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Alien reef-building polychaete drives long-term changes in invertebrate biomass and diversity in a small, urban estuary

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A B S T R A C T

Two of the greatest threats to native biodiversity are the construction of artificial structures in natural environments and the introduction of invasive species. As the development and urbanisation of estuaries continues at an increasing rate worldwide, these environments are being simultaneously affected by these threats. This study quantifies the spread of an invasive reef-building polychaete, *Ficopomatus enigmaticus*, in a small, highly manipulated urban estuary in South Africa and investigates its role as an ecosystem engineer. Anthropogenic changes to the Zandvlei Estuary, including construction of a rubble weir and canalisation near the estuary mouth, construction of an extensive marina development and hardening of the banks with concrete, have facilitated the expansion of *F. enigmaticus*. The standing stock of *F. enigmaticus* increased from 13.69 t, as measured in 1986, to 50.03 t in 2012, due both to increase in the total area colonised and standing stock per m^2. Since *F. enigmaticus* reefs support a greater biomass of infauna than adjacent sandy areas, total invertebrate biomass in the estuary is estimated to have increased from less than 0.30 t in 1942, to over 56.80 t in 2012, due mainly to hardening of banks in parts of the main estuary with concrete and construction of a marina system. A positive correlation between reef mass and infaunal biomass, density and diversity was also found.

1. Introduction

Estuaries have become increasingly developed and urbanised worldwide, as the human population continues to grow and the popularity of coastal areas increases (Chapman, 2006; Blockley, 2007). Natural estuarine habitats are being replaced by man-made ones, often leading to the formation of hard surfaces in areas which were previously soft sand or sediment (Bulleri and Airoldi, 2005; Chapman, 2006; Blockley, 2007; Glasby et al., 2007; Dafforn et al., 2009). These artificial structures are then colonised by a different fauna, often one dominated by non-indigenous species (Bulleri and Airoldi, 2005; Glasby et al., 2007). This can, in turn, further alter the habitat by creating new surfaces and increasing habitat complexity, which will then influence the abundance, diversity and distribution of associated organisms (Coull and Wells, 1983). This world-wide phenomenon represents the convergence of two of the greatest threats to native biodiversity: habitat destruction and the introduction of non-indigenous species (Glasby et al., 2007).

The reef-building polychaete *Ficopomatus enigmaticus* (=*Mercierella enigmatica*), belonging to the family Serpulidae, is an excellent example of a highly invasive, habitat-modifying species. *F. enigmaticus* is originally from Australia and has now been spread around the world to colonise brackish waters in many tropical and subtropical areas (Ten Hove and Weerdenberg, 1978; Day, 1981; Fornós et al., 1997; Bianchi and Morri, 2001; Mead et al., 2011). *F. enigmaticus* makes large reefs attached to hard substrata and consisting of a dense network of calcareous tubes (Mead et al., 2011). Neighbouring clumps of similar size may eventually join together to form larger platforms several metres in diameter (Obenat and Pezzani, 1994; Bianchi and Morri, 2001; Schwindt et al., 2004a). Larval recruitment and growth rates are high and individual worms may live up to several years (Bianchi and Morri, 2001).

Ficopomatus enigmaticus has been shown to have major impacts on the systems it invades and is therefore considered an ecosystem engineer (Schwindt et al., 2001, 2004b). In the Mar Chiquita coastal lagoon in Argentina it has one of the strongest ecological effects of all species introduced to the area (Schwindt et al., 2004a), changing the physical environment by creating a complex network of tubes, which create habitat for associated organisms and alter the physical characteristics of the system (Coull and Wells, 1983; Schwindt et al.,

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2001). The reefs are extremely important providers of shelter, food and substratum for many different infaunal species and may also affect interactions between native species, such as competition, predation and parasitism (Obenat and Pezzani, 1994; Schwindt et al., 2001, 2004b). Affected organisms include polychaetes, amphipods, juvenile crabs and gastropods (Schwindt and Iribarne, 2000; Schwindt et al., 2004b).

Over the past few decades there has appeared to have been a great increase in *Ficopomatus enigmaticus* abundance in the Zandvlei Estuary, Cape Town, South Africa. The Zandvlei is a temporarily open/closed system which has been highly modified and manipulated. Its catchment area on the southern slopes of Table Mountain covers approximately 8500 ha and has been highly developed and modified through human activities, including light industry, housing, agriculture, forestry, conservation and commerce (Morant and Grindley, 1982; Davies et al., 1989; Brown and Magoba, 2009; C.A.P.E., 2010b). As a result, Zandvlei now receives low quality, high nutrient inflowing water (Morant and Grindley, 1982). Other major human-induced physical changes to Zandvlei itself have included dredging of the estuary and reclamation of surrounding fields, with subsequent stabilisation of parts of the shore into steep concrete banks; canalisation near the estuary mouth and associated installation of a rubble weir to stabilise water levels; development of a complex, canalised marina system – the 'Marina da Gama' – and construction of a railway embankment that cuts the headwater wetlands off from the rest of the estuary (Davies et al., 1989; C.A.P.E., 2010a).

With the development of concrete walls along the banks of Zandvlei in the early 1960s and excavation of the concrete-walled canals of the Marina da Gama development in the 1970s, large areas of hard substratum were created within a system which previously comprised only soft sand and sediments. This facilitated the invasion and expansion of *Ficopomatus enigmaticus*, which was previously absent, or at least undetected, in the system, as there had been little to no hard substratum available there for attachment. The concrete walls, boats and jetties in the Zandvlei have subsequently become increasingly covered in *F. enigmaticus* reefs, leading to complaints from local canoeists and recreational users of the estuary that the number and size of reefs have reached a point where boat movement within some of the canals is now restricted (C.A.P.E., 2010a). Despite these complaints, little work has been done on *F. enigmaticus* within the Zandvlei Estuary, other than a survey of its biomass within the Marina da Gama development by Davies et al. (1989).

The primary aim of this study is to quantify the spread and densification of the invasive polychaete, *Ficopomatus enigmaticus*, by comparing its current distribution and abundance in Zandvlei to those determined by Davies et al. (1989). The secondary aim is to investigate its role as an ecosystem engineer, by surveying the invertebrate communities associated with areas of reef and comparing this to the fauna of uncolonised areas. No other organism within Zandvlei is found playing a comparable role as an ecosystem engineers and its role in the estuary is thus unique.

2. Materials and methods

Sampling was carried out in the Zandvlei Estuary, 20 km south of Cape Town, South Africa. The sampling methods followed, but were modified slightly from, those carried out by Davies et al. (1989). The perimeter of the estuary was divided into 200 m sections, including the Marina da Gama canals and all of the islands. In sections where the banks were formed of concrete walls, one random sample of *Ficopomatus enigmaticus* reef, approximately 0.0044 m^2, was collected per section. Where the banks were of untransformed sand, one sediment sample of the same size was taken per section. This resulted in a total of 65 reef samples and 9 sediment samples. Samples were collected using a metal corer that was pushed into the reef or sediment and pulled out to extract a core sample. For each 200 m section an estimate of the percentage cover (m^2) of the wall by *F. enigmaticus* reef was made by eye and the vertical height of the reef was recorded using a metre ruler. Samples were taken back to the laboratory, where they were frozen in water until processing.

After being defrosted, each reef sample was broken into smaller pieces to release the infauna trapped between the polychaete tubes. The infauna were then counted and identified under a dissecting microscope. This process was repeated with the nine sediment samples. Between five and 100 individuals of each infaunal species (depending on size) were oven-dried for 24 h at 70 °C in order to obtain average individual mass per species and the mean biomass of invertebrates per m^2 of reef and sand was then calculated as mean mass × density. The total infaunal biomass in the Zandvlei was estimated by summing the biomass of infauna in reef and that in soft sediment. For the reef samples, the mean biomass of infauna per m^2 of reef was multiplied by the number of metres of concrete wall in that 200 m section and the mean depth of the reef. For the sediment samples, the mean biomass of infauna per m^2 of sand was multiplied by section length (200 m) and then by the mean length (m) of sand bank measured from the shore to a depth of 0.6 m. This was done to account for the great decrease in surface area available for infauna associated with transformation of parts of the shore from a gentle, sloping, sandy bank into landfill, edged by an almost vertical wall at a mean depth of 0.6 m.

The wet weight of *Ficopomatus enigmaticus* reef in each sample was obtained using a top-loading balance and converted to dry mass using a conversion ratio determined by oven-drying five samples for 24 h at 70 °C and calculating the mean ratio of wet weight to dry weight. The biomass of *F. enigmaticus* in each 200 m section was calculated by multiplying the mass in the core sample up to 1 m^2 and then multiplying this by the reef area in that section. Finally, mass in each section was summed to obtain estimates of total standing stock within the Marina da Gama development, and then the estuary, as a whole. The mean total standing stock of *F. enigmaticus* in the Marina da Gama can be compared with the mean obtained for the same area by Davies et al. (1989). The sites sampled in the Marina da Gama did not correspond exactly to those sampled by Davis et al. (1989) because we chose to sample systematically once in every 200 m section, while Davis et al. (1989), for unknown reasons, had several sites that were extremely close together (Fig. 1). While *F. enigmaticus* does occasionally also attach in low density to the submerged aquatic plant *Potamogeton pectinatus* and to hard objects on the bottom of the estuary, such as rocks, logs, bottles and cans, these contributions to the total biomass were considered negligible in relation to the large area of reef on the concrete walls and were not incorporated in our estimates of overall biomass.

The Davies et al. (1989) methods also differed in their calculations of total standing stock in the marina. When estimating the surface area of the canal walls covered by *Ficopomatus enigmaticus*, they simply used a mean depth of 2 m, based on the Morant and Grindley (1982) description of the depth of the canals, and they did not measure actual heights of the canal walls or reef. Preliminary observations carried out in 2012 revealed a maximum reef height of only 1.1 m, and hence the Davies et al. (1989) estimate of surface area was therefore greatly over-estimated. This was adjusted using the actual mean vertical reef height calculated in this study, allowing for direct comparison between the two studies. A further difference in the methods of these studies was that Davies et al. (1989) used mean dry mass of reef per m^2 to determine total standing stock. In our study the biomass of each sample was used