DEVELOPING FISHERIES AND AQUACULTURE INDUSTRIES FOR PANOEPA ZELANDICA IN NEW ZEALAND

PAUL E. GRIBBEN1*† AND KEVIN G. HEASMAN2
1Institute of Natural & Mathematical Sciences, Massey University, Private Bag 102904, Albany, Auckland 0745, New Zealand; 2Cawthron Institute, 98 Halifax Street East, Private Bag 2, Nelson 7042, New Zealand

ABSTRACT Valuable fisheries and aquaculture industries for the geoduck Panopea generosa in North America, have stimulated interest in developing similar activities for geoduck species in New Zealand. The potential for establishing commercial enterprises for P. zelandica in New Zealand is reviewed. Although small fisheries for this species have existed since the late 1980s, the total annual landings have never exceeded 31.4 t. In 2006, P. zelandica was placed onto the New Zealand Quota Management System, with a total allowable catch of 40.5 t. Despite low capture rates, P. zelandica has several traits—similar to those for Panopea generosa—that may make it amenable for fisheries and aquaculture development. In terms of fisheries, it is typically found in benign coastal embayments and harbors, and it appears most dense in shallow subtidal waters (<15 m). Developing a sustainable fishery, however, will be contingent on a full understanding of the reproductive biology and ecology of P. zelandica; its unusual reproductive strategy (functional protandry) may result in a fishery that specifically targets females, which dominate the larger/older size classes in wild populations. With respect to aquaculture, adults can be readily spawned and larvae grown through to settlement. The largest impediment to fisheries development is a lack of information on the location of actual populations, and the low densities and natural mortality rates of known populations. The development of aquaculture will be hindered primarily by the ability to cultivate postsettlement individuals. Under current legislation, cultured marine organisms must be grown on structures, as a result of seabed ownership issues, although pond culture may be an alternative method for cultivating hatchery-reared stock. Despite these issues, P. zelandica shows potential for commercial exploitation, and it is a primary species identified to meet the New Zealand aquaculture sector’s ambitious target of NZ$1 billion by 2025.

KEY WORDS: aquaculture, fisheries, geoduck, Panopea zelandica, New Zealand

INTRODUCTION

Successful development of fisheries and aquaculture industries in North America for the Pacific geoduck Panopea generosa Gould, 1850, has prompted increasing interest in developing commercial industries for other species of geoduck found throughout western North, Central, and South America, and the Asia–Pacific region (Gribben et al. 2004a, Aragon-Noriega et al. 2012, Perez-Valencia & Aragon-Noriega 2013). Indeed, Panopea abbreviata Valenciennes, 1839, has been harvested in Argentina since 1999, and Panopea spp. have been harvested from the coast of Mexico since 2002 (Morsán & Ciocco 2004, Aragon-Noriega et al. 2012, Perez-Valencia & Aragon-Noriega 2013). The New Zealand aquaculture sector has set an ambitious target of NZ$1 billion by 2025 (Aquaculture New Zealand 2005). Key to meeting this goal is the development of new species for commercial exploitation, and the New Zealand geoduck Panopea zelandica (Quoy and Gaimard, 1835), is one of two primary species (the other being the flat oyster Ostrea chilensis Philippi, 1844), which have been identified by industry as potentially suitable for development. A second geoduck species Panopea smithae Powell, 1950, also endemic to New Zealand, is thought to occur in deeper water (110–130 m) (Willan et al. 2010), but known populations are very rare and it is not being considered for aquaculture.

In New Zealand, a fishery for Panopea zelandica exists in Golden Bay, Nelson (Fig. 1). An initial harvest of 95.2 t was made in this region in 1989/1990. Yields dropped to 29.3 t and 31.4 t in 1990/1991 and 1991/1992, respectively (Ministry for Primary Industries 2013) and the fishery was subsequently closed because of a lack of information about the size of the populations and concerns about the sustainability and impacts of the fishery. In 2003/2004 and 2004/2005, a total of 1.4 t and 2.9 t were harvested under a special permit. In 2006, P. zelandica was placed onto the New Zealand Quota Management System, with a total allowable catch of 40.5 t. Harvesting based on the Quota Management System started in 2007/2008 with 0.3 t, and increased to 10.8 t in 2011/2012. Currently, the fishery is divided into nine quota management areas (QMA), although geoducks are currently only fished in three QMA, with 99% coming from Golden Bay (P. zelandica QMA zone 7, PZL7).

The purpose of this study was to review the potential for establishing various types of fisheries and aquaculture industries for Panopea zelandica, and to describe the ecology of this species, with a focus on identifying information gaps necessary to fill prior to developing a sustainable industry. In addition, nonecological impediments (e.g., policy and land use) to establishing commercial geoduck enterprises in New Zealand are discussed.

FISHERY AND AQUACULTURE OPTIONS AND IMPEDIMENTS

Capture Fisheries

A preliminary assessment of the feasibility of establishing a fishery requires an understanding of the stock structure (including distribution and abundance), the individual components of productivity (i.e., recruitment processes, individual
growth, and mortality rates) (Haddon 2001) and the potential effect of harvesting on population dynamics. The fundamental problem facing the establishment of a large-scale geoduck fishery in New Zealand is that there are only a few known populations of *Panopea zelandica* (Fig. 1). These known populations, however, occur at discrete areas along the coast of New Zealand (Fig. 1), making it possible that many other, as yet unexplored, populations exist.

Morton and Miller (1968) originally described the habitat of *Panopea zelandica* as “ocean beach,” but the basis of this assumption is unclear. Attempts to find populations of *P. zelandica* off ocean beaches in northern New Zealand, where shells are known to occur, proved unsuccessful (Gribben unpubl. data). These shells could have been washed in from other areas or they may actually be those of the “deeper water” *Panopea smithiae*, which is very similar in appearance to *P. zelandica*. Current data on known *P. zelandica* populations suggest it is more common in sheltered bays and harbors (Gribben et al. 2004a), consistent with *in situ* accounts of other populations in Patterson Inlet, Stewart Island, and throughout Golden Bay, Nelson (Powell 1976, Breen et al. 1991). Thus, efforts to find harvestable geoduck populations should focus on those habitats.

On a local scale, similar to *Panopea generosa* (Goodwin & Pease 1991, Beattie 1992, Campbell et al. 1996), *Panopea zelandica* exhibits gradients in abundance related to both sediment type and water depth. At two sites, Kennedy Bay and Shelly Bay, *P. zelandica* was more abundant in fine sediments than in coarser or more silty sediments (Gribben et al. 2004a). Unlike *P. generosa*, *P. zelandica* appears restricted to subtidal habitats generally greater than 5 m in water depth. This information should also help refine efforts to locate new populations of *P. zelandica*.

From a fishing perspective, the benign nature of these habitats makes harvesting *Panopea zelandica* relatively straightforward, yet the low-density estimates (<0.5 geoducks/m²) and small area occupied by *P. zelandica* in Shelly Bay, Wellington Harbour, and Kennedy Bay (Gribben et al. 2004a) indicate these populations are not suitable for harvesting. As mentioned previously, those populations in Golden Bay are currently being harvested.

More broadly, estimates of population parameters such as growth, mortality, and recruitment, which have a large influence on productivity, raise serious concerns about harvesting *Panopea zelandica* sustainably. Indeed, the low levels of actual (i.e., for *Panopea generosa*) or recommended (i.e., for *P. zelandica*) exploitation reflect the low levels of estimated natural mortality (0.02–0.07) (e.g., Breen & Shields 1983, Sloan & Robinson 1984, Noakes & Campbell 1992, Gribben & Creese 2005). Yield models for *P. zelandica* (Breen 1994) and *P. generosa* (Bradbury & Tagart 2000) were most sensitive to estimates of mortality. Fishery harvests for *P. generosa* in British Columbia are based on a constant catch of 0.5%–2%, which itself is pegged to estimates of virgin biomass (Orensanz et al. 2000). However, in Washington state, a constant harvest rate of 2.7% of present biomass has been introduced, which is predicted to preserve 40% of unfished spawning biomass (Orensanz et al. 2000). Similarly, Mexican management
authorities have established harvest rates of 1% for commercial geoduck beds, aimed at maintaining 50% virgin biomass for 50 y (see Aragon-Noriega et al. [2012] for review). Breen (1994) suggested that sustainable yields for *P. zelandica*, with realistic management constraints, were of the order of 2%–4% of virgin biomass. The higher estimate of sustainable yield for *P. zelandica* compared with *P. generosa* reflects the higher estimated rate of natural mortality for the New Zealand species. In addition, like *P. generosa* (up to 168 y [Bureau et al. 2002]) and *Panopea globosa* Dall, 1898 (up to 34 y [Perez-Valencia & Aragon-Noriega 2013]), *P. zelandica* is extremely long-lived (up to 86 y [Gribben & Creese 2005]), older/larger individuals dominate populations, and recruitment is sporadic. In terms of establishing sustainable fisheries, these life history characteristics make fisheries management for this species more difficult. Yet, despite these population attributes, successful fisheries for *P. generosa* have existed since the 1970s, possibly as a result of setting low harvest rates. Similar low harvesting rates for populations of *P. zelandica* may also support sustainable fisheries, but populations of sufficient size to support fisheries need to be found, and then population parameters for them determined. Like other geoduck species (Shaul & Goodwin 1982, Sloan & Robinson 1984, Vadopalas et al. 2011, Perez-Velencía & Aragon-Noriega 2013), the internal growth rings of *P. zelandica* are laid down annually (Gribben & Creese 2005). Thus, after populations are found, population recruitment, growth, and natural mortality estimates can be easily determined.

Other biological attributes may inhibit sustainable fisheries. The geoduck *Panopea zelandica* is protandric, with almost all geoducks developing first as males and some changing sex to female as they age/grow (Gribben & Creese 2003). Supporting this observation, hatchery-reared *P. zelandica* appear to mature at 18–24 mo and potentially transition to female at year 3 (=200 g; K. G. Heasman unpubl. data). This pattern results in sex ratios dominated by males in the smaller and younger size and age classes but females in the larger and older size and age classes. Divers searching for geoducks generally target the largest siphon holes visible at the surface. Although for *Panopea generosa* there appears to be no correlation between siphon hole diameter and the size of the geoduck (Anderson unpubl.), Gribben (unpubl.) showed that, for *P. zelandica*, there was a strong correlation with small-diameter holes generally containing small geoducks and larger holes yielding larger geoducks (the relationship was more variable for medium-size geoducks). Thus, any fishery that targets larger individuals may inadvertently target and deplete large female clams whose egg production possibly contributes disproportionately to population maintenance. Such biased selection of females coupled with low densities may make *P. zelandica* susceptible to Allee effects (where the fertilization potential of a population is compromised when densities fall below a critical level) (Allee 1931). Harvested marine molluscs that are broadcast spawners (eggs and sperm are spawned into the water column, where fertilization occurs) can be particularly susceptible to Allee effects. Indeed, the Allee effect is a major issue with many declining marine species, including abalone in the western United States (Tegner et al. 1996). Allee effects occur in some harvested species when the density of adults is low and/or the remaining adults are small and produce fewer gametes. Spawned gametes dilute in the water column very quickly, thus the likelihood of fertilization decreases dramatically at low densities and reduced initial gamete concentrations (Pennington 1985, Levitan 1991). Because broadcast spawners have open populations—a population that receives its recruits from the larvae of another population—a fishery that reduces the density of one population may put other populations at risk. In fact, other geoduck species show similar size/age sex ratio skewedness (Anderson unpubl.). Vadopalas (unpubl. data) showed that the sex ratio of young cultured *P. generosa* (<5 y) was dominated by males, but the sex ratio of wild geoducks was equal when all size/ages classes were included. Thus, functional protandry may be a general reproductive strategy for other *Panopea* spp., and Allee effects a general problem for geoduck species. Even if other *Panopea* spp. are dioecious, with females simply maturing at a larger size/older age and dominating the larger size classes, the issue of Allee effects does not change. A full understanding of the reproductive biology and ecology for all *Panopea* spp., not just *P. zelandica*, is a clear impediment to developing sustainable fisheries and should be a primary focus of future research.

Allee effects may not, however, be critically important for *Panopea zelandica* for two reasons. First, because of the economics of diving constraints, geoduck fisheries are generally restricted to less than a 12-m water depth. Given that *P. zelandica* populations can extend down to at least 25 m (P. Gribben pers. obs.), fisheries may only be harvesting a fraction of the population, leaving harvest refugia where individuals may serve as broodstock. In fact, Quinn et al. (1993) suggested that management strategies should include harvest refugia for species that show strong Allee effects. Most studies, however, including those of other geoduck species, have only examined that part of the population considered harvestable (i.e., occurring in less than 20 m of water) although, as noted earlier, most harvesting occurs at depths <12 m) (e.g., Sloan 1985, Bradbury & Tagart 2000). How geoducks living below this depth contribute to harvestable biomass, and whether the biomass of geoducks in deeper water can be considered a refuge from which recruits are supplied to harvested areas have not been investigated. Observing the spatial patterns of geoduck populations is essential for understanding fertilization and recruitment processes (Legendre & Fortin 1989, Thrush et al. 1989, Morrissey et al. 1992).

Second, *Panopea zelandica* has open populations, and larvae are known to have a larval duration of up to 12 days (Gribben & Hay 2003). Thus, coastal populations of geoducks may not be self-recruiting, although large bays such as Golden Bay at the top of South Island, New Zealand, where harvesting is conducted, may entrain larvae long enough for populations to be self-sustaining. Vadopalas et al. (2004, 2012) found few genetic differences temporally within populations and spatially across distinct aggregations of *Panopea generosa*. In fact, they found similar genetic variation between populations at small scales (<100 km) and larger scales (>1,000 km). In contrast, nothing is known about population connectivity for *P. zelandica*. A better understanding of larval dispersal patterns and the population genetics of the New Zealand geoduck are important areas for future research.

**Harvesting Impacts**

Geoducks are harvested by injecting water into the substrata around the geoduck, which liquefies the substrate and frees the...
geoduck from the sediment. This practice is widely used today in Canada, the United States (Orensanz et al. 2000), Mexico (Perez-Valencia & Aragon-Noriea 2013), and New Zealand (P. E. Griibben & K. G. Heasman pers. obs.). Such harvesting can result in the disturbance of the sediment substrate down to a depth of 0.5 m, including epifauna and infauna associated with the sediment. Harvesting also resuspends silt, which may influence habitats downstream. Research on harvested populations of Panopea generosa has shown that, 1 y after removing geoducks from experimental plots, there was no difference in sediment structure when compared with unharvested control plots (e.g., Breen & Shields 1983). In contrast, some change was observed in the dominant taxa of meiofaunal communities (Goodwin 1978). In general, however, little is known about the ecological impacts of harvesting on benthic communities (including the recruitment of geoducks), and further investigation is needed.

Official assessments of the harvesting of geoducks at potential sites in New Zealand are scheduled, and it is unlikely that any commercial aquaculture operation will be permitted in New Zealand before these assessments are completed.

Aquaculture Production

The development of aquaculture industries relies on a regular supply of juveniles and the capacity to culture seed to market size. Spat can be obtained through wild capture, as occurs with the two largest bivalve aquaculture industries in New Zealand, the Greenshell mussel *Perna canaliculus* (Gmelin, 1791) and the Pacific oyster *Crassostrea gigas* (Thunberg, 1793). Hatchery production of larvae and seed is also a viable option because it is highly unlikely that there will be a known source of wild seed supply for Panopea zelandica. Therefore, the development of commercial culture will likely be dependent on hatchery-produced seed.

The culture of hatchery-reared seed, although more expensive than wild capture, offers the opportunity for better management of the supply and greater quality control. Populations of Panopea zelandica appear to spawn between spring and autumn, and ripe individuals collected from the field can be readily spawned using serotonin (0.5 mL 1 × 10^{-3} M) injected directly into the gonads surrounding the visera. Spawning generally occurred within the first 5 min of injection (Gribben et al. 2004b, Gribben et al. 2014). Optimal fertilization can be expected at sperm densities of 10^{7}–10^{8} sperm/μL, at gamete contact times of 5–10 min, and sperm ages of less than 30 min (Gribben et al. 2014). Moreover, the resulting larvae can be easily cultured to settlement in approximately 12 days (Gribben & Hay 2003, K. G. Heasman unpubl. data), consistent with results obtained from studies on other infaunal bivalves (e.g., *Spisula solidissima* [Dillwyn 1817] [Clotteau & Dube 1993], *Cerastoderma edule* [Linnaeus, 1758], [Andre & Lindegarth 1995]). The geoduck Panopea zelandica is a good candidate for hatchery culture because many of the techniques used to rear Panopea generosa in hatcheries are directly transferable. There are similarities in larval development between the two species; however, *P. zelandica* takes significantly less time to reach metamorphosis than *P. generosa* (Goodwin et al. 1979, Beattie & Goodwin 1993).

Postsettlement infaunal bivalve culture usually involves planting seed into intertidal areas (e.g., *Ruditapes philippinarum* [Adams & Reeve, 1850] [Spencer et al. 1992], *Leukoma staminea* [Conrad, 1837] [Aiken 1993]). The bivalve Panopea zelandica appears to occur in habitats and sediments similar to those for Panopea generosa (as mentioned earlier), with one significant difference: *P. zelandica* is restricted to subtidal environments whereas *P. generosa* can be found in waters as shallow as the low intertidal (Goodwin & Pease 1987). Indeed, the culture of *P. generosa* in Washington is mainly intertidal (Beattie & Blake 1999). The intertidal culture of infaunal bivalves is generally preferable to subtidal culture, because of ease of accessibility and harvesting. Experiments are currently underway to determine whether *P. zelandica* can survive in the intertidal zone (K. G. Heasman unpubl. data). Under current legislation, however, there are issues with regard to ownership, involving the culture of marine organisms in the intertidal in New Zealand, currently requiring both resource consent and a Marine Farm License. Unless an organism is grown on or in a structure for the duration of its culture period, rather than aquaculture the operation is considered “reseeding” or “ranching,” which does not give the farmer ownership of the organism. Thus, a quota holder could legally harvest the geoduck as could persons with a cultural (customary) harvesting permit.

Research into various aquaculture methods ranging from suspended culture, culture on and above the seafloor and within tube structures inserted in the seabed are being undertaken by the Cawthron Institute (Nelson, New Zealand) currently. Challenges to refining aquaculture techniques include meeting the regulatory and biological requirements of this species, and ensuring economic sustainability. The economic and legislative viability of reseeding geoduck juveniles onto existing beds is also being investigated.

Several species of infaunal bivalves, especially Venus clams (*Ruditapes largillierii* [Philippi, 1847], are amenable to culture out of the sediment in trays or mesh bags (e.g., Paterson & Nell 1996, Gribben et al. 2002). This method does not appear to be suitable for growing Panopea zelandica because geoducks do not thrive living out of the sediment. Thus, any future grow-out of *P. zelandica* will be restricted to subtidal environments or pond culture. Intertidal pond culture may also be a possibility and offers several advantages over subtidal culture, because ponds are more accessible and stock is more easily maintained and harvested. Pond culture, however, will be restricted by the availability of coastal land, accessibility to seawater, ability to gain resource consent and the potential cost of pumping water to ensure sufficient food is delivered to the geoducks for the duration of the grow-out period. Although subtidal culture is a much cheaper alternative to pond culture, it, too, will be restricted by the availability of appropriate sites. There are several characteristics of sites—for example, Golden Bay and Kennedy Bay (Fig. 1)—which suggest that these areas may be suitable for culturing Panopea zelandica. Both bays have geoducks that occur as shallow as 4 m, and both bays offer large, gently sloping areas of shallow subtidal bottom that may be suitable for the intensive culture of Panopea zelandica. Despite taking 5–7 y to reach market size, the high price fetched by geoducks makes it a potentially lucrative aquaculture prospect. The much smaller *P. zelandica* has lower estimated densities than those for Panopea generosa; thus, factors such as stocking density will be an important consideration when evaluating its economic potential for commercial culture. As a consequence, more research needs to be conducted on maximizing stocking densities without compromising growth rates.
Aquaculture Impacts

Intertidal impacts of aquaculture include the disturbance of seeding, harvesting vehicle traffic, imposed surface structures such as predator netting, and the extraction of seston from the water. Interestingly, intertidal geoduck aquaculture practices in Puget Sound, Washington, can have positive effects on faunal diversity (although results are spatially variable), possibly through the structures (e.g., predator exclusion devices) added to growth settlement juveniles (Brown & Thuesen 2011, McDonald et al. 2015). The deposition of additional organic matter, via pseudofecal and fecal material from geoducks, may also promote diversity by providing an additional food source for benthic invertebrates, although a small-scale, short-term study by Sauchyn et al. (2013) found no effect of geoduck out-planting on sediment organic matter loading. Facilitation of faunal diversity in the vicinity of geoduck beds could have additional effects for higher trophic levels. Indeed, greater abundances of large predatory crabs may be associated with geoduck farms compared with control sites (Brown & Thuesen 2011). Increases in organic load could also enhance sediment anoxia by stimulating the microbial consumption of oxygen and the production of toxic hydrogen sulfide (Jørgensen 1982, Holmer et al. 2003).

The effects of harvesting cultured geoducks are likely to be similar to removing clams in natural fisheries (i.e., changes in sediment chemistry, disturbance, and redistribution of sediments and associated infauna), although Sauchyn et al. (2013) found that many sediment variables (e.g., median grain size, organic matter total nitrogen content) were not affected in the long term by either culture or harvesting activities. Although harvest activities did affect silt and clay fractions of sediments, these features returned to their former state after approximately 120 days (Sauchyn et al. 2013). In addition, VanBlaricom et al. (2015) found few impacts of geoduck aquaculture on infauna in Puget Sound and suggested that naturally induced spatial and temporal variation in infaunal assemblages as a result of natural disturbance is far more significant than changes imposed by harvesting of cultured geoducks. The impacts of both growing and harvesting geoducks may be greater in deeper subtidal waters (VanBlaricom 2008), where there is generally less natural physical disturbance of the sediments. Despite recent studies advancing our understanding of some of the potential impacts of geoduck aquaculture (Brown & Thuesen 2011, Sauchyn et al. 2013), we still know little about the potential long-term effects of large-scale aquaculture on ecosystem processes and biodiversity, and it remains an important topic for future research.

Because it is unlikely that aquaculture of Panopea zelandica will be permitted to occur until the environmental impacts are assessed more fully, studies from other parts of the world must be considered, because each tenure application in New Zealand will have to show that there are no “undue adverse effects” to the environment. User conflict may also come in to play because some of the potential intertidal growing areas are near urban areas, regions of “outstanding beauty,” existing cockle beds, and fishing grounds. These will have to be addressed on a case-by-case basis.

CONCLUSIONS

Although the New Zealand geoduck Panopea zelandica shows commercial promise, research on existing populations and aquaculture is still in its infancy, and several impediments (biological, policy, and user conflict issues) need to be overcome. Progress is being made and the investment community is showing an interest in developing aquaculture, which will drive further research and development.

ACKNOWLEDGMENTS

The authors thank Drs. Brent Vadopalas and Jonathan Davis for the invitation to write this review and for improving earlier drafts of the manuscript, and Dr. Jeremy Nelson (Ministry of Primary Industries, New Zealand) for information on current geoduck harvesting in New Zealand.

LITERATURE CITED


