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ORIGINAL ARTICLE

Quantifying the filtration ecosystem services of an invasive bivalve, *Arcuatula senhousia*, in an anthropogenically modified estuary

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Abstract: Estuarine systems are among the most biodiverse globally yet are increasingly threatened by anthropogenic modification and nutrient enrichment. Filter-feeding bivalves provide vital ecosystem services by improving water quality, reducing turbidity and enhancing nutrient cycling. Many native bivalve populations have declined due to anthropogenic pressures and increasing water temperatures. Invasive bivalves may compensate for the losses in filtration ecosystem services formerly supplied by declining native species. However, most studies have focused more on their distribution, establishment and ecological impacts, with comparatively little attention given to their potential contribution to filtration-related ecosystem services. This study assesses the filtration ecosystem services that the invasive mussel *Arcuatula senhousia* can provide relative to the native *Mytilus galloprovincialis* on artificial hard structures in the highly anthropogenically modified Peel-Harvey Estuary, Western Australia. Physiological feeding behaviours were quantified using biodeposition experiments with natural seston collected during incoming and outgoing tides. Feeding parameters differed significantly between species, with *A. senhousia* exhibiting consistently lower rates across all measured variables. Tidal phase also significantly influenced feeding behaviour. These results indicate that within the shared hard-substrate habitat examined, *A. senhousia* did not provide filtration-associated ecosystem services to the same extent as *M. galloprovincialis*. Limited filtration by *A. senhousia* may reduce nitrification-denitrification coupling, limit top-down control of phytoplankton, and minimise eutrophication mitigation potential. The findings emphasise the need for broader population-level assessments of *A. senhousia* and *M. galloprovincialis* across the wider estuarine system, and for management strategies that reduce land-based nutrient inputs, aiding the provisioning of filtration ecosystem services.
Keywords: feeding physiology; *Mytilus galloprovincialis*; *Arcuatula senhousia;* invasive species; mussel; Peel-Harvey Estuary; ecosystem services

Sažetak: PROCJENA DOPRINOSA INVAZIVNOG ŠKOLJKAŠA, *ARCUATUA SENHOUSIA*, PROCESU FILTRIRANJA U ESTUARIJU IZLOŽENOM ANTROPOGENIM PRITISCIMA. Estuariji se ubrajaju među sustave s najvećom bioraznolikošću na svijetu, no sve su ugroženiji zbog antropogenog utjecaja i obogaćivanja hranjivim tvarima. Školjkaši koji se hrane filtriranjem pružaju važne ekosustavne usluge poboljšanjem kvalitete vode, smanjenjem zamućenosti i poticanjem kruženja hranjivih tvari. Brojnost mnogih populacija autohtonih školjkaša smanjila se zbog antropogenih pritisaka i porasta temperature vode. Invazivni školjkaši mogli bi nadoknaditi gubitak usluga ekosustava povezanih s filtracijom vode koje su prethodno pružale autohtone vrste čije su populacije u opadanju. Međutim, većina istraživanja bila je usmjerena na njihovu rasprostranjenost, uspostavu populacija i ekološke utjecaje, dok je razmjerno malo pozornosti posvećeno njihovu mogućem doprinosu ekosustavnim uslugama povezanima s filtracijom. U ovom se istraživanju procjenjuju doprinosi filtraciji vode kao usluzi ekosustava, koje invazivna dagnja *Arcuatula senhousia* može pružiti u usporedbi s autohtonom vrstom *Mytilus galloprovincialis* na umjetnim čvrstim strukturama u estuariju Peel-Harvey u zapadnoj Australiji, koji je pod snažnim antropogenim pritiscima. Fiziološki procesi hranjenja kvantificirani su pokusima biodepozicije uz upotrebu prirodnog sestona, prikupljenog tijekom plime i oseke. Parametri hranjenja značajno su se razlikovali između vrsta, pri čemu je *A. senhousia* dosljedno pokazivala niže vrijednosti svih mjerenih varijabli. Faza plimnog ciklusa također je značajno utjecala na hranjenje. Rezultati upućuju na to da u istraživanom zajedničkom staništu na čvrstoj podlozi vrsta *A. senhousia* nije pružala usluge ekoustava povezane s filtracijom vode u jednakoj mjeri kao *M. galloprovincialis*. Ograničena filtracija vrste *A. senhousia* mogla bi smanjiti povezanost procesa nitrifikacije i denitrifikacije, ograničiti kontrolu fitoplanktona putem potrošača te umanjiti potencijal ublažavanja eutrofikacije. Nalazi naglašavaju potrebu za obuhvatnijim procjenama na razini populacija *vrsta A. senhousia* i *M. galloprovincialis* u cijelom estuarijskom sustavu, kao i za strategijama upravljanja kojima se smanjuje unos hranjivih tvari s kopna i time podupire pružanje ekosustavnih usluga filtracije.
Ključne riječi: fiziologija hranjenja; *Mytilus galloprovincialis*; *Arcuatula senhousia*; invazivne vrste; dagnja; estuarij Peel-Harvey; usluge ekosustava

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INTRODUCTION

Temperate estuaries are highly productive transitional environments that support diverse biological communities and provide a wide range of ecosystem services (Kennish, 2002; Barbier *et al.,* 2011). At the same time, they are among the most intensively modified and degraded marine ecosystems because they receive the accumulated effects of human activities occurring throughout their catchments and along their shorelines (Jackson *et al*., 2001). Coastal development, habitat alteration, pollution and resource exploitation have placed increasing pressure on these systems, particularly as human populations continue to concentrate near the coast (Cosby *et al*., 2024). One of the most pervasive pressures is the delivery of excessive nutrients from agricultural and urban catchments, which can stimulate primary production, promote harmful algal blooms and drive eutrophication (Jackson *et al*., 2001; Smith, 2003).

Filter-feeding bivalves can partly counteract these pressures by removing suspended particles from the water column and transferring nutrient-rich material from pelagic to benthic environments (Petersen *et al*., 2019; Cubillo *et al.,* 2023). Through filtration, assimilation, biodeposition, organic matter burial and enhanced nitrification–denitrification coupling, bivalves can improve water clarity, regulate nutrient cycling and mitigate eutrophication (Kellogg *et al.,* 2013; Rose *et al*., 2014; Zhang *et al.,* 2019). Their feeding activity can also exert top-down control on phytoplankton biomass (Newell *et al.,* 2005). These ecosystem services depend not only on the abundance of bivalves, but also on species-specific differences in clearance rate, particle selection, ingestion and absorption.

Many native bivalve populations have declined because of overharvesting, habitat modification, destructive fishing practices, pollution and increasing water temperatures. Globally, approximately 85% of oyster reefs are considered lost or severely degraded (Beck *et al*., 2011). Declines in native bivalves may therefore result in substantial losses of filtration and nutrient-regulation services. At the same time, non-indigenous bivalves have become widespread, with introductions occurring on every continent (Sousa *et al*., 2009; Cottingham *et al*., 2025). Where invasive species become abundant, they may provide some of the ecological functions formerly supplied by declining native species (Cottingham *et al*., 2025). However, whether they can functionally compensate for native bivalves depends on both their population density and their per-capita feeding performance (Galimany *et al.,* 2018).

The Mediterranean mussel, *Mytilus galloprovincialis* Lamarck, 1819, is an important filter feeder in temperate estuaries and coastal waters in the Mediterranean and southern Australia (Dias *et al.,* 2014; Oyarzún *et al.,* 2024). Although some details regarding the evolution of southern hemisphere mussels (*Mytilus* spp.) remain unclear, studies generally agree that *M. galloprovincialis* present in Australia are a native, genetically distinct species to those found in the Northern Hemisphere, rather than occurring through recent introductions through accidental or deliberate human transport (Gardner *et al*., 2021). Growing up to 120 mm in length (Edgar, 2008), *M. galloprovincialis* is an epifaunal, reef-building bivalve that attaches to hard substrates and other individuals to form large three-dimensional structures in intertidal and shallow subtidal waters up to 8 m deep, and generally in sea temperatures below 24 °C (Anestis *et al.,* 2007; Gillies *et al.,* 2018). Through relatively high clearance and filtration rates, populations of this species can remove substantial quantities of particulate material from the water column, as demonstrated in a Spanish bay in the NW Mediterranean, where an individual *M. galloprovincialis* cleared up to 4.88 L h^{-1} (Galimany *et al*., 2011; Cottingham *et al*., 2023). However, *M. galloprovincialis* is vulnerable to environmental stressors including elevated temperatures, pollution and habitat modification, raising concern that declines in its abundance could reduce the filtration services provided within modified estuaries (Cottingham *et al*., 2023). In systems where invasive bivalves occur alongside *M. galloprovincialis*, an important management question is therefore whether the invasive species can compensate for any reduction in the abundance or ecological functioning of the native mussel.

One potential functional replacement is the Asian date mussel, *Arcuatula senhousia* (W. H. Benson, 1842), a semi-infaunal bivalve with a native range extending approximately 5,000 km from Singapore to Siberia (Barfield *et al*., 2018; Dey, 2023). *Arcuatula senhousia* is a comparatively small mussel, with adults typically less than 40 mm in length (Watson *et al*., 2021). They are found embedded within the sediment, using byssal threads to construct a cocoon-like 'bag' around their shells, interlinking with neighbouring individuals to form dense mussel mats, in waters up to 20 m deep (Creese *et al*., 1997; Watson *et al*., 2021). *Arcuatula senhousia* also attach to hard substrates, including dead or live bivalve species (Dey, 2023) and jetty pylons. Established populations were first detected on the Pacific coast of North America during the 1920s and have since been recorded in Australia, New Zealand, New Caledonia, the Mediterranean and Black Seas, West Africa, islands off eastern Africa and other parts of East Asia (e.g., Chartosia *et al*., 2018; Watson *et al*., 2021; Hamza *et al*., 2022).

Introduced species are often assessed primarily in terms of their ecological impacts, yet some may also maintain or enhance ecosystem functions in invaded habitats (Katsanevakis *et al.*, 2014; Cottingham *et al*., 2025). For example, dense aggregations of *A. senhousia* can modify benthic habitats and store carbon within their shells, indicating that the species may function as both an ecosystem engineer and a contributor to carbon storage (Tsirintanis *et al*., 2022). However, most studies have focused on its distribution, establishment and eco-

logical impacts, with comparatively little attention given to its potential contribution to filtration-related ecosystem services (Mistri, 2002; Hamza *et al*., 2022; Bariche *et al.*, 2025).

In Western Australia, *A. senhousia* was first recorded in the Swan–Canning Estuary in 1982 (Slack-Smith and Brearley, 1987) and had reached densities of up to 2,600 individuals m^{-2} by 1994 (McDonald and Wells, 2010). An unseasonal rainfall event in 2000 contributed to a toxic algal bloom, after which the species was considered locally eradicated from several waterbodies (McDonald and Wells, 2010). Subsequent surveys have nevertheless recorded established populations in the Swan–Canning Estuary (Wildsmith *et al*., 2011), adjacent Cockburn Sound (BMT, 2018) and the nearby Peel–Harvey Estuary (Cronin-O'Reilly, 2021).

High population density alone does not necessarily indicate that an invasive bivalve can replace the ecological function of a native species. For example, if individual *A. senhousia* filter substantially less water, relative to *M. galloprovincialis*, even dense populations of *A. senhousia* may provide only limited compensation for the loss of native filtration services. Conversely, sufficiently high densities could offset lower individual feeding rates and result in comparable or greater population-level clearance. Although the two species differ in their broader habitat use, both occur on artificial hard structures (Cottingham *et al*., 2023; Liu *et al*., 2026), including within the Peel-Harvey Estuary, located on the temperate lower west coast of Western Australia. Therefore, this study compared the feeding physiology and potential filtration ecosystem services of *A. senhousia* and *M. galloprovincialis* occurring on artificial hard structures in the main channel of the Peel-Harvey Estuary. The comparison is also relevant to Mediterranean coastal systems, where *A. senhousia* is now widely established (Hamza *et al.*, 2022; Bariche *et al.,* 2025) and increasing temperatures may alter its functional relationship with *M. galloprovincialis*. Specifically, clearance rate, filtration rate, particle rejection, organic ingestion, absorption rate and absorption efficiency were quantified under incoming and outgoing tides. These measurements were combined with estimates of density and size structure on jetty platforms to compare the potential population-level filtration services of *A. senhousia* and *M. galloprovincialis* within this shared habitat, and to determine whether differences in local abundance could offset differences in individual feeding performance.

MATERIALS AND METHODS

Location of the study

The Peel-Harvey Estuary (Fig. 1), situated approximately 80 km south of Perth, is a very shallow, microtidal estuary with an average depth of 0.5 m, and is the largest estuary in the southwest of Western Australia (Cronin-O'Reilly, 2021). The system has undergone sig-

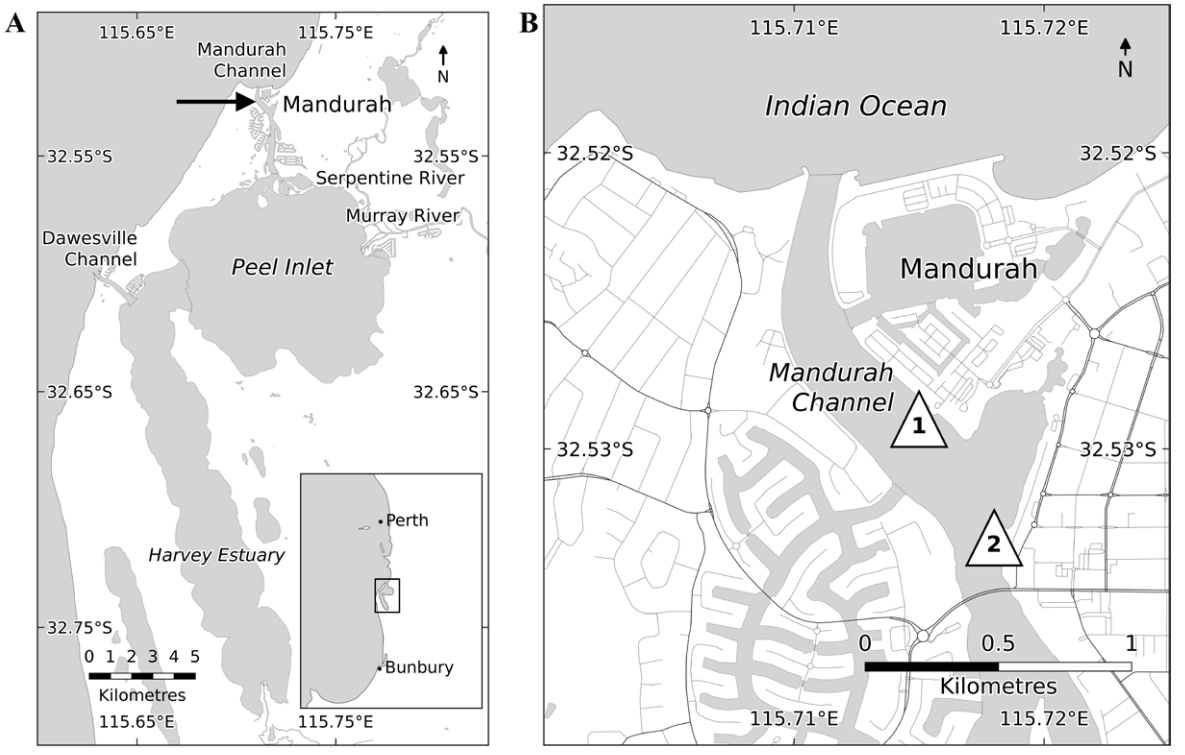


Fig. 1. Map of the Peel-Harvey Estuary with an arrow to show the location of the study. Insert map shows the location of the estuary in Australia **(A)**; map of Mandurah Channel showing (1) the water collection site and (2) the collection site for *Arcuatula senhousia* and *Mytilus galloprovincialis* **(B)**; maps produced using data from OpenStreetMap in Python v.3.14.6.

nificant anthropogenic modification, notably the draining of its natural wetlands for agriculture and human settlement (Elliott *et al*., 2016), and it has previously been identified as hyper-eutrophic (Elliott *et al*., 2016). The Mandurah Channel forms the northern part of the estuary and has also undergone significant anthropogenic modifications to support a local population of more than 100,000 people (City of Mandurah, 2026).

Experimental set up

Feeding experiments were undertaken between October 2025 and December 2025 (austral spring) in the laboratory, using water collected from the Mandurah Channel, an area where both *Arcuatula senhousia* and *Mytilus galloprovincialis* inhabit and could easily be collected from jetty floating platforms. The experiments were conducted on six occasions, comprising three incoming-tide trials and three outgoing-tide trials. Approximately 560 L of estuary water was collected at the mid-point of each tide using a submersible pump lowered 50 cm below the water surface, to replicate the depth from which mussels were collected, and transported to a sump tank at the laboratory. The specific days for which trials were undertaken were determined by the mid-point of the tide correlating with a practical water collection opportunity. On the morning of each experiment *A. senhousia* and *M. galloprovincialis* were manually collected from jetty platforms in the Mandurah Channel, transported wet to the laboratory, cleaned of any epibionts, and placed in individual feeding chambers. For the first two experiments, five bivalves of each species were collected, and to increase the probability of a higher number of mussels opening throughout the experiment, an additional mussel of each species was collected for the remaining four experiments. Mussels with broadly similar shell lengths (the longest antero-posterior distance (Beggel *et al.*, 2015)) were selected (*A. senhousia*: 28.14 ± 0.65 mm, *M. galloprovincialis*: 34.16 ± 1.66 mm).

Feeding physiology methodology

Feeding behaviours were determined for each individual bivalve using the biodeposition method, which is based on using the inorganic matter as a tracer for ingestive and digestive processes (Iglesias *et al.,* 1998). This is an approach that has been highly regarded as one of the few methodologies suitable for feeding experiments involving natural seston and performed in the field (Bayne, 2004; Petersen *et al.,* 2004; Galimany *et al.*, 2011), allowing for the collection of comprehensive data on bivalves' feeding behaviour in relation to varying seston characteristics (Iglesias *et al*., 1998; Bayne, 2004; Galimany *et al*., 2018).

Feeding behaviour was quantified using the same apparatus described and used by Cottingham *et al.* (2023, 2025), which was based on the design used by Galimany *et al.* (2011, 2018) (Fig. 2). Estuary water was pumped from the sump tank to a header tank fitted with an overflow pipe to ensure a consistent water depth and flow. Estuary water was added to the sump tank periodically throughout the experiment to ensure water was continuously agitated and to prevent the settlement of particulate matter. Bivalve feeding chambers were connected to the header tank by a hose fitted with adjustable valves that were calibrated to a flow of 12 L h^{-1}. Adjoining feeding chambers which did not contain a bivalve had their adjustable valves left closed. Each feeding chamber was fitted with permanent and removable baffles that forced the water directly onto the mussel and away from the bottom of the chamber to minimise disruption to settled biodeposits. The tissue from an additional two bivalves of each species was removed, and the empty shells were placed in control chambers, used to account for the settling or accumulation of particles caused by physical factors rather than biological activity (Iglesias *et al.,* 1998).

Prior to the commencement of the experiments, the gut transit time (GTT) of each bivalve species was determined. The GTT is the period required for particulate matter to transit through the bivalve gut (Galimany *et al.,* 2018) and is important to measure to ensure that the deposits collected throughout the experiment correspond to the supplied water and not previously ingested particles. Six mussels of each species were placed in beakers with 300 mL estuary water and 2 mL *Tetraselmis* sp. monoculture. The mean time taken for the algae to pass through the digestive tract, indicated through the expulsion of bright green faeces, was recorded. At the end of the GTT, chambers were cleaned of any faeces and pseudofaeces, signifying the start of the experiment. Estuary water was pumped through the apparatus and past each mussel for 3 h after the offset of the GTT.

For the duration of the experiment (3 h), each mussel's faeces and pseudofaeces were collected as they were produced and stored separately. Pseudofaeces are lightly packed, cloud-like deposits, whereas faeces are dense pellet-like expulsions. At the end of the experiment, the samples were filtered through 25 mm diameter Whatman GF/C glass fibre filters that had been previously washed, dried, burned and weighed, and rinsed with deionised water to remove salt. Filters were pre-combusted at 450 ºC for 4 h to remove any volatile substances, moisture or organic matter which may affect future measurements (Cytiva, 2022).

After the biodeposit collection, the filters were then dried at 60 ºC for at least 24 h and weighed. The initial mass of the filter was subtracted from the dried mass to determine the total particulate matter of the biodeposits (mg h^{-1}). All filters were then placed in a furnace at 450 ºC for 4 h to burn off any organic matter, left in a desiccator to cool, and weighed again. The mass of the burned filter was subtracted from the initial mass of the filter to determine the inorganic matter of the biodeposits (IM, mg h^{-1}). The organic matter (OM, mg h^{-1}) was determined by subtracting the mass of inorganic matter

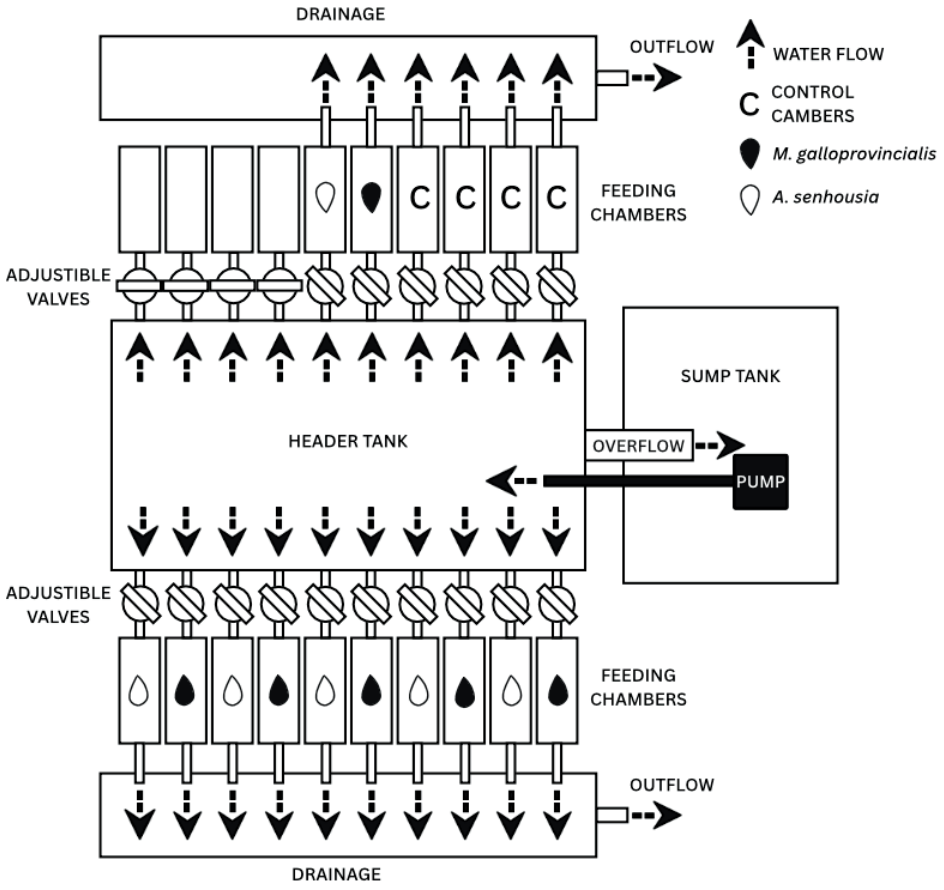


Fig. 2. Illustration of the experimental apparatus used to determine the feeding behaviours of *Arcuatula senhousia* and *Mytilus galloprovincialis*. The exact arrangement of control and feeding chambers varied between trials. Arrows show flow of estuary water through the apparatus.

from the mass of the total matter. The studied parameters determined using the biodeposition method have been summarised in Table 1 from previous studies undertaken by Cottingham *et al*. (2023), Galimany *et al.* (2011) and Velasco and Navarro (2002).

Then, the feeding variables were standardised for each mussel (Ys) to one gram of dried bivalve flesh. The soft flesh of the mussels from each experiment was dried at 60 ºC for at least 24 h and then individually weighed. Standardisation was employed using the equation:

$$Y_s = Y_e \cdot \left(\frac{1}{W_e}\right)^b$$

where Y_e is the experimentally determined physiological feeding rate, W_e is the dried body mass of the bivalve and b is the constant predetermined feeding rate of 0.67, as utilised in other feeding studies of *Mytilus* sp. (Galimany *et al.*, 2011; Cottingham *et al*., 2023). Data from any bivalves that closed their valves for extended periods of time were excluded from the analysis.

Water characterization

At the beginning, middle and end of the experiment, 2,000 mL of water was collected from the header tank and the control chambers and separately filtered through prepared (washed, ashed and weighed) 47 mm diameter Whatman GF/C glass fibre filters. The filters were then processed for total particulate matter (TPM, mg L^{-1}), particulate inorganic matter (PIM, mg L^{-1}) and particulate organic matter of the seston (POM, mg L^{-1}) using the method described above for the biodeposits. Seston quality (*f*) was estimated by dividing POM by TPM. At the beginning of each new experiment, the salinity, dissolved oxygen concentrations and temperature of the water were measured using a multiparameter water quality probe.

Densities, mass-length relationship and clearance capacity of jetty populations

At the mussel collection site, fourteen 120 × 120 mm samples were taken from the underside of the floating jetty platforms at randomly selected locations using a metal

Table 1. Summary of the feeding behaviours of bivalves determined *via* the biodeposition method, where IM and OM are the inorganic and organic matter produced by the bivalve in the faeces (f) and pseudofaeces (p), respectively, *per* unit of time (mg h^{-1}), and PIM, POM and TPM are the total mass of inorganic, organic and total particulate matter available in the seston, respectively, *per* unit of volume (mg L^{-1}).

Parameter	Definition	Unit	Equation
Clearance Rate (CR)	The volume of water cleared of particles *per* unit of time	L h^{-1}	$\frac{(IMf + IMp)}{\widehat{PIM}}$
Filtration Rate (FR)	The quantity of particulate organic matter removed from the water column *per* unit of time	mg h^{-1}	$CR \cdot \widehat{TPM}$
Rejection Proportion (RP)	The percentage of particles that are selectively rejected by the bivalve as pseudofaeces prior to ingestion	%	$\frac{100 \cdot (IMp + OMp)}{FR}$
Organic ingestion rate (OIR)	The quantity of organic particles selectively ingested by the bivalve *per* unit of time	mg h^{-1}	$\left(CR \cdot \widehat{POM}\right) - OMp$
Absorption Rate (AR)	The quantity of ingested particles selectively digested by the bivalve *per* unit of time	mg h^{-1}	$OIR - OMf$
Absorption Efficiency (AE)	The proportion of ingested organic matter absorbed by the bivalve	%	$\frac{AR}{OIR} \cdot 100$

scraper. In the laboratory, every mussel from each species was separated and counted, and each shell length was measured to a resolution of 0.1 mm using vernier callipers. Mean population densities were then scaled to 1 m².

Approximately 100 individuals of each target species were randomly selected and had their tissue removed from their shell, dried for ~24 h at 60 ºC and weighed. The mass-length relationship was then derived by fitting the equation $W = aL^b$ to the mass (W, g) and shell length (L, mm) of the mussels. This was performed using linear regression on the log components of W and L, where the residuals were the coefficient a and exponent b.

Estimates of the potential water clearance capacity of each species scaled to 1 m² were based on the average mussel densities on the jetty platform and average individual clearance rates. Individual clearance rates for each mussel present in the density samples were derived from their mass (calculated using the mass-length relationship model), and by rearranging equation 1, which determined the clearance rate of each individual mussel, relative to their mass, rather than *per* gram:

$$Y_e = \frac{\widehat{Y_s}}{{W_e}^{-b}}$$

where $\widehat{Y_s}$ is the average of the experimentally determined standardised feeding variable. The sum of the clearance rates of the mussels in each 120 × 120 mm sample was then derived from which the mean clearance rate *per* jetty sample was calculated. The mean sample clearance rate was then scaled for each species to 1 m², and further to *a* 24 h period.

Statistical analyses

Analyses were undertaken using the programming language Python v3.14.6, and any differences were considered statistically significant at $p \leq 0.05$. The mean PIM, POM, TPM and seston quality of each tide were tested for normality and equal variance using the Shapiro-Wilk and Levene tests, then compared using one-way ANOVA.

Data from the clearance, filtration, organic ingestion and absorption rates were log-transformed to improve normality and each parameter was compared in turn among tide and species using a two-way ANOVA with heteroscedasticity-robust standard errors, to account for unequal variances.

Shell lengths between species were also tested for normality and equal variance utilising the Shapiro-Wilk and Levene tests and compared using a Mann-Whitney U test. To compare the densities of the target species at the study site, a negative binomial model was used, due to overdispersion in the data set. Mass–length relationships were compared between species using analysis of covariance applied to log-transformed dry tissue mass and shell length, including the interaction between species and shell length to test whether the allometric slopes differed.

RESULTS

Water characterization

The estuary water, on an outgoing tide, had mean POM, PIM and TPM concentrations (± 1SE) of 1.45 ± 0.2 mg L^{-1}, 3.26 ± 0.6 mg L^{-1} and 4.71 ± 0.8 mg L^{-1}, respectively. On an incoming tide, POM, PIM and TPM concentrations were 2.41 ± 0.6 mg L^{-1}, 6.38 ± 2.1 mg L^{-1} and 8.80 ± 2.8 mg L^{-1}, respectively. The mean differences in POM, PIM and TPM concentrations between outgoing and incoming tides were not statistically significant (p = 0.216, p = 0.230 and p = 0.228, respectively). Additionally, there was no statistical difference in mean seston quality (f) between tides (outgoing: 32 ± 0.04%; incoming: 29 ± 0.02%; p = 0.525) (Fig. 3).

Mean water temperature was similar between tidal phases at 21.9 ± 1.0 °C during an outgoing tide and at 22.5 ± 1.0 °C during an incoming tide (Fig. 4). Dissolved oxygen concentrations were ~7 mg L^{-1} during both tides (outgoing: 7.14 ± 0.05 mg L^{-1}; incoming: 6.98 ± 0.09 mg L^{-1}). Salinity was also stable across tidal state at ~35 g kg^{-1} (outgoing: 35.09 ± 0.51 g kg^{-1}; incoming: 35.15 ± 0.44 g kg^{-1}).

Physiological measurements

The physiological feeding behaviours of *Arcuatula senhousia* and *Mytilus galloprovincialis* have been summarised in Tables 2 and 3 and Fig. 5. In summary, the physiological feeding rates, standardised to 1 g dried mussel flesh, of *A. senhousia* were significantly lower than those of *M. galloprovincialis* across all measured parameters ($p < 0.05$ in all cases). Additionally, significant differences in filtration rates and rejection proportion were observed between outgoing and incoming tides (p = 0.049 and p = 0.028 respectively). No significant tide × species interaction was observed in any of the feeding parameters ($p > 0.05$ in all cases).

Densities and mass-length relationship

Samples from the mussel collection site consisted of individuals from both species and showed mean population sizes of 10.4 ± 3.9 individuals for *M. galloprovincialis* and 21.4 ± 9.6 individuals for *A. senhousia*, corresponding to densities of 724 ± 271 and 1488 ± 664 ind. m^{-2}, respectively. The density of *M. galloprovincialis* was 48% of that of *A. senhousia,* however, the difference

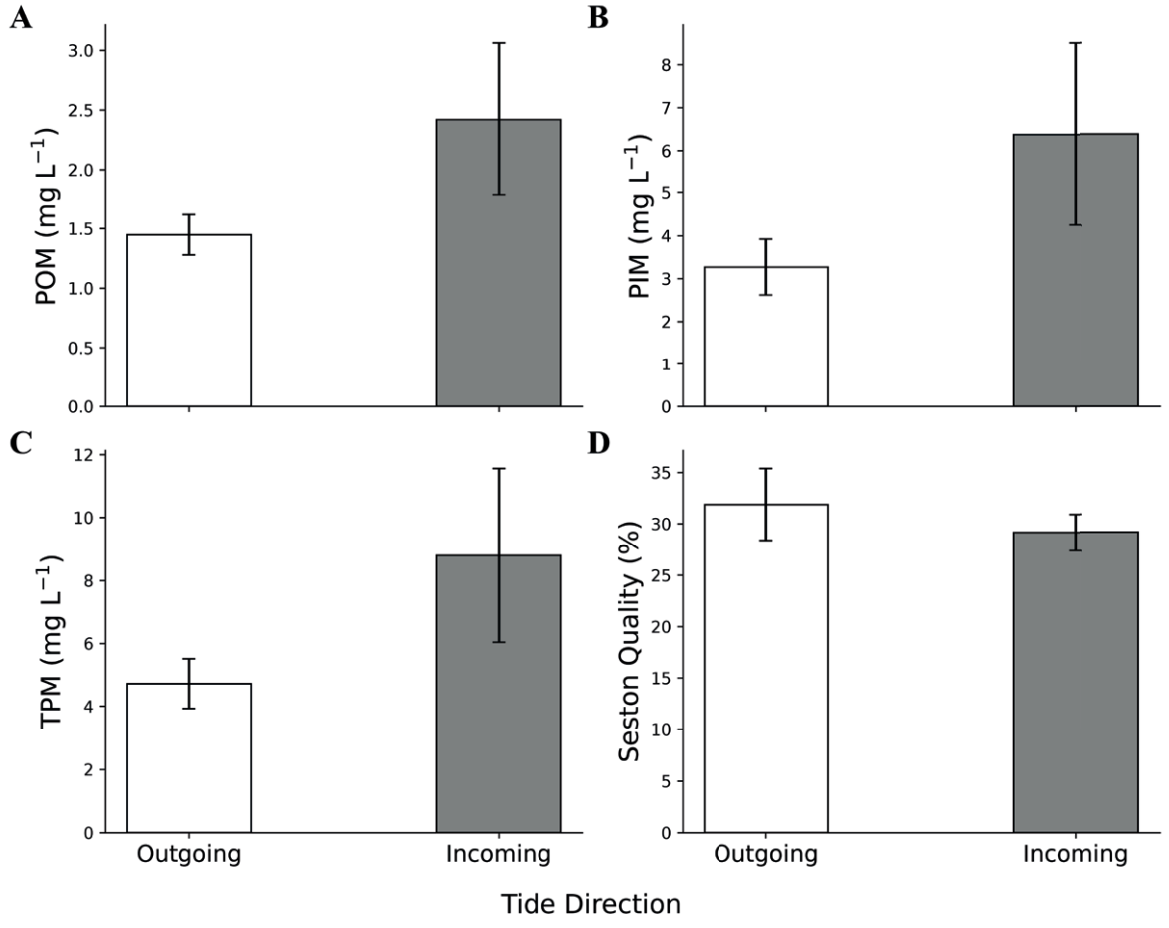


Fig. 3. Experimentally determined mean (±SE) seston characteristics of Mandurah Channel water during an outgoing and incoming tide. POM: particulate organic matter **(A)**; PIM: particulate inorganic matter **(B)**; TPM: total particulate matter **(C)**; seston quality (%) **(D)**.

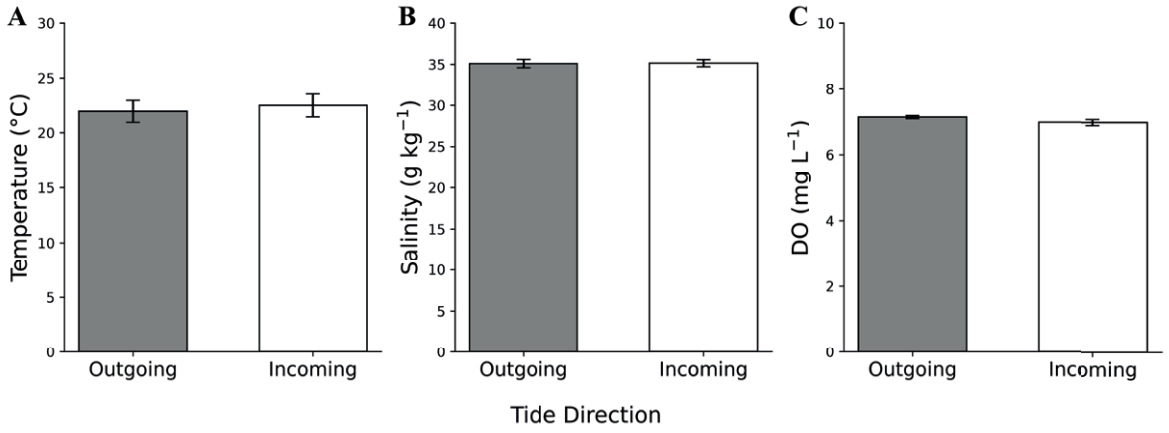


Fig. 4. Mean (±1 SE) water chemistry parameters of Mandurah Channel water measured throughout experiments during an outgoing and incoming tide; temperature (ºC) **(A);** salinity (g kg^{-1}) **(B);** DO: dissolved oxygen (mg L^{-1}) **(C)**.

between population densities for each species were not found to be statistically significant ($p = 0.066$).

The mass–length relationship provided a good fit to the dry mussel flesh (g) and shell length (mm) data for both *M. galloprovincialis* and *A. senhousia*, as indicated by the coefficient of determination ($R^2 = 0.95$ and 0.86, respectively) (Fig. 6A and 6B). The allometric exponent (b) was 2.88 for *M. galloprovincialis* and 3.09 for *A. senhousia*, indicating that mussel mass increases approximately cubically with shell length. *Arcuatula senhousia*'s slightly higher exponent indicates a marginally faster increase in mass with length compared to *M. galloprovincialis*, however, this was not found to be statistically significant ($p = 0.131$).

Clearance capacity of jetty populations

The clearance rate for each individual mussel within the density samples was quantified, and it was determined that, on average, a single *M. galloprovincialis* can clear 1.12 ± 0.15 L h^{-1}, and a single *A. senhousia* can clear 0.22 ± 0.01 L h^{-1}, across tides. Based on the average densities recorded at the mussel collection site, this reveals that *M. galloprovincialis* populations have the potential to clear 809.08 ± 237.60 L h^{-1} m^{-2}, equating to ~19,418 L of estuary water each day. Meanwhile, the same area of *A. senhousia* has the potential to clear, on average, 321 ± 158.43 L h^{-1} m^{-2}, and ~7,717 L day^{-1}.

DISCUSSION

Characteristics of estuary water

The mean characteristics of the estuary water across tides were found to be within a similar range of other studies undertaken in temperate estuaries throughout Australasia (Mitchell, 2001; Gardner, 2002). For example, the mean values recorded for TPM in the Peel-Harvey Estuary (4.7-8.8 mg L^{-1}) were similar to those recorded during summer in the Swan-Canning Estuary, which lies 70 km north (7.9 mg L^{-1}), representative of relatively shallow estuarine systems that receive large inputs of land-derived sediment which are also subjected to resuspension due to wind-generated waves (Cottingham *et al*., 2023, 2025). However, the values recorded in this study were much higher than studies conducted in other temperate zones, such as the 1.03 to 2.30 mg L^{-1} recorded by Galimany *et al*. (2011) in a Spanish estuary during spring.

Tide as a factor for variability in feeding behaviours

Tidal state influenced feeding performance, aligning with the expectation that bivalves adjust their feeding behaviour in response to changing seston availability (Iglesias *et al*., 1998; Bayne, 2004). Filtration rates were greater during the incoming tide than the outgoing tide, whereas clearance rates were higher during the outgoing tide, noting the latter was not significant. Although several studies have reported a positive relationship between increasing TPM and clearance rate (Iglesias *et al*., 1992; Urrutia *et al*., 1996), the lower clearance rate observed during the incoming tide in the study, when TPM was higher, suggests that the mean TPM of the incoming tide (8.8 mg L^{-1}) exceeded the optimal seston concentration for these species (Gardner, 2002; Shin *et al*., 2011). The higher particle concentration meant that the bivalves could obtain sufficient particulate food from a smaller volume of water, indicated by the increased filtration rates. Consequently, less water needed to be pumped through the gills to meet dietary requirements, and clearance rates were reduced, likely to conserve energy and prevent gut saturation (Shin *et al*., 2011).

A significant difference in rejection proportion was also observed between tides, most likely as a consequence of the higher mass of inorganic material present in the seston during the incoming tide, which was re-

Table 2. Mean values (± 1 SE) of the clearance rate (CR), filtration rate (FR), rejection proportion (RP), organic ingestion rate (OIR), absorption rate (AR) and absorption efficiency (AE) for *Arcuatula senhousia* and *Mytilus galloprovincialis* during an outgoing and incoming tide.

Species	Tide	CR ($L\ h^{-1}$)	FR ($mg\ h^{-1}$)	RP (%)	OIR ($mg\ h^{-1}$)	AR ($mg\ h^{-1}$)	AE (%)
A. senhousia	Outgoing	2.00 ± 0.36	8.36 ± 1.07	45.77 ± 5.21	1.61 ± 0.35	0.54 ± 0.21	13.03 ± 10.69
	Incoming	1.37 ± 0.13	12.09 ± 1.65	62.64 ± 2.93	1.23 ± 0.17	0.13 ± 0.09	-0.95 ± 8.50
M. galloprovincialis	Outgoing	5.67 ± 0.67	24.46 ± 2.26	68.39 ± 2.51	2.97 ± 0.57	1.54 ± 0.61	17.89 ± 18.73
	Incoming	4.44 ± 0.45	31.63 ± 3.26	72.01 ± 1.80	2.88 ± 0.32	1.02 ± 0.23	28.90 ± 7.00

moved as pseudofaeces to enrich the ingested diet (Iglesias *et al*., 1998; Ward and Shumway, 2004). This increased pre-ingestive selection allowed absorption efficiency to remain consistent across tides. This behaviour has also been observed in Mediterranean environments where, instead of tides, *Mytilus galloprovincialis* adapt their feeding behaviour according to increasing sediment resuspended from the bottom to the water column (Ward and Shumway, 2004).

Species as a factor for variability in feeding behaviours

The clearance and filtration rates obtained for *M. galloprovincialis* were generally high but remained within the range of previous estimates of feeding behaviours for the species (Galimany *et al*., 2011; Fernández-Reiriz *et al*., 2015; Cottingham *et al*., 2023). Given that the mean water temperature across the experiments was 22.2 ºC, these higher rates may indicate that the bivalves were operating towards the upper limit of the temperature tolerance interval, when pumping rates are often at their highest (Anestis *et al*., 2007; Riisgard and Larsen, 2025).

Whilst by comparison, relatively few studies have quantified the feeding physiology of *Arcuatula senhousia*, despite its broad invasive distribution and capacity to form dense populations in estuarine and coastal habitats, Inoue and Yamamuro (2000) measured ingestion and filtration rates at approximately 10, 20 and 30 °C. They found that ingestion increased markedly between 10 and 20 °C but did not increase further at 30 °C. Their filtration estimates also varied depending on whether chlorophyll *a*, particulate nitrogen or particulate phosphorus was used, suggesting selective ingestion of phytoplankton (Inoue and Yamamuro, 2000). Reproductive activity and spat growth are optimal within the native range of *A. senhousia* at temperatures between 22.5 °C and 30 °C (Liang *et al*., 2009; Dey, 2023). The mean experimental temperature of 22.2 °C therefore occurred near the lower end of this range, which may in part explain the lower observed feeding rates, although the results of Inoue and Yamamuro (2000) indicate that feeding performance does not necessarily increase continuously at higher temperatures.

Coastal water temperatures along southwestern Australia have increased since the 1970s, while recent Mediterranean summer temperatures have approached 29 °C (Caputi *et al*., 2009; Napolitano *et al*., 2025). Under continued warming, the relative feeding performance of the two species may shift if the more warm-tolerant *A. senhousia* remains physiologically active at temperatures that increasingly constrain *M. galloprovincialis*. This may be especially important in Mediterranean estuaries and lagoons where the two species occur within the

Table 3. Results of two-way ANOVA for each feeding behaviour, showing p-values for the effects of species, tide and the species × tide interaction. Clearance rate (CR), filtration rate (FR), rejection proportion (RP), organic ingestion rate (OIR), absorption rate (AR) and absorption efficiency (AE).

	CR ($L\ h^{-1}$)	FR ($mg\ h^{-1}$)	RP (%)	OIR ($mg\ h^{-1}$)	AR ($mg\ h^{-1}$)	AE (%)
Species	3.56×10^{-12}	2.56×10^{-11}	0.00001	9.50×10^{-6}	2.91×10^{-5}	0.018
Tide	0.054	0.049	0.028	0.994	0.361	0.603
Species × tide	0.750	0.902	0.062	0.523	0.569	0.326

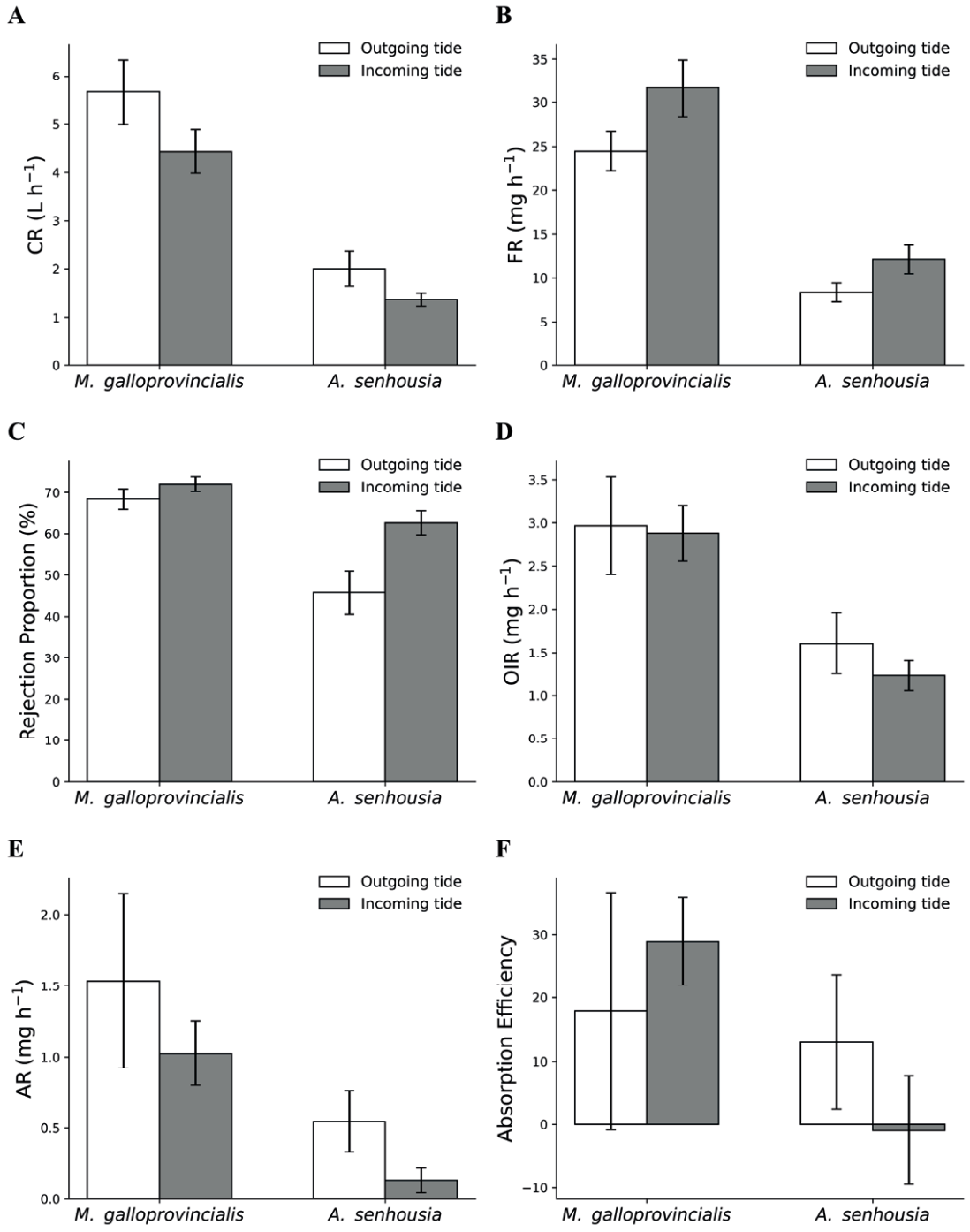


Fig. 5. Mean (± 1 SE) feeding parameters for mussels *Arcuatula senhousia* and *Mytilus galloprovincialis*; clearance rate (CR) **(A)**; filtration rate (FR) **(B)**; rejection proportion (RP) **(C)**; organic ingestion rate (OIR) **(D)**; absorption rate (AR) **(E)**; and absorption efficiency (AE) **(F)** for each species and tide.

same broader region and where changes in their relative filtration capacity could influence nutrient cycling and eutrophication mitigation. However, experiments conducted across seasons and a broader temperature range are required to test this possibility.

The quality of the seston throughout the study was relatively low, reaching a maximum of 32%, and this is reflected in the high mean rejection proportions recorded across tides (*M. galloprovincialis*: 70.2%; *A. senhousia*: 54.5%), which was approximately double that reported for *M. galloprovincialis* across winter and summer (30% and 40% respectively) in the nearby Swan-Canning Estuary (Cottingham *et al*., 2023). Of the particulate organic matter present in the seston, on average, only

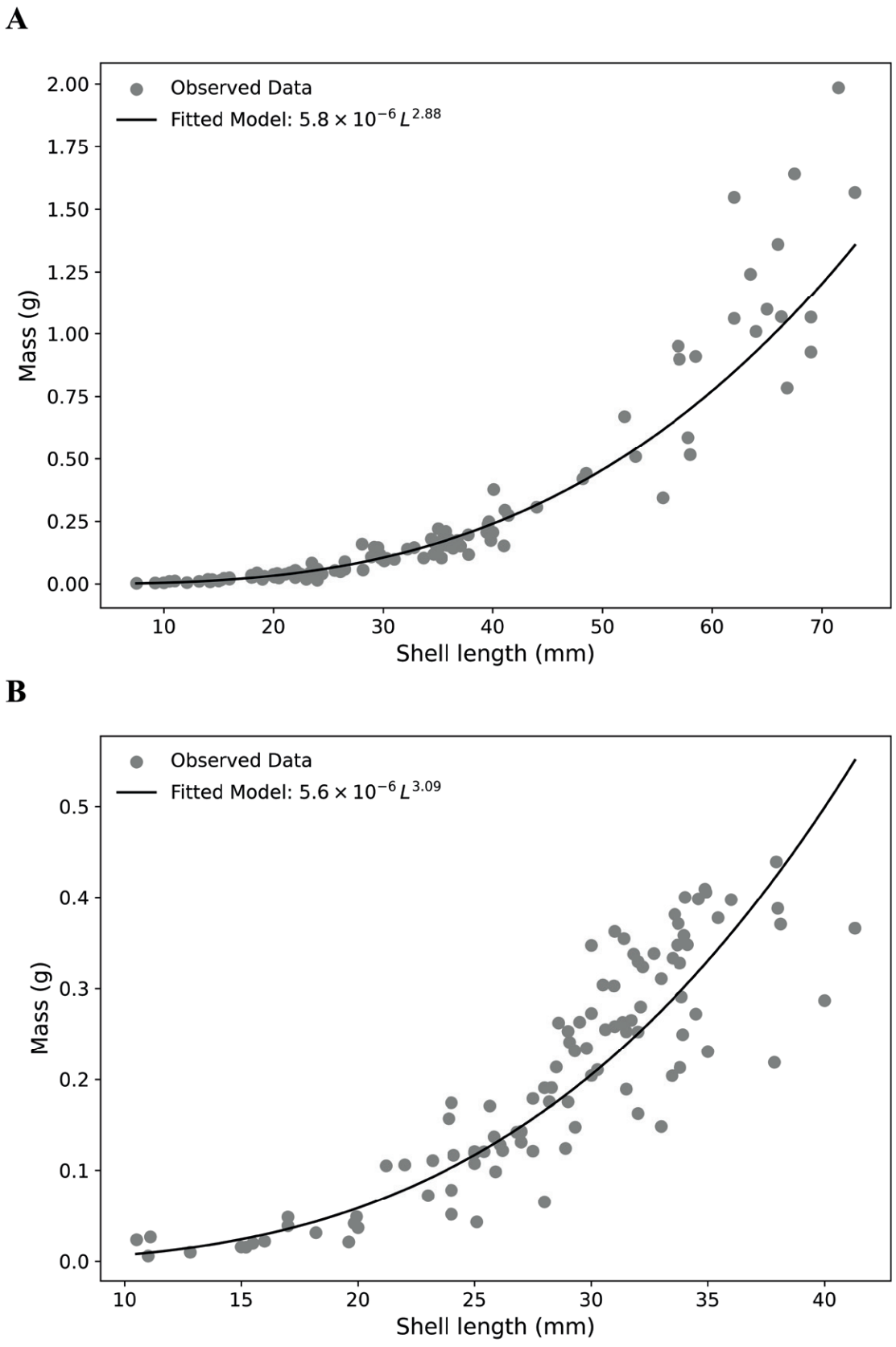


Fig. 6. Mass-length relationship (dry mass-shell length) derived for: *Mytilus galloprovincialis* collected from jetties in the Mandurah Channel ($M = 5.8 \times 10^{-6} L^{2.88}$; $R^2 = 0.95$) **(A)**; *Arcuatula senhousia* collected from jetties in the Mandurah Channel ($M = 5.6 \times 10^{-6} L^{3.09}$; $R^2 = 0.86$) **(B)**.

23.5% was absorbed by *M. galloprovincialis*, and 6.0% by *A. senhousia*, which appears notably low. This may suggest that, although organic matter was available in the diet, the ingested particles were of poor nutritional quality and were rejected in the stomach rather than being digested (Fernández-Reiriz *et al*., 2015). Continued processing of particulate matter by *A. senhousia,* when the nutritional quality of the diet was poor, likely led to the excretion of endogenous material within the faeces (Gardner, 2002), resulting in the observed mean negative absorption efficiencies during an incoming tide.

Comparisons between the physiological feeding behaviours of invasive and native bivalves are limited, with freshwater species often the foci of studies (Douda and Čadková, 2017; Cottingham *et al*., 2025; Prestes *et al*., 2026). Nevertheless, the observed significant differences in the feeding behaviours of *M. galloprovincialis* and *A. senhousia*, which suggest *A. senhousia* bivalves do not have comparable clearance and filtration capacities to their native counterparts, are not necessarily in line with other studies that compare native and non-native filtration capacities. For example, Douda and Cadkova (2017) found the invasive *Sinanodonta woodiana* reduced seston loads to a similar extent to the native *Unio tumidus* in freshwater streams, in China. Similarly, the invasive *Corbicula fluminea* was found to preferentially select more phytoplankton groups than the native *Diplodon parodizi*, showing greater capacity for organic matter removal (Prestes *et al*., 2026). This emphasises how interactions between native and invasive bivalves are highly site- and species-specific, and that quantifying these in systems where invasive populations are established is essential for informing environmental management plans.

Capacity of *Arcuatula senhousia* to mitigate eutrophication

It was found that, based on the average densities recorded at the mussel collection site, *M. galloprovincialis* populations have the potential to clear 809.08 ± 237.60 L h^{-1} m^{-2}, equating to ~19,418 L of estuary water each day. Meanwhile, the same area of *A. senhousia* has the potential to clear, on average, 321 ± 158.43 L h^{-1} m^{-2}, and ~7,717 L day^{-1}. Thus, populations of *A. senhousia* present at the mussel collection site are unlikely to provide water filtration and eutrophication mitigation services on hard structures to the same capacity as the native *M. galloprovincialis,* even when the density of invasive individuals is nearly double that of the native. Threats to native *M. galloprovincialis* populations include increasing water temperatures, pollution, and anthropogenic modification of the environment (Gillies *et al*., 2018; Seuront *et al*., 2019). As human coastal populations continue to rise (Cosby *et al*., 2024), posing greater risks of anthropogenic nutrient input, the projected loss of filtration ecosystem services by the native species, and the limited capacity of *A. senhousia* to compensate for this, may have severe ecological implications at the study site.

Reduced filtration and biodeposition by *A. senhousia* can be expected to limit the enhancement of nitrification-denitrification coupling, reduce top-down control on phytoplankton biomass, and result in lower assimilation of nutrients into mussel tissues (Newell *et al*., 2005; Petersen *et al*., 2019). As a result, the comparatively lower physiological feeding rates of *A. senhousia,* relative to *M. galloprovincialis,* may further increase eutrophication risk. This study highlights the need for large-scale density and percentage cover surveys to quantify this loss of ecosystem services on a wider scale, with the results only representing a snapshot of the population dynamics of the species in the wider estuarine system. Similarly, the quantified feeding behaviours of *M. galloprovincialis* and *A. senhousia* observed in this study are limited only to the environmental conditions relevant to austral spring and can therefore be expected to fluctuate across seasons. Water temperatures in the estuary are highest during the summer months between December and February (Johnston *et al*., 2014), and near the critical thermal tolerance of *M. galloprovincialis.* Consequently, the physiological feeding behaviours of *M. galloprovincialis* may decline throughout the season, as observed in the Swan-Canning Estuary, Perth (Cottingham *et al*., 2023), and a Mediterranean embayment (Galimany *et al*., 2011). These declines in clearance rates throughout summer can be expected to become more pronounced as southwestern Western Australia is situated in one of the fastest-warming ocean regions in the world (Caputi *et al*., 2009), and the global rate of ocean warming has increased two-fold over the past two decades (von Schuckmann *et al*., 2024). Meanwhile, the temperature tolerance of *A. senhousia* is expected to be higher than that of *M. galloprovincialis,* based on the average summer water temperatures of its native range, which extend up to 30 ºC (Dey, 2023). As filtration and clearance rates generally increase linearly with temperature within the tolerance interval (Riisgard and Larsen, 2025), higher physiological feeding rates may be observed in *A. senhousia* throughout the summer months, compensating more greatly for the loss of filtration ecosystem services by the native species, notably when the risk of eutrophication is at its highest (Government of Western Australia, 2022).

CONCLUSION

The physiological feeding performance of *Arcuatula senhousia* was consistently lower than that of *Mytilus galloprovincialis* across all measured parameters. Under the environmental conditions tested, *A. senhousia* was therefore less effective at clearing estuarine water, retaining particulate matter and assimilating organic material. At the surveyed jetties, its higher local density was insufficient to offset this lower per-capita performance, resulting in a lower estimated population-level

clearance capacity on artificial hard structures. Reduced filtration and biodeposition by *A. senhousia* may consequently provide less support for nutrient assimilation, benthic–pelagic coupling and top-down regulation of phytoplankton biomass than equivalent populations of *M. galloprovincialis* (Newell *et al*., 2005; Petersen *et al*., 2019). Feeding responses also varied with tide, particularly for filtration rate and particle rejection, emphasising the capacity for bivalves to alter their feeding behaviours in relation to changing seston characteristics (Iglesias *et al*., 1998; Bayne, 2004). Whilst previous work has quantified aspects of ingestion and filtration in *A. senhousia*, this study provides a comparatively comprehensive assessment of its feeding physiology.

These results may have significant implications for the Peel-Harvey Estuary system, for which excessive algal blooms, driven by anthropogenic nutrient inputs, remain a significant threat. They also have broader relevance to other rapidly warming temperate systems, including the Mediterranean, where both species occur and where their relative functional roles may shift as water temperatures continue to rise. However, broader spatial and seasonal assessments, including in populations occurring on soft sediments, are required before the total estuary-wide contribution of *A. senhousia* can be determined.

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REFERENCES

Anestis, A., Lazou, A., Portner, H.O., Michaelidis, B. 2007. Behavioral, metabolic, and molecular stress responses of marine bivalve *Mytilus galloprovincialis* during long-term acclimation at increasing ambient temperature. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 293(2), 911-921. https://doi.org/10.1152/ajpregu.00124.2007

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C., Silliman, B.R. 2011. The value of estuarine and coastal ecosystem services. Ecological Monographs, 81(2), 169-193. https://doi.org/10.1890/10-1510.1

Bariche, M., Abd Ellah, S.M., Akyol, O., Alfergani, E.S., Alvito, A., Alshawy, F., Ammar, I.A., *et al.* 2025. New records of introduced species in the Mediterranean Sea (December 2025). Mediterranean Marine Science, 26(4), 941-971. https://doi.org/10.12681/mms.43526

Barfield, P., Holmes, A., Watson, G., Rowe, G. 2018. First evidence of *Arcuatula senhousia* (Benson, 1842), the Asian Date Mussel, in UK waters. Journal of Conchology, 43(2), 217-222.

Bayne, B.L. 2004. Comparisons of measurements of clearance rates in bivalve molluscs. Marine Ecology Progress Series, 276, 305-306. https://doi.org/10.3354/meps276305

Beck, M.W., Brumbaugh, R.D., Airoldi, L., Carranza, A., Coen, L.D., Crawford, C., Defeo, O., *et al*. 2011. Oyster reefs at risk and recommendations for conservation, restoration, and management. BioScience, 61(2), 107-116. https://doi.org/10.1525/bio.2011.61.2.5

Beggel, S., Cerwenka, A.F., Brandner, J., Geist, J. 2015. Shell morphological versus genetic identification of quagga mussel (*Dreissena bugensis*) and zebra mussel (*Dreissena polymorpha*). Aquatic Invasions, 10(1), 93-99. https://doi.org/10.3391/ai.2015.10.1.09

BMT. 2018. Cockburn Sound-Drivers-Pressures-State Impacts-Responses Assessment 2017 Final Report. Western Australian Government, 192 pp.

Caputi, N., de Lestang, S., Feng, M., Pearce, A. 2009. Seasonal variation in the long-term warming trend in water temperature off the Western Australian coast. Marine and Freshwater Research, 60(2), 129-139. https://doi.org/10.1071/MF08199

Chartosia, N., Anastasiadis, D., Bazairi, H., Crocetta, F., Deidun, A., Despalatović, M., Di Martino, V., *et al.* 2018. New Mediterranean biodiversity records (July 2018). Mediterranean Marine Science, 19(2), 398-415. https://doi.org/10.12681/mms.18099

City of Mandurah. 2026. Annual Report 2024-2025. https://www.mandurah.wa.gov.au/our-council/governance-and-transparency/community-and-annual-reports (accessed 14 October 2026).

Cosby, A.G., Lebakula, V., Smith, C.N., Wanik, D.W., Bergene, K., Rose, A.N., Swanson, D., *et al.* 2024. Accelerating growth of human coastal populations at the global and continent levels: 2000–2018. Scientific Reports, 14, 22489. https://doi.org/10.1038/s41598-024-73287-x

Cottingham, A., Bossie, A., Valesini, F., Tweedley, J.R., Galimany, E. 2023. Quantifying the potential water filtration capacity of a constructed shellfish reef in a temperate hypereutrophic estuary. Diversity, 15(1), 113. https://doi.org/10.3390/d15010113

Cottingham, A., Bossie, A., Valesini, F., Maus, C., Cronin-O'Reilly, S., Tweedley, J.R., Galimany, E. 2025. Potential of mussel habitat enhancement to alleviate eutrophication in nutrient-enriched estuaries. Ecological Management & Restoration, 26(2), e70004. https://doi.org/10.1111/emr.70004

Creese, R., Hooker, S., de Luca, S., Wharton, Y. 1997. Ecology and environmental impact of *Musculista senhousia* (Mollusca: Bivalvia: Mytilidae) in Tamaki Estuary, Auckland, New Zealand. New Zealand Journal of Marine and Freshwater Research, 31(2), 225-236. https://doi.org/10.1080/00288330.1997.9516760

Cronin-O'Reilly, S. 2021. Benthic community structure, health and function of a microtidal estuary in south-western Australia. PhD Thesis, University of Murdoch, 169 pp.

Cubillo, A.M., Lopes, A.S., Ferreira, J.G., Moore, H., Service, M., Bricker, S.B. 2023. Quantification and valuation of the potential of shellfish ecosystem services in mitigating coastal eutrophication. Estuarine, Coastal and Shelf Science, 293, 108469. https://doi.org/10.1016/j.ecss.2023.108469

Cytiva. 2022. The role of water filtration in chemistry and ecological parameter research. https://www.cytivalifesciences.com/en/us/insights/filtration-in-water-chemistry-water-quality-research (accessed 23 November 2025).

Dey, K.G. 2023. The Asian date mussel (*Arcuatula senhousia*) in the UK: A threat to ecological communities and blue economies? PhD thesis, University of Portsmouth, 286 pp.

Dias, J.P., Fotedar, S., Snow, M. 2014. Characterisation of mussel (*Mytilus* sp.) populations in Western Australia end evaluation of potential genetic impacts of mussel spat translocation from interstate. Marine and Freshwater Research, 65(6), 486-496. https://doi.org/10.1071/MF13179

Douda, K., Čadková, Z. 2017. Water clearance efficiency indicates potential filter-feeding interactions between invasive *Sinanodonta woodiana* and native freshwater mussels. Biological Invasions, 20, 1093-1098. https://doi.org/10.1007/s10530-017-1615-x

Edgar, G.J. 2008. *Mytilus galloprovincialis.* Reef species of the world. https://reeflifesurvey.com/species/mytilus-galloprovincialis/ (accessed 22 October 2026).

Elliott, M., Mander, L., Mazik, K., Simenstad, C., Valesini, F., Whitfield, A., Wolanski, E. 2016. Ecoengineering with ecohydrology: Successes and failures in estuarine restoration. Estuarine, Coastal and Shelf Science, 176, 12-35. https://doi.org/10.1016/j.ecss.2016.04.003

Fernández-Reiriz, M.J., Irisarri, J., Labarta, U. 2015. Feeding behaviour and differential absorption of nutrients in mussel *Mytilus galloprovincialis*: Responses to three microalgae diets. Aquaculture, 446, 42-47. https://doi.org/10.1016/j.aquaculture.2015.04.025

Galimany, E., Ramon, M., Ibarrola, I. 2011. Feeding behavior of the mussel *Mytilus galloprovincialis* (L.) in a Mediterranean estuary: A field study. Aquaculture, 314(1-4), 236-243. https://doi.org/10.1016/j.aquaculture.2011.01.035

Galimany, E., Rose, J.M., Dixon, M.S., Alix, R., Li, Y., Wikfors, G.H. 2018. Design and use of an apparatus for quantifying bivalve suspension feeding at sea. JoVE, 136, 58213. https://doi.org/10.3791/58213

Gardner, J.P.A. 2002. Effects of seston variability on the clearance rate and absorption efficiency of the mussels *Aulacomya maoriana*, *Mytilus galloprovincialis* and *Perna canaliculus* from New Zealand. Journal of Experimental Marine Biology and Ecology, 268(1), 83-101. https://doi.org/10.1016/S0022-0981(01)00378-1

Gardner, J.P.A., Oyarzún, P.A., Toro, J.E., Wenne, R., Zbawicka, M. 2021. Phylogeography of southern hemisphere blue mussels of the genus *Mytilus*: Evolution, biosecurity, aquaculture and food labelling. *In* Oceanography and Marine Biology: An Annual Review, Volume 59 (eds. S.J. Hawkins, A.J. Lemasson, A.L. Allcock, A.E. Bates, M. Byrne, A.J. Evans, L.B. Firth *et al*.). CRC Press. pp. 139-228.

Gillies, C.L., McLeod, I.M., Alleway, H.K., Cook, P., Crawford, C., Creighton, C., Biggles, B., *et al.* 2018. Australian shellfish ecosystems: Past distribution, current status and future direction. PLOS ONE, 13(2), e0190914. https://doi.org/10.1371/journal.pone.0190914

Government of Western Australia. 2022. Water quality snapshot: Bindjareb Djilba (Peel-Harvey Estuary) 2021-2022. https://www.wa.gov.au/government/publications/water-quality-snapshot-bindjareb-djilba-peel-harvey-estuary-2021-22 (accessed 14 October 2026).

Hamza, H., Mammeria, A.B., Bain, A., De Wit, R., Klein, J. 2022. First record of the invasive Asian date mussel *Arcuatula senhousia* (Benson, 1842) in El Mellah Lagoon (Southern coast of Algerian Basin, Western Mediterranean). BioInvasions Records, 11(3), 686-699. https://doi.org/10.3391/bir.2022.11.3.11

Iglesias, J.I.P., Navarro, E., Alvarez Jorna, P., Armentia, I. 1992. Feeding, particle selection and absorption in cockles *Cerastoderma edule* (L.) exposed to variable conditions of food concentration and quality. Journal of Experimental Marine Biology and Ecology, 162(2), 177-198. https://doi.org/10.1016/0022-0981(92)90200-T

Iglesias, J.I.P., Urrutia, M.B., Navarro, E., Ibarrola, I. 1998. Measuring feeding and absorption in suspension-feeding bivalves: an appraisal of the biodeposition method. Journal of Experimental Marine Biology and Ecology, 219(1-2), 71-86. https://doi.org/10.1016/S0022-0981(97)00175-5

Inoue, T., Yamamuro, M. 2000. Respiration and ingestion rates of the filter-feeding bivalve *Musculista senhousia*: implications for water-quality control. Journal of Marine Systems, 26(2), 183-192. https://doi.org/10.1016/S0924-7963(00)00053-1

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., *et al.* 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science, 293(5530), 629-637. https://doi.org/10.1126/science.1059199

Johnston, D., Chandrapavan, A., Wise, B., Caputi, N. 2014. Fisheries Research Report No. 258: Assessment of blue swimmer crab recruitment and breeding stock levels in the Peel-Harvey Estuary and status of the Mandurah to Bunbury Developing Crab Fishery. Department of Fisheries, Western Australia, 142 pp. https://doi.org/10.13140/RG.2.1.2130.3765

Katsanevakis, S., Wallentinus, I., Zenetos, A., Leppäkoski, E., Çinar, M.E., Oztürk, B., Grabowski, M., *et al.* 2014. Impacts of invasive alien marine species on ecosystem services and biodiversity: A pan-European review. Aquatic Invasions, 9(4), 391-423. https://doi.org/10.3391/AI.2014.9.4.01

Kellogg, M.L., Cornwell, J.C., Owens, M.S., Paynter, K.T. 2013. Denitrification and nutrient assimilation on a restored oyster reef. Marine Ecology Progress Series, 480, 1-19. https://doi.org/10.3354/meps10331

Kennish, M.J. 2002. Environmental threats and environmental future of estuaries. Environmental Conservation, 29(1), 78-107. https://doi.org/10.1017/S0376892902000061

Liang, Z.L., Kim, Y.H., Zhang, Z.F., Lim, S.M., Kang, K.H. 2009. Water temperature and salinity tolerance of embryos and spat of the mussel, *Musculista senhousia*. The Korean Journal of Malacology, 25(3), 179-187.

Liu, C., Deng, L., Huang, H., Zeng, R., Xu, Y., Ai, Y., Zhang, J. 2026. Phased ecological responses and effectiveness assessment of subtidal oyster reef restoration: a case study from Dashentang, Bohai Bay. Frontiers in Marine Science, 13, 1954927. https://doi.org/10.3389/fmars.2026.1954927

McDonald, J.I., Wells, F.E. 2010. The apparent demise of the Asian date mussel *Musculista senhousia* in Western Australia: Or using acts of god as an eradication tool. Biological Invasions, 12(4), 715-719. https://doi.org/10.1007/s10530-009-9478-4

Mistri, M. 2002. Ecological characteristics of the invasive Asian date mussel, *Musculista senhousia*, in the Sacca Di Goro (Adriatic Sea, Italy). Estuaries, 25, 431-440. https://doi.org/10.1007/BF02695985

Mitchell, I.A. 2001. Relationship between water quality parameters (nutrients, seston, chlorophyll *a*), hydrodynamics and oyster growth in three major Pacific oyster (*Crassostrea gigas*) growing areas in Southern Tasmania (Australia). PhD thesis, University of Tasmania, 223 pp.

Napolitano, E., Carillo, A., Iacono, R., Struglia, M.V., dell'Aquila, A., Palma, M., Marullo, S., *et al.* 2025. Unprecedented Mediterranean Sea warming in 2024: Analysis of the driving mechanisms. Frontiers in Marine Science, 12, 1668204. https://doi.org/10.3389/fmars.2025.1668204

Newell, R.I.E., Fisher, T.R., Holyoke, R.R., Cornwell, J.C. 2005. Influence of eastern oysters on nitrogen and phosphorus regeneration in Chesapeake Bay, USA. *In* The comparative roles of suspension feeders in ecosystems (eds. R. Dame, S. Olenin). NATO Science Series IV: Earth and Environmental Series, vol. 47. Springer, Dordrecht. pp. 97-120. https://doi.org/10.1007/1-4020-3030-4_6

Oyarzún, P.A., Toro, J.E., Nuñez, J.J., Ruiz-Tagle, G., Gardner, J.P.A. 2024. The Mediterranean Mussel, *Mytilus galloprovincialis* (Mollusca: Bivalvia) in Chile: Distribution and genetic structure of a recently introduced invasive marine species. Animals, 14(6), 823. https://doi.org/10.3390/ani14060823

Petersen, J.K., Bougrier, S., Smaal, A.C., Garen, P., Robert, S., Larsen, J.E.N., Brummelhuis, E. 2004. Intercalibration of mussel *Mytilus edulis* clearance rate measurements. Marine Ecology Progress Series, 267, 187-194. https://doi.org/10.3354/meps267187

Petersen, J.K., Holmer, M., Termansen, M., Hasler, B. 2019. Nutrient extraction through bivalves. *In* Goods and services of marine bivalves (eds. A.C. Smaal, J.G. Ferreira, J. Grant, J.K. Petersen, Ø. Strand). Springer Cham. pp. 179-208. https://doi.org/10.1007/978-3-319-96776-9_10

Prestes, J.G., Pedroso, C.R., de Siqueira Pereira, H., Miiler, N.O.R., Braga, R.R., Vitule, J.R.S. 2026. Filtration, ingestion, and food selectivity in the freshwater bivalves *Diplodon parodizi* (native) and *Corbicula fluminea* (invasive). Hydrobiologia, 853, 2889-2907. https://doi.org/10.1007/s10750-025-06062-2

Riisgard, H.U., Larsen, P.S. 2025. Effect of temperature on filtration in the Blue Mussel, *Mytilus edulis*—Our present understanding. Journal of Marine Science and Engineering, 13(11), 2033. https://doi.org/10.3390/jmse13112033

Rose, J.M., Bricker, S.B., Tedesco, M.A., Wikfors, G.H. 2014. A role for shellfish aquaculture in coastal nitrogen management. Environmental Science and Technology, 48(5), 2519-2525. https://doi.org/10.1021/es4041336

Seuront, L., Nicastro, K.R., Zardi, G.I., Goberville, E. 2019. Decreased thermal tolerance under recurrent heat stress conditions explains summer mass mortality of the blue mussel *Mytilus edulis*. Scientific Reports, 9, 17498. https://doi.org/10.1038/s41598-019-53580-w

Shin, P.K.S., Gao, Q., Cheung, S.G. 2011. Nutrient assimilation by organisms on artificial reefs in a fish culture (Example of Hong Kong). *In* Recent advances in fish farms (eds. F. Aral, Z. Dogu). IntechOpen. pp. 41-60. https://doi.org/10.5772/27348

Slack-Smith, S.M., Brearley, A. 1987. *Musculista senhousia* (Benson, 1842); A mussel recently introduced into the Swan River Estuary, Western Australia (Mollusca, Mytilidae). Records of the Western Australian Museum, 13(2), 225-230.

Smith, V.H. 2003. Eutrophication of freshwater and coastal marine ecosystems: A global problem. Environmental Science and Pollution Research, 10(2), 126-139. https://doi.org/10.1065/espr2002.12.142

Sousa, R., Gutierrez, J.L., Aldridge, D.C. 2009. Non-indigenous invasive bivalves as ecosystem engineers. Biological Invasions, 11, 2367-2385. https://doi.org/10.1007/s10530-009-9422-7

Tsirintanis, K., Azzurro, E., Crocetta, F., Dimiza, M., Froglia, C., Gerovasileiou, V., Langeneck, J., *et al.* 2022. Bioinvasion impacts on biodiversity, ecosystem services, and human health in the Mediterranean Sea. Aquatic Invasions, 17(3), 308-352. https://doi.org/10.3391/ai.2022.17.3.01

Urrutia, M.B., Iglesias, J.I.P., Navarro, E., Prou, J. 1996. Feeding and absorption in *Cerastoderma edule* under environmental conditions in the Bay of Marennes-Oléron (Western France). Journal of the Marine Biological Association of the United Kingdom, 76(2), 431-450. https://doi.org/10.1017/S0025315400030654

Velasco, L.A., Navarro, J.M. 2002. Feeding physiology of infaunal (*Mulinia edulis*) and epifaunal (*Mytilus chilensis*) bivalves under a wide range of concentrations and qualities of seston. Marine Ecology Progress Series, 240, 143-155. https://doi.org/10.3354/meps240143

von Schuckmann, K., Moreira, L., Cancet, M., Gues, F., Autret, E., Baker, J., Bricaud, C., *et al.* 2024. The state of the global ocean. 8th Edition of the Copernicus Ocean State Report (OSR8). Copernicus Publications. pp. 1-30. https://doi.org/10.5194/sp-4-osr8-1-2024

Ward, J.E., Shumway, S.E. 2004. Separating the grain from the chaff: Particle selection in suspension- and deposit-feeding bivalves. Journal of Experimental Marine Biology and Ecology, 300(1-2), 83-130. https://doi.org/10.1016/j.jembe.2004.03.002

Watson, G.J., Dyos, J., Barfield, P., Stebbing, P., Dey, K.G. 2021. Evidence for self-sustaining populations of *Arcuatula senhousia* in the UK and a review of this species' potential impacts within Europe. Scientific Reports, 11, 9678. https://doi.org/10.1038/s41598-021-86876-x

Wildsmith, M.D., Rose, T.H., Potter, I.C., Warwick, R.M., Clarke, K.R. 2011. Benthic macroinvertebrates as indicators of environmental deterioration in a large microtidal estuary. Marine Pollution Bulletin, 62(3), 525-538. https://doi.org/10.1016/j.marpolbul.2010.11.031

Zhang, Y., Song, C., Zhou, Z., Cao, X., Zhou, Y. 2019. Coupling between nitrification and denitrification as well as its effect on phosphorus release in sediments of Chinese shallow lakes. Water, 11(9), 1809. https://doi.org/10.3390/w11091809