Rapid re-establishment of an invasive bivalve following its apparent eradication

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Abstract

The invasive mytilid *Arcuatula senhousia* was thought to be eradicated from the Swan-Canning Estuary in temperate Western Australia in 2000 following an unseasonal heavy rainfall event. The novel use of a drop camera survey at 2,037 sites throughout the lower estuary over a 15 day period in February 2019 demonstrated *A. senhousia* was present at 212 sites, representing >10% of those surveyed. The presence of *A. senhousia* was most prominent in the upper half of the estuary basin and the lower Canning River, with those 1,288 sites accounting for 98% of detections. Of those, 75 sites had percentage covers of *A. senhousia* of 0 – 25 %, 66 sites coverage of 25 – 50 %, 19 had 50 – 75% and 12 sites had coverages of >75%. While the vast majority of *A. senhousia* occurred at depths of 2 to 8 m, a small number of detections occurred at 1-2 m, where percentage coverage was always <50%. The use of simple drop camera was cost-effective and facilitated the collection of data at a fine spatial scale and was shown to be suitable for benthic species such as *A. senhousia* that form benthic matts and whose spatial distribution and abundance may change markedly and so be missed by less exhaustive sampling.

Introduction

Many thousands of non-native species have been introduced to aquatic ecosystems through, for example, aquaculture, the aquarium trade and ship biofouling and ballast water (Kolar & Lodge, 2002; Strayer, 2010). Amongst these species, bivalves are well represented and, due to their ability to form prominent structures, can cause substantial ecosystem and economic impacts (Mackie and Claudi, 2010; Gallardo et al., 2019). Estuaries are particularly susceptible to non-native species as they are often the centre for anthropogenic activities and as such often represent stressed systems. Western Australia's largest and busiest container port, Fremantle, located at the mouth of the Swan-Canning Estuary, contains 46 of the States' 60 non-native aquatic species, including the Asian Date Mussel *Arcuatula senhousia* (Huisman et al., 2008). This small (maximum length 35 mm) mytilid is highly fecund (> 100,000 eggs), has a high dispersal capability, fast growth and a relatively high tolerance to environmental conditions (Watson et al., 2021). Individuals burrows into sediment and produces a protective cocoon-like structure that joins with those of neighbouring mussels to form a dense mat. While the mussel is native to Asia, it has been accidentally introduced to at least 15 countries, including Australia, New Zealand and America, where it is regarded as an invasive species (Zenetos, 2016).

This species was first recorded in the Swan-Canning Estuary in 1982 (Slack-Smith & Brearley, 1987) and a subsequent study in 1994 found it was well established at six locations in the estuary with densities of up to 2,600 individuals m^{-2} (McDonald & Wells, 2010). Although a relatively small number of *A. senhousia* were found in the estuary during 2003 (Wildsmith et al., 2011), a detailed study undertaken in 2007, which included sites where *A. senhousia* had previously been recorded as well as sites that provides the optimum conditions for this species, failed to record any individuals (McDonald & Wells, 2010). The apparent disappearance of *A. senhousia* from the estuary was thought to be related to a combination of high seasonal variability in the mussel's population and a 'natural eradication' event caused by extremely high and unseasonal freshwater discharge during January 2000 (summer), which rapidly reduced salinity (< 5 in surface waters) and caused a bloom of the toxic cyanobacterium *Microcystis aeruginosa* (130 million cells ml^{-1}; Atkins et al., 2001).

As no human implemented eradication approaches have been applied successfully for any established invasive bivalve species (Sousa et al., 2014), this study aimed to document the current distribution of *A. senhousia* in the Swan-Canning Estuary to elucidate, whether thirteen years since the previous study, there is evidence that natural eradication events can permanently remove an invasive species.

Material And Methods

Study site and sampling regime

The Swan-Canning Estuary (~ 55 km^2), located on the temperate microtidal lower-west coast of Australia and experiences a Mediterranean climate, with most rainfall occurring between May and October (Hallett et al. 2018). It comprises a short, narrow entrance channel, a relatively large main basin (Melville Water), a small second basin, and the tidal reaches of the Swan and Canning rivers (Hodgkin & Hesp, 1998; see also Fig. 2). Sampling was restricted to the entrance channel, Melville Water and lower Canning Estuary, as bottom waters of these areas of the estuary typically experience marine salinities throughout the year, provide a stable habitat for this species and within which visibility was sufficient to facilitate data collection using cameras. These areas are characterised by shallow marginal shoals (2 m deep), but depths further offshore reach a maximum of 17 m in Melville Water and 20 m in the entrance channel.

Sampling sites were selected systematically by overlaying a 100 ×100 m grid pattern on a bathymetric map of the estuary in ArcGIS v10.6 and selecting grid line intersection points. Between depths of 0.3 m (the depth restriction of the camera frame) and 5 m, sites were spaced 100 m apart and in depths > 5 m, were 200 m apart. The coordinates for the resultant 2,037 sites were extracted from ArcGIS, loaded onto a mobile GPS device and surveyed in the field over fifteen days in February 2020 (Austral summer).

A high-resolution (1080p at 60 fps) video of each site was obtained using a GoPro Hero 2018 (GoPro Inc) mounted downwards on a 0.4 m tall stainless-steel tetrapod frame. The frame provided a field of view of 0.3 × 0.3 m. At each site, the drop camera was slowly lowered from a small boat until it rested on the substratum. Videos were viewed and a photo of the substrate extracted immediately before the frame impacted the sediment, suspending sediment and reducing visibility. If *A. senhousia* was present, the percentage coverage was calculated using the open-source software package Image J 1.x (Schneider et al. 2012). Images were firstly cropped to exclude the metal frame and the total number of pixels calculated. Areas of aggregated *A. senhousia*, with obvious surface valves present, were measured using the polygon tool and used to calculate percentage cover (see Fig. 1). The estimates were considered conservative as *A. senhousia* mats can have areas that lack obvious surface valve perforation. The percentage cover data were imported to ArcGIS as a layer and the coordinates matched with depths extracted from a high-resolution bathymetric map made in 2016 using a laser airborne depth sounder and shallow water lidar sensor (Fugro N.V.). The resultant data were used to explore the extent to which percentage coverage of *A. senhousia* was related to depth.

Results

During February water quality conditions in area of the Swan-Canning Estuary where the drop cameras were deployed were homogeneous and only 1.2 mm of rain fall in the week preceding the study and over its duration. Salinities, temperature and dissolved oxygen concentrations were ~ 38, 23°C and > 5 mg l^{-1}, respectively, throughout the entire water column (i.e. no vertical stratification; Department of Biodiversity, Conservation and Attractions, 2022).

Individuals of *Arcuatula senhousia* were present within the camera frame at 173 of the 2,037 sites, with individuals detected just outside the camera frame at a further 39 sites, i.e. identified as the drop camera approached the sediment. The presence of *A. senhousia* was most prominent in the upper half of Melville Water and the lower Canning River (Fig. 2). Within the 1,288 sites in the latter two areas, 75 had percentage covers of *A. senhousia* of 0–25%, 66 sites had a coverage of 25–50%, 19 had 50–75% and 12 sites had coverages of > 75%. While the vast majority of *A. senhousia* occurred at depths of 2 to 8 m, a small number of detections occurred at 1–2 m, where percentage coverage was always < 50% (Fig. 3).

Samples collected previously by McDonald and team from sites in the upper part of Melville waters (corresponding with sites identified as > 75% coverage in this study) document mean densities of this species of 2950 animals m^{-2} (range 2622–3288 m^{-2}). These values are greater than those previously documented by Slack-Smith and Brearley (1987) who identified maximum densities of 2600 animals m^{-2}.

Discussion

The spatially intensive sampling regime employed in the current study using drop cameras recorded the presence of *A. senhousia* at 212 sites throughout the lower Swan-Canning Estuary. It thus provides clear evidence that not only was *A. senhousia* present in this estuary but was prominent at many locations and particularly in the lower Canning River and upper half of Melville Water. While this is the first study to explore the distribution of *A. senhousia* in this estuary since its apparent disappearance in the summer of 2000, large mats of dead shell were trawled up during otter trawling sampling for prawns during the summer of 2017 (Brian Poh, pers. comms). The occurrence of these dead individuals followed an extreme rainfall event resulting in pronounced water column stratification in Melville Water and the formation of a 'dead zone' where dissolved oxygen concentrations fell below 2 mg L^{-1} in bottom waters (Department of Parks and Wildlife, 2017).

It would be thus reasonable to assume that the presence, distribution and even the persistence of this species in the Swan-Canning Estuary is dynamic, potentially undergoing die offs followed by re-colonisations. This conclusion is consistent with the finding of previous studies in that the beds of *A.*

senhousia usually disappear after a couple of years, possibly due to low oxygen and salinities following substantial freshwater flow (National Introduced Marine Pest Information System, 2002). Furthermore, populations are thought to be highly dynamic, presumably due to highly variable recruitment (NIMPIS, 2002; McDonald and Wells, 2010) and mortality even though this mussel species is known to be tolerant to low oxygen concentrations and relatively low salinities (Government of Western Australia, 2005). Although, it cannot be ruled out that re-colonisation of the benthic habitats could be from re-introductions through the nearby port, given the speed of the recovery it is more likely that re-colonisation is from residual population within the estuary system.

Unlike the native mytildae, *Mytilus galloprovincialis* and *Xenostrobus securis*, which colonises hard structure in the Swan-Canning Estuary, *A. senhousia* has a preference for soft sediments, which comprises much of the estuary bottom. In contrast, mussel beds comprise a structurally complex matrix of living mussels, shells, sediment, and debris, and are considered among the most diverse temperate ecosystems containing several hundred species (Smith et al., 2006) and thus invasions of *A. senhousia*, such as those in the Adriatic Sea and Tyrrhenian Sea, have been found to have gross positive effects on the benthic community Munari (2008). In Mission Bay, California, an invasion of *A. senhousia* was also found to contribute substantially to the diets of the fish, the Yellowfin Croaker *Umbrina roncador*, Spotfin Croaker *Roncador stearnsii* and Sargo (*Anisotremus davidsonii*) and the birds the Willet *Catoptrophorus semipalmatus* and Marbled Godwit *Limosa fedoa* (Crooks 2002). Although beds of *A. senhousia* beds have been postulated to compete with seagrasses in other systems (NIMPIS, 2002), the data collected during the present study found that seagrass throughout the study area was almost exclusively found in depths of < 2 m and thus any competition by *A. senhousia* with seagrass would be limited to a narrow depth range.

The use of simple drop camera, comprising a readily available off-the-shelf camera and simple stainless-steel frame (total cost = AUD500) was cost-effective and facilitated the collection of data at a fine spatial scale (100–200 m) across an area of 28 km^2 over the 15 days of sampling. This is a larger extent than could be achieved in the same timeframe using traditional methods involving the collection of sediment from grabs or cores. Moreover, visual analysis of the photos would also be less destructive and time intensive than extraction, identification and quantification of specimens from sediment samples as has been done in many previous studies. It should be noted, that our survey was conducted at a time of year when environmental conditions are stable and that microtidal estuaries, such as the Swan-Canning Estuary are less turbid than macrotidal systems thus facilitative the use of visual methods (Tweedley et al., 2016). The drop camera method employed here is considered is suitable for species such as *A. senhousia* that form distinct benthic matts and whose spatial distribution and abundance may change markedly and so be missed by less exhaustive sampling.

Statements & Declarations

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Data availability: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Figures

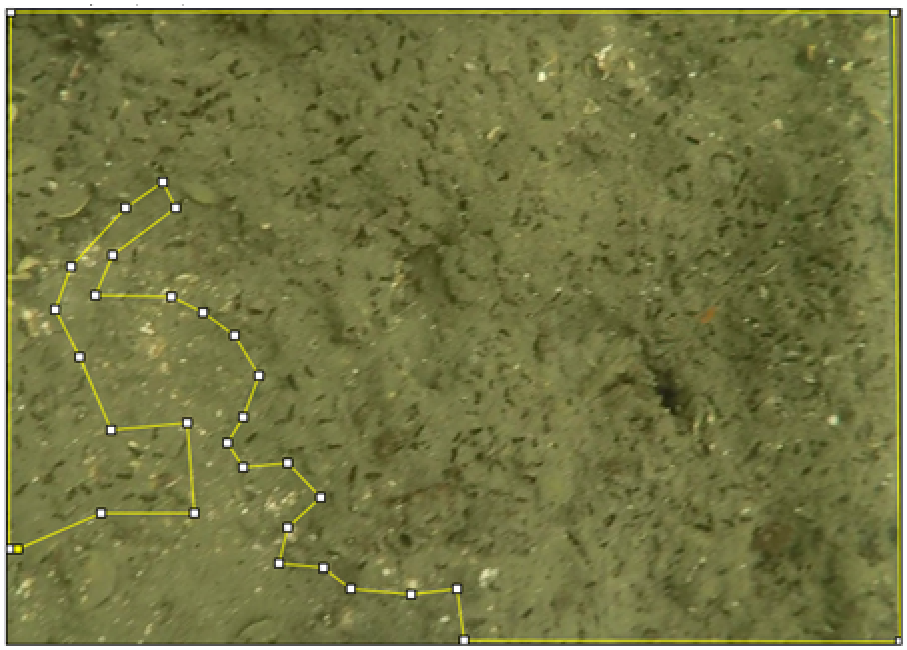

Figure 1

Drop camera image of a mat of *Arcuatula senhousia* covering 85% of the surface of the substrate.

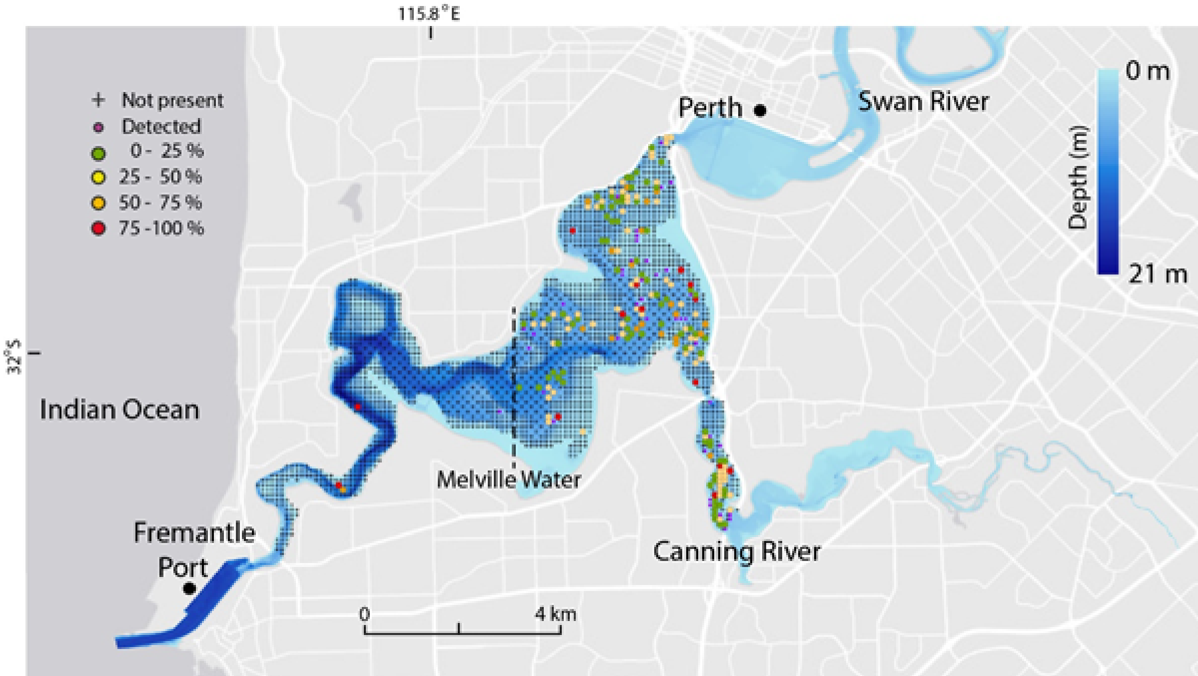

Figure 2

Bathymetric map of the Swan-Canning Estuary showing the locations of each of the 2,037 drop camera sampling sites and the percentage cover of *Arcuatula senhousia*. Dashed line delineates the lower and upper regions of the sampling area.

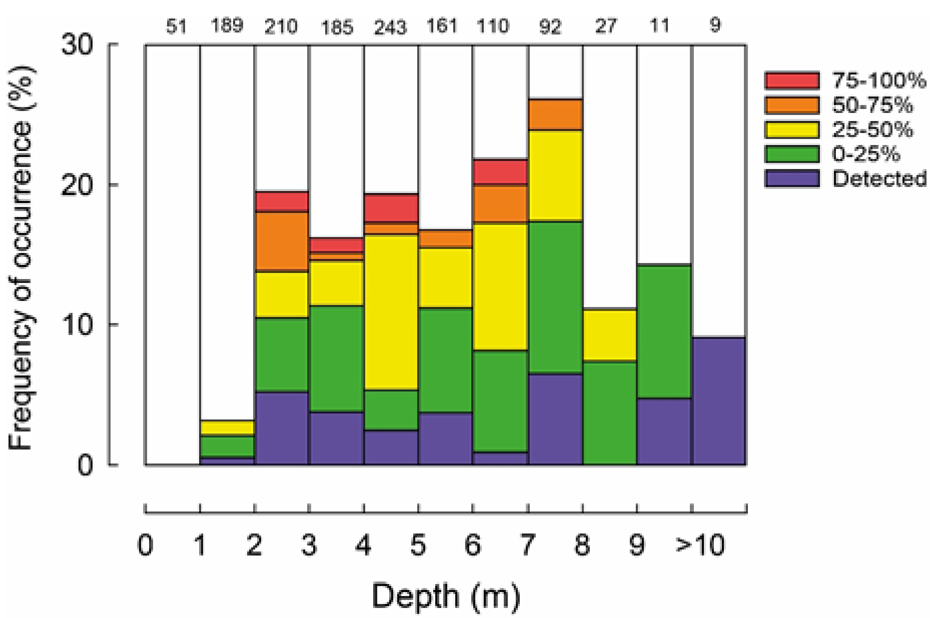

Figure 3

Frequency of occurrence (%) of the various percentage coverages of *Arcuatula senhousia* at the depths. Detected refers to *A. senhousia* being present just outside the camera frame. The numbers of samples in each depth is provided above each bar.