **30**, 382–387.

Hartman O. (1941) Polychaetous annelids. Part III. Spionidae. Some contributions to the biology and life story of Spionidae from California. *Allan Hancock Pacific Expeditions*, **7**, 289–324, pls. 45-58.

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.

Isla F.I., Aliotta S. (1999) Storm dispersal of volcanogenic sands from Buenos Aires, where heavy-metal concentrations are heavy-mineral segregations. *Marine Georesources and Geotechnology*, **17**, 357–370.

Isla F.I., Pérez Guzzi J., Folabella A. (1998) Aportes de coliformes a la costa de Mar del Plata (Argentina) por vias naturales e inducidas. *Thalassas*, **14**, 63–70.

Isla F.I., Bertola G., Farenga M., Cortizo L.C. (2001) Morfodinámica y balance sedimentario de playas del partido de Pinamar (1995–1991), Provincia de Buenos Aires. *Revista de La Asociación Geológica Argentina*, **56**, 150–160.

Jaubet M.L. (2013) *Boccardia proboscidea*, um poliqueto invasor em El Atlántico Sudoccidental y su efecto sobre la comunidad bentónica intermareal. Ph.D. dissertation. Universidad Nacional de Mar del Plata, Argentina.

Jaubet M.L., Sanchez 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*, **32**, 188–197.

Jaubet M.L., Garaffo G.V., Sánchez M.A., Elías R. (2013) Reef-forming polychaetes outcompetes ecosystem engineering mussels. *Marine Pollution Bulletin*, **71**, 216–221.

Jones C.G., Lawton J.H., Shachak M. (1994) Organisms as ecosystem engineers. *Oikos*, **69**, 373–386.

Jones C.G., Lawton J.H., Shachak M. (1997a) Ecosystem engineering by organisms: why semantics matters. *Trends in Ecology and Evolution*, **12**, 275.

Jones C.G., Lawton J.H., Shachak M. (1997b) Positive and negative effects of organisms as physical ecosystem engineers. *Ecology*, **78**, 1946–1957.

Kamel S.J., Oyarzun F.X., Grosberg R.K. (2010) Reproductive biology, family conflict and size of offspring in marine invertebrates. *Integrative Biology and Communicative*, **50**, 619–629.

Lleonart M. (2001) Australian abalone mudworms: Avoidance and Identification. A Farm Manual. Fisheries Research and Development Corporation, Project No. 98/301. http://www.frdc.com.au/subprograms/aas/download/mudworm.a.farm.manual.pdf

MacNally R. (2000) Regression and model-building in conservation biology, biogeography and ecology: the distinction between — and reconciliation of — 'predictive' and 'explanatory' models. *Biodiversity and Conservation*, **9**, 655–671.

Manolidis N., Alvarez J.A. (1994) Grandes tormentas em 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.

McCullagh P., Nelder J.A. (1989) *Generalized Linear Models*, 2nd edn. Chapman and Hall/CRC, Boca Raton, FL: 511 pp.

Nicholls A.O. (1989) How to make biological survey go further with Generalized Linear Models. *Biological Conservation*, **50**, 51–75.

Occhipinti-Ambrogi A., Savini D. (2003) Biological invasions as a component of global change in stressed marine ecosystems. *Marine Pollution Bulletin*, **46**, 542–551.

Petch D.A. (1989) Variation in the spionid polychaete *Boccardia proboscidea* Hartman. Ph.D. Dissertation. University of Melbourne.

Piola R.F., Johnston E.L. (2008) Pollution reduces native diversity and increases invader dominance in marine hard-substrate communities. *Diversity and Distributions*, **14**, 329–342.

R Core Team (2013) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/

Read G.B. (2004) Guide to New Zealand shell polychaetes. http://www.biocollections.org/pub/worms/nz/Polychaeta/ShellsPoly/NZShellsPolychaeta.htm

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.

Sánchez M.A., Jaubet M.L., Garaffo G.V., Elías R. (2013) Spatial and long-term analyses of reference and sewage-impacted sites in the SW Atlantic (38°S, 57°W) for the assessment of sensitive and tolerant polychaetes. *Marine Pollution Bulletin*, **74**, 325–333.

Sato-Okoshi W. (2000) Polydorid 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) Polydorid 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**, 491–501.

Scagliola M., Furchi P., Von Haeften G., Comino A.P., Moschione E., Gonzales R., Gayoso G., Caldararo A., Cerda 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. In: Fourth International Conference on Marine Waste Water Disposal and Marine Environment (www.mwwd.org) Antalya, Turquía, 6–10 November, p. 22.

Scelzo M.A., Elías R., Vallarino E.A., Charrier M., Lucero N. (1996) Variación estacional de La estructuracomunitaria y de la fauna acompañante del bivalvo *Brachidontes rodriguezii* (D'Orb., 1846) desarrollada em sustratos artificiales (Mar del Plata, Argentina). *Nerítica*, **10**, 87–102.

Seed R., Suchaneck T.H. (1992) Population and community ecology of *Mytilus*. In: Gosling E., (Ed.), *The Mussel Mytilus: Ecology, Physiology, Genetics and Culture*. Elsevier, Amsterdam, Chapter 4: 589 pp.

Simon C.A., Booth A.J. (2007) Population structure and growth of polydorid polychaetes that infest the cultured abalone, *Haliotismidae*. *African Journal of Marine Science*, **29**, 499–509.

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.

Venables W.N., Ripley B.D. (2002) *Modern Applied Statistics with S*, 4th edn. Springer, New York, NY: 495 pp. ISBN 0-387-95457-0.

Vincent P.J., Haworth J.M. (1983) Poisson regression models of species abundance. *Journal of Biogeography*, **10**, 153–160.

Wallentinus I., Nyberg C.D. (2007) Introduced marine organisms as habitat modifiers. *Marine Pollution Bulletin*, **55**, 323–332.

Woodwick K.H. (1963) Comparison of *Boccardia columbiana* Berkeley and *Boccardia proboscidea* Hartman (Annelida, Polychaeta). *Bulletin of the Southern California Academy of Sciences*, **62**, 134–139.

Wright J.P., Gurney W.S.C., Jones C.G. (2004) Patch dynamics in a landscape modified by ecosystem engineers. *Oikos*, **105**, 336–348.