The introduced ribbed mussel (*Geukensia demissa*) in Estero de Punta Banda, Mexico: interactions with the native cord grass, *Spartina foliosa*

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Abstract

Introduced populations of *Guekensia demissa* occur on the west coast of North America. They have been reported in San Francisco Bay, four southern California wetlands, and in Estero de Punta Banda (EPB), Baja California Norte, Mexico. We randomly sampled benthic invertebrates in four habitat types within EPB: marsh, channel, mudflat and pan. *Geukensia demissa* was the most abundant bivalve in the wetland at EPB. It was significantly associated with the native cordgrass, *Spartina foliosa*, and occurred at higher average densities in vegetated marsh sites ($24/m^2$) and *Spartina*-dominated tidal channels ($35/m^2$), compared to mudflat ($0/m^2$), and pan ($0/m^2$) sites. We estimated that the total biomass of this invader was over four times that of the next most abundant bivalve, *Tagelus* spp., in EPB. We examined *G. demissa* for parasites and found that only a few native parasites colonized this introduced host at very low prevalences and intensities. We performed bird surveys to determine the habitat overlap and potential impact of this mussel on the EPB population of light-footed clapper rails (*Rallus longirostrus levipes*), an endangered species in the United States. The high abundance of *G. demissa* in EPB, its presence in clapper rail habitat, and its known effects on salt marsh habitat in it's native range, warrant further investigations of the impact of this invader in EPB and elsewhere.

Introduction

The ribbed mussel, *Geukensia demissa*, is native to the Atlantic Coast of North America where it ranges from the Gulf of Saint Lawrence, Canada to northeastern Florida, USA (Abbott 1974). It was inadvertently introduced to San Francisco Bay, California in the 1800s, presumably along with eastern oysters (*Crassostrea virginica*) transported for aquaculture (Carlton 1979, 1992; Cohen and Carlton 1995). Populations were later discovered in four embayments in Southern California, including Alamitos, Anaheim, and Newport Bays, and Bolsa Chica Lagoon (Carlton 1979, 1992; Cohen and Carlton 1995). Regional introductions within California were likely due to a combination of ballast water and shellfish movements (Carlton 1992). The ribbed mussel has not been reported in the published literature from locations south of Orange County, California, including relatively extensive and well-studied estuarine habitats in San Diego County

(Zedler et al. 1992; Levin et al. 1998). Also, in recent surveys of benthic invertebrates in the Estero de Punta Banda, Mexico (EPB), no *G. demissa* were reported (Villareal-Chavez 1991; Sinicrope Talley and Ibarra-Obando 2000), albeit, in both studies, marsh habitat, where *G. demissa* occurs in greatest densities, may not have been surveyed. However, biologists from the Universidad Autonoma de Baja California (UABC) are aware that *G. demissa* occurs at EPB. Marcos Miranda-Aguilar identified the species in the early 1980s (Guillermo Viareal-Chavez, UABC, personal communication). In addition, Fernando Garcia-Pamanes (personal communication) and colleagues collected a specimen ca. 1992.

We report on the distribution, abundance, and biomass of the introduced ribbed mussel, *G. demissa*, at EPB. We also examine the association between the introduced mussel and native cordgrass (*Spartina foliosa*), assess the degree of parasitism of the introduced mussel, and discuss potential impacts of this invasion.

Materials and methods

The Estero de Punta Banda (EPB) is a tidal wetland located at 31°45′ N, 116°37′ W, on the Pacific Coast of Baja California Norte, Mexico (Figure 1). EPB is approximately 10 by 1 km in dimension and possesses several habitat types: tidal channels, subtidal lagoon, intertidal pans, flats, and salt marsh. This coastal area has a Mediterranean climate with long, hot, dry summers and cool winters. Winter rainfall is unpredictable with mean annual precipitation usually around 200 mm and 500 mm in sporadic wet years (Ibarra-Obando and Poumian-Tapia 1991). There is no continual fresh water input, and evaporation exceeds precipitation in summer and fall (Pritchard et al. 1978).

We conducted a detailed sampling of the benthic invertebrates of EPB in October and November 2002. Different habitat types were digitized on a georectified 1 m resolution satellite image of EPB taken on 13 April 2001 (Figure 1). Twenty-three coordinates representing five marsh, seven channel, seven mudflat, and four pan sites were randomly selected using ArcView 3.2. At each site, we laid out six parallel transects spaced 2 m apart. We placed adjacent 10×50 cm quadrats lengthwise along each transect, and recorded the presence of epifaunal taxa in each quadrat. From these, we randomly selected up to 20 quadrats and collected all *G. demissa* in each, measuring the length, height, and width of each mussel using calipers (to 0.1 mm). We took a sub-sample of mussels from each site for parasitological examination (total = 78 mussels). We deposited voucher *G. demissa* at the Santa Barbara Museum of Natural History.

To examine the association between *G. demissa* and the native cordgrass, *S. foliosa*, at each site,
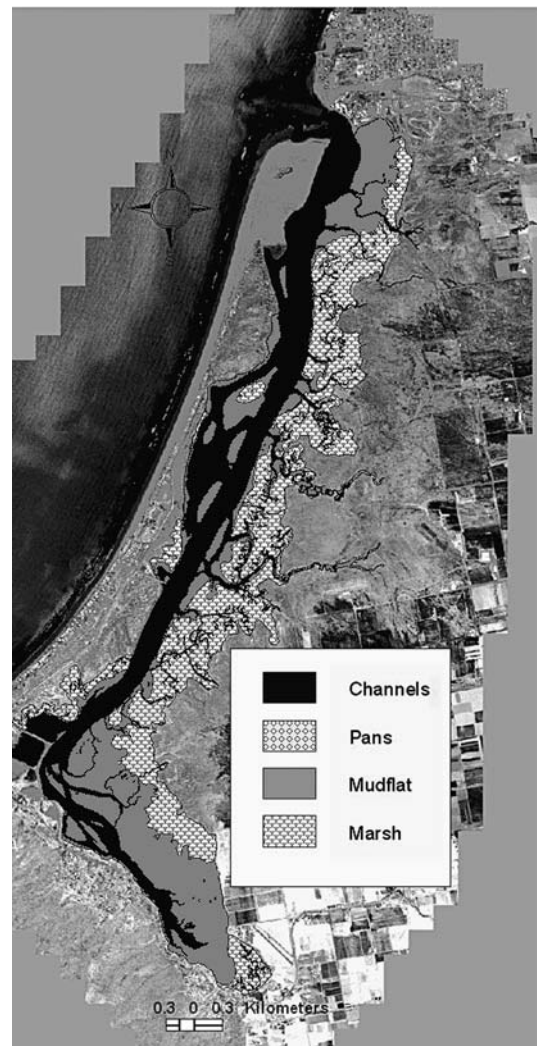

Figure 1. Habitat map of Estero de Punta Banda, Baja California, Mexico, produced from an April 1991 satellite image.

we also conducted a survey of the vegetation. We used point-contact measurements every 10 cm along three 10 m transects that extended across our site. From this, we determined the percent coverage of native cordgrass at each site. For a more refined comparison, we also examined the association between the introduced mussel and the native cordgrass at one focal site. For this, we divided the 10×10 m^2 site into a 100 1 m^2 grid and determined the presence or absence of mussels and cordgrass in each square. We then randomly selected 60 of these squares, placed a 10×10 cm^2 quadrat at the lower right corner of each, and counted individual mussels and cordgrass stems within this quadrat.

We also examined the association between *G. demissa* and *S. foliosa* density vs percent sand and percentage of organic content in the sediment. At each site, and at every other randomly selected quadrat, we collected sediment samples using 6.5 cm long $\times$ 2.5 cm diameter cores. We took 10 sediment samples per site, which were kept on ice and then frozen for future analysis. In the laboratory, we determined percent sand and percent organic content. Percent sand was determined by sieving sediments through 63 μm mesh sieve, and percent organic content was determined by combusting samples at 475 °C for 12 h.

We estimated the total number and biomass of *G. demissa* in EPB. The total area of each habitat polygon was calculated using ArcView 3.2. We then multiplied the density of mussels in each habitat type (as obtained above) by the summed area of each habitat type to generate an estimate of total mussel abundance. To estimate biomass of mussels in EPB, we first determined the relationship between shell volume (length $\times$ width $\times$ height) and shell and soft tissue mass, using linear regression analyses on two samples of mussels. We used these relationships to convert the size-frequency (volume) distribution of mussels to a mass-frequency distribution for each habitat. Then, using mean mass estimates for each habitat, we estimated the biomass of mussels in the entire wetland.

To determine whether mussels have the potential to impact clapper rails in EPB, we assessed whether clapper rails occurred in the same habitat as mussels (i.e., *Spartina* marsh). We performed standardized bird surveys at each of our 23 randomly selected sites. The bird survey area was a 100 m diameter circle around each site. We conducted surveys between 25 June and 2 July 2003. Each site was surveyed four times between dawn and dusk: twice during the lowest tidal range (0–0.7 m) and twice at higher tides (0.75–1.4 m). We used timed 15 min circular walking transects at a 50 m radius from the center of the site to detect birds in the vegetated habitat; no taped calls or other means of eliciting territorial response were used. We also mapped the location of *Spartina* vegetation within the bird survey area.

For statistical analyses, we used non-parametric tests, as the data were not normally distributed (Shapiro–Wilks, $P < 0.05$ for density and size data). We estimated 95% confidence intervals for habitat means of density and size by bootstrapping the data with 10,000 iterations (Efron's percentile method (Manly 1997)). Bootstrapping was preferable to parametric estimation since the latter gives impossible lower confidence limits (i.e., less than zero). To examine the association between *G. demissa* and *S. foliosa*, we used the Spearman rank order correlation coefficient (r_s). The Kruskal–Wallis test was used to compare *G. demissa* density in the four habitats we sampled, and to compare *G. demissa* density in sites with and without *S. foliosa*. We used χ^2 to compare the association between mussel presence and cordgrass presence within blocks at the single focal site.

Results

Mussel distribution, densities, size and association with native cordgrass

Geukensia demissa was common at Estero de Punta Banda and generally associated with native cordgrass (*Spartina foliosa*). Sites where cordgrass was present had an average density of 32 mussels/m^2 compared to 1 mussel/m^2 at sites where cordgrass was not present in our transects ($\chi^2 = 7.6$, $P = 0.006$, df $= 1$, $n = 23$). There was no association between *G. demissa* or *S. foliosa* density and sediment grain size ($r_s = -0.26$, $P > 0.05$, $n = 23$ and $r_s = -0.36$, $P > 0.05$, $n = 23$, respectively). There was however a positive association between both *G. demissa* and *S. foliosa*

density and organic composition of sediment ($r_s = 0.73$, $P < 0.0001$, $n = 23$ and $r_s = 0.58$, $P < 0.005$, $n = 23$, respectively).

Within our focal site, there was a significant association between mussel and cordgrass presence ($\chi^2 = 71.9$, $P < 0.0001$, df = 1, $n = 100$). At our focal site, mussel density was positively correlated with cordgrass density (Figure 2, $r_s = 0.82$, $P = 0.0001$, $n = 60$). There was significant variation in mussel density among habitats ($\chi^2 = 11.5$, $P = 0.009$, df = 3, $n = 23$). Vegetated channel and marsh sites had high densities of mussels and no mussels occurred at mudflat and pan sites (Table 1). At four of the five vegetated marsh sites, cordgrass was the dominant ground-cover. Interestingly, there were no mussels present at the one marsh site where cordgrass was absent, and where the vegetation was dominated by *Salicornia bigelovii*. The mean length of mussels was significantly greater at channel sites (63.3 mm, $n = 47$) than at marsh sites (58.0 mm, $n = 60$) (Figure 3; $\chi^2 = 4.3$, $P = 0.037$, df = 1).

Mussel abundance and biomass in EPB

The total vegetated marsh area of EPB was 3.56 km^2, with channels representing a negligible area (0.15 km^2) in comparison (Figure 1; Table 1). Mean mussel density in marsh was 24/m^2 and there were an estimated 90.4×10^6 total introduced mussels at EPB (see Table 1). In comparison, the most common native bivalves (albeit in different habitats – channels, pans, and mudflats) were the native jackknife clams, *Tagelus californianus*, *T. affinis* and *T. subteres*. Using random coring and the same statistical method, the total number of jackknife clams (pooling *Tagelus* species) at EPB was 69.5×10^6 (15.3×10^6–150.4×10^6) (R.F. Hechinger et al., in preparation).

For *G. demissa* the relationship between shell mass and shell volume was: sm = 0.00017 × (sv) −0.28 ($R^2 = 0.98$, $P < 0.0001$, $n = 38$), where sm is shell mass (g) and sv is shell volume (mm^3). The equation for the relationship between wet soft tissue and shell volume was: tm = 0.000086 × (sv) + 1.4 ($R^2 = 0.88$, $P < 0.0001$, $n = 49$), where tm is tissue mass (g) and sv is shell volume (mm^3). The total estimated biomass of *G. demissa* at EPB was 369.6 metric tons wet soft-tissue weight and 837.6 metric tons total
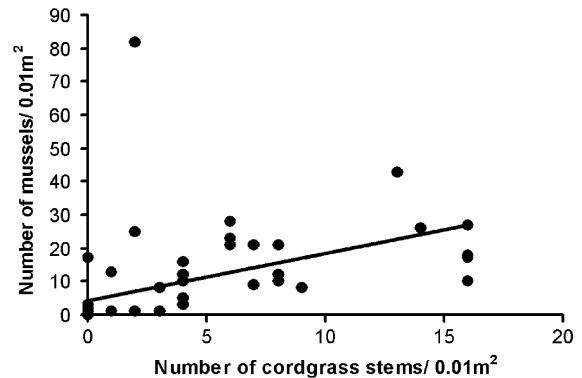

Figure 2. Scatter plot and trend line of native cordgrass, *Spartina foliosa*, cover and introduced ribbed mussel, *Geukensia demissa*, density within 10 × 10 cm^2 quadrats ($r_s = 0.82$, $P = 0.0001$, $n = 60$) at a site in Estero de Punta Banda, Baja California, Mexico.

weight (Table 1). For comparison, we estimated the total biomass of the most abundant native bivalves, *Tagelus* spp., to be 81.9 (28.8 – 152.7) metric tons wet soft-tissue weight and 183.3 (61.7 – 346.9) metric tons total weight.

Mussel parasites

Three species of parasites infected *G. demissa* at EPB. Many mussels harbored an unidentified cyclopoid copepod in the mantle cavity. Although most mussels we examined had at least one copepod, we cannot determine their prevalence in EPB, as we suspect that transmission occurred in aquaria used to hold our animals. Additionally, 2% and 8% of mussels were infected with the native trematodes, *Acanthoparyphium spinulosum* and *Renicola* sp., respectively. The mean number of metacercarial cysts (±1 SE) per infected mussel was 2 (±0) for *A. spinulosum* and 1.6 (±0.6) for the *Renicola* sp. In comparison, we found eight parasite species in the 83 native jackknife clams we dissected. All jackknife clams were infected with *A. spinulosum* and 60% were infected with the *Renicola* sp. The mean number of metacercarial cysts per infected jackknife clam was 355 (±81) for *A. spinulosum* and 11 (±3) for *Renicola* sp.

Habitat overlap with clapper rails

We frequently detected light-footed clapper rails in *Spartina* marsh during our general bird sur-

Table 1. Density, abundance, and biomass of *Geukensia demissa* in Estero de Punta Banda.

|	Average Density (/m²) (95% c.i.)	Average individual mass (g) Soft tissue (95% c.i.)	Average individual mass (g) Total (95% c.i.)	Habitat area (km²)	Total numbers (millions of individuals) (95% c.i.)	Total soft tissue mass (metric tons) (95% c.i.)	Total biomass (metric tons) (95% c.i.)
Channel	35.4 (1.2–98.3)	3.9 (3.4–4.3)	10.3 (8.8–11.8)	0.15	5.3 (0.3–14.4)	20.7 (2.2–40.5)	54.9 (5.8–94.9)
Flat	0	0	0	3.15	0	0	0
Marsh	23.9 (11.6–33.2)	4.1 (3.6–4.7)	9.2 (7.7–10.9)	3.56	85.1 (45.7–115.0)	348.9 (239.2–470.3)	782.6 (629.4–897.9)
Pan	0	0	0	0.01	0	0	0
			Sum total EPB	6.87	90.4 (45.9–129.3)	369.6 (241.4–510.8)	837.6 (532.4–1182.1)
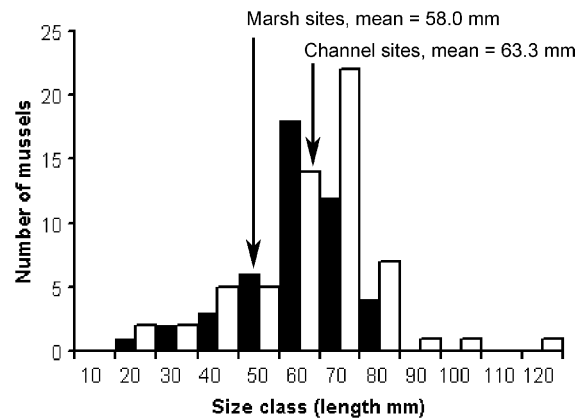
Figure 3. Size frequency distribution of the introduced ribbed mussel, *Geukensia demissa* in channel (open bars) and marsh sites (solid bars) in Estero de Punta Banda, Baja California, Mexico. Mean size in channel sites is significantly greater than in marsh sites which may be a result of differences in tidal elevation between the two habitats (see Franz 2001).

veys at EPB. *Spartina* vegetation occurred within the bird survey area at 17 of our 23 sites. We observed territorial clapper rails in 15 of these 17 sites. Although general bird surveys undersample clapper rails, we detected one to three clapper rails at each of these sites, and every rail we observed was in *Spartina* vegetation. Although nest searching was not specifically performed, we found active clapper rail nests at four of these sampling sites; one site contained three incubation nests, and numerous fledging platforms. In total, we observed 27 clapper rails in our survey.

Discussion

The introduced Atlantic ribbed mussel, *G. demissa*, is well established in Estero de Punta Banda, Baja California, Mexico. The biomass of this invader was 4.6 times that of the next most abundant bivalve, *Tagelus* spp. The high abundance and high biomass of *G. demissa* in EPB suggests it is likely impacting this coastal wetland. Additionally, our estimate of *G. demissa* abundance may be conservative considering that ribbed mussels generally occur at highest densities on the lower edge of the marsh (Nielsen and Franz 1995; Franz 1997), areas which were not specifically targeted in our study.

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Geukensia demissa exhibits sufficiently different habitat use compared to native bivalves and probably does not compete directly with native bivalve species for space in EPB. However, it is more likely that *G. demissa* populations compete with native bivalves and other suspension feeders for food because *G. demissa* are capable of filtering large volumes of water. In a small marsh within its native range, the *G. demissa* population filtered a volume of water exceeding the total volume of water in the entire marsh each tidal cycle (Jordan and Valiela 1982). Mussels filtered 1.8 times the particulate nitrogen exported from the marsh and absorbed half of this, excreting the other half, which resulted in biodeposition (Jordan and Valiela 1982). Much of the resulting mussel production entered the food web in the form of gametes (Jordan and Valiela 1982). In its native range, *G. demissa* has been shown to ingest organic particles from a wide variety of sources, including *Spartina* detritus (Kreeger and Newell 2001). We note that a direct comparison of EPB with east coast systems would require an examination of differences in marsh tidal elevation between *S. foliosa* and *S. alterniflora*. Recent multiple stable isotope work in southern California indicates that *S. foliosa* supplies the bulk of the organic matter that sustains wetland fishes via detrital-based food webs (Kwak and Zedler 1997). *Geukensia demissa* may therefore significantly alter the EPB food web.

As is common for introduced species (Torchin et al. 2003), compared to native bivalves, ribbed mussels in EPB do not appear to serve as major hosts for parasites. We found relatively few species of parasites at low prevalences and low numbers per infected host. The potential exception to this is the single species of copepod (for which we lack conclusive data). This lack of parasites could confer an advantage to *G. demissa*. However, we found no reports of metazoan parasites infecting it on the east coast for a comparison. Ford et al. (1995) indicate that *G. demissa* is not known to become infected with the protozoan oyster pathogen *Haplosporidium nelsoni*. Evaluating this hypothesis will require substantially more information on parasites in both native and introduced regions.

The most dramatic impact of *G. demissa* could be its affect on vegetation. The association that we found between the mussel and *S. foliosa* has also been well documented in salt-marshes on the Atlantic coast of North America, where *G. demissa* attaches to the roots of *S. alterniflora* by byssal threads (Bertness 1980, 1984; Fell et al. 1982). Cordgrass production increases growth and reproduction of the mussel, and the presence of the mussel increases production of the cordgrass, which results in increased marsh net primary production and stability (Bertness 1984). If increased stability and deposition result in elevation increases sufficient for recruitment and growth of cordgrass, this could expand marsh habitat onto tidal flats and increase the representation of cordgrass in the wetland (Bertness 1984). Facilitation of cordgrass by *G. demissa* could decrease habitat for other benthic mud-dwelling invertebrates, and many of the birds that tend to forage on tidal flats. However, an increase in cordgrass habitat could favor some species, such as clapper rails.

The most unusual impact of this introduced mussel is that it has the potential to trap and drown young birds foraging in marshes because the posterior margins of the mussel's shell typically protrude above the surface of the mud and can clamp onto the beaks and feet of small birds. This has been documented for endangered California clapper rails (*Rallus longirostris obsoletus*), which commonly feed on *G. demissa* in San Francisco Bay (see de Groot 1927; Carlton 1979; Takekawa 1993; Cohen and Carlton 1995). Here, clamping by *G. demissa* causes toe loss in 75% of adult clapper rails and may kill one or two young rails of each brood (de Groot 1927). At EPB, there is considerable habitat overlap between *G. demissa* and the light-footed clapper rails (*Rallus longirostris levipes*), creating the potential for this to occur.

The widespread occurrence and high abundance of *G. demissa* in Estero de Punta Banda, suggests that the likely effects of this introduced mussel are pronounced. The mussel's ability to facilitate cord grass growth and productivity, filter the water column, and drive biodeposition suggest it is altering the ecology and nutrient cycling in EPB. These issues, as well as the potential impact on clapper rail populations, merit further exploration and evaluation. Should the impact be deemed substantial, consideration

could be given to control. Fishing is one potential method for controlling introduced marine pests (Lafferty and Kuris 1996), and some have suggested that *G. demissa* could be commercially harvested from the Gulf coast of Mexico (Baqueiro et al. 1993). The benefit of reducing the abundance of *G. demissa* in EPB via fishing would have to be weighed against the environmental disturbance of fishing for mussels in the estuary, as well as the potential a growing market demand could encourage the intentional spread of *G. demissa* to other estuaries.

Acknowledgements

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