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An investigation of benthic sediments and macrofauna within pearl farms of Western Australia

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ABSTRACT

The pearl oyster (*Pinctada maxima*) aquaculture industry in the Kimberley region of Western Australia has been established for decades. However, investigation of benthic sediments and macrobenthic communities within pearl farms for this region has not taken place until now. Pearl oysters may have the potential to foul the benthic layer under the farms through the deposition of feces and pseudo-feces from the cultured oysters and fouling organisms, and the fallout of debris from the longlines that suspend the pearl oysters. This organic waste and debris can accumulate in the sediments below the oyster longlines and potentially lead to organic enrichment and even eutrophication. Other aquacultures (such as some finfish and other shellfish) have caused eutrophication of marine sediments and a concurrent change in benthic macrofauna.

For two years we sampled the sediments below three *P. maxima* pearl oyster farms in remote regions of the Kimberley coast. Sediment core samples were taken to measure physico-chemical variables (redox potential, nutrients loads and total organic matter) while grab samples collected the benthic macrofauna (>1 mm in size). Each farm was compared to four control locations (total = 12 control locations) within the same region. At all three pearl farms there was no indication of eutrophication (nutrient enrichment). We concluded that the variability in benthic physico-chemistry beneath pearl farms was within the bounds of natural variability at reference locations. There were also no consistent differences in the benthic macrofauna assemblages below the pearl oyster farms when compared to control locations. There was considerable natural variability of the benthic macrofauna among all locations, but especially among the reference locations. The reference locations were as different from one another as they were from the farm locations, indicating that the diversity of benthic macrofauna taxa, and their relative abundances within sediments underlying the farms fell within the range of natural variability found at these spatial scales. The importance of robust assessment of potential environmental impact of aquaculture facilities is stressed.

1. Introduction

The gold or silver lipped pearl oyster, *Pinctada maxima*, forms the basis of Australia's pearl oyster culture industry located on the Kimberley coast of northern Western Australia (Fletcher et al., 2006; Prince, 1999). No artificial feed or chemicals are required in the culture of pearl oysters. The primary potential impact is thought to be the deposition of feces and pseudofeces from the cultured oysters and the fallout of debris from the longlines that suspend the pearl oysters (Gifford et al., 2004; O'Connor et al., 2003; Yokoyama, 2002).

Pearl oysters (like other bivalves) are filter feeders of suspended particles in the water column. They produce biodeposits in the form of feces and pseudofecal pellets as a waste product. It is thought that these biodeposits are similar in composition to the natural sediments because they are derived from phytoplankton and suspended particles (Grant et al., 1995). However these biodeposits and shell debris can accumulate in the sediments below the oyster longlines and potentially lead to localised organic enrichment and even eutrophication (a detrimental increase of nutrients such as carbon and nitrogen). Further, the cleaning of biofouling organisms from oyster shells during deployment may accumulate beneath the lease. This may reduce oxygen content (Hatcher et al., 1994), increase nutrient load and alter dependent benthic macrofaunal communities (Chamberlain et al., 2001; Kaspar et al., 1985; Pearson and Rosenberg, 1978).

Few studies to date have directly considered the potential impacts of pearl oyster farming on the marine benthos (but see Enzer Marine, 1998; Fletcher et al., 2006; O'Connor et al., 2003; Prince, 1999; Wells and Jernakoff, 2006; Yokoyama, 2002). Although a number of studies have established impacts on benthic systems from other bivalve aquacultures, namely mussel aquaculture (e.g. Crawford et al., 2003; Grant et al., 1995; Hatcher et al., 1994; Lasiak et al., 2006; Miron et al., 2005), it cannot be assumed that pearl oyster aquaculture may exhibit the same impacts. This is due to inherent differences in stocking

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densities, molluscan filtering and biodeposition rates, removal practices of biofouling organisms from oyster shells, other husbandry practices and farm locations.

The detection of aquaculture-related impacts in the marine environment, especially in the soft sediments of inshore regions, usually involves testing for nutrient and organic enrichment of the sediments and a change in benthic macrofaunal communities (e.g. Grant et al., 1995; Hartstein and Rowden, 2004; Pearson and Rosenberg, 1978). Benthic macrofauna are sensitive to organic enrichment levels perhaps undetectable via bulk chemical measures and can reflect an accumulation of impacts over time (Crawford et al., 2003). Numerous studies on shellfish aquaculture have demonstrated that a change in benthic macrofaunal communities is one of the most sensitive measures of organic enrichment (Dernie et al., 2003; Krassulya, 2001; Thompson et al., 2003).

In some parts of the world, mussel farms have been found to alter the characteristics of seabed sediments (Grenz et al., 1990). Mussel farms in sheltered sites may exhibit biodeposit and shell debris accumulation rates of up to 10 cm/year, resulting in changes to the seabed up to approximately 20 m from the farm boundaries (Dahlback and Gunnarsson, 1981; Mattson and Lindén, 1983). Build up of mussel biodeposits can create a situation of organic enrichment in the sediments under the farms (Grenz et al., 1990), which may also cause an alteration of macrofaunal assemblages in these sediments (Callier et al., 2007; Christensen et al., 2003; Giles et al., 2006; Mattson and Lindén, 1983; Mirto et al., 2000; Stenton-Dozey et al., 1999; Tenore et al., 1982).

Changes in benthic macrofauna can include a decrease in the number of individuals and lower species richness (Callier et al., 2007; Chamberlain et al., 2001; Kaspar et al., 1985; Mattson and Lindén, 1983). It may also involve dominance of opportunistic species at mussel farms compared to reference sites (Chamberlain et al., 2001: Site 2; Callier et al., 2007) or the dominance of deposit feeders (Stenton-Dozey et al., 1999).

Other studies, however, have demonstrated that bivalve aquaculture may not cause a build up in sediment nutrients, nor cause a concurrent change in benthic macrofauna (Crawford et al., 2003; Goncalves da Costa and Cunha Nalesso, 2006; Grant et al., 1995; Hatcher et al., 1994; Lasiak et al., 2006; Miron et al., 2005). Some authors have suggested that oceanographic characteristics are principally responsible for such findings (Chamberlain et al., 2001; Goncalves da Costa and Cunha Nalesso, 2006; Hartstein and Rowden, 2004; Miron et al., 2005). Chamberlain et al. (2001) demonstrated that for mussel cultivation, benthos beneath farms with tidal flushing exhibited negligible impacts, yet the benthos beneath farms with little tidal flushing experienced significant impacts. When currents are not strong enough to transport biodeposited material, the depth of the oxygenated layer of the sediment decreases and bottom oxygen may be depleted, leading to anoxia of the sediment and the overlying water (Chamberlain et al., 2001). Furthermore, in a study investigating the effects of different hydrodynamic regimes on biodeposits from mussel aquaculture, it was found that significant differences in macroinvertebrate assemblage composition occurred between farm and reference locations only at low energy sites. No such difference was observed between farm and reference locations at high-energy sites (Hartstein and Rowden, 2004).

In general, the inconsistencies among studies may be attributed to differences in site hydrodynamics, water depth, topography, background enrichment, sediment type and especially culture characteristics such as bivalve stocking density, shell size and depth of line deployment (Callier et al., 2007). The potential impacts may also vary as a function of the unique assemblages of a particular region and their ecological requirements. For these reasons, the potential or predicted impacts of pearl oyster aquaculture cannot be assumed nor extrapolated from the numerous studies to date assessing effects of mussel aquaculture. Further, little is known of the benthos of this remote region of the Kimberly coast, and it is considered one of the last pristine marine environments in Australia. Thus, it is prudent to investigate the potential impacts of all aquatic ventures in this region.

In this study we investigated the influence of pearl oyster *P. maxima* culture on the benthic assemblages and sediment physico-chemistry of the Kimberley coast, Western Australia. We sampled the benthic macrofauna communities under the pearl longlines and compared these with communities from reference locations. We also measured the physico-chemistry of sediments such as the redox potential, nutrient loads (nitrogen, carbon, phosphorus and carbonates) and total organic matter. These sediment variables were chosen because they have been identified as some of the most sensitive indicators of nutrient enrichment due to aquaculture (Hargrave et al., 1997).

We hypothesised that if pearl farms have an impact on the natural environment then we would detect significant and sustained differences in sediment characteristics (physico-chemistry) and benthic macrofaunal assemblages between reference and farm locations.

2. Methods

2.1. Study locations

The three pearl farms studied were located in the remote Kimberley coast of North Western Australia in Cygnet Bay (16°28′S, 123°02′E), Port George (15°23′S, 124°40′E) and Vansittart Bay (14°01′S, 126°11′E) (Fig. 1). Each farm has been in operation for at least 10 years, and all were located in separate embayments on the coast. The pearl oysters were suspended (within the top 2–3 m of water) on floating longlines that were approximately 200 m in length and spaced 50 m apart. The industry standard for the stocking density of pearl oysters is no more than 16,250 shells per square nautical mile. Mussel farming (in New Zealand) suspends 800 mussels per meter of longline (Hartstein and Rowden, 2004), so by comparison to other shell aquacultures, pearl farming has low stocking densities.

The region has a tropical monsoon climate with annual maximum temperature of 32.1 °C (minimum = 23.1 °C), annual rainfall between 766 to 1388 mm and 50–70% relative humidity (Bureau of Meteorology 2008). The wet season (December to March) may be subject to monsoons and even severe tropical cyclones (average rainfall between 167 and 310 mm/month) while the dry seasons (April to November) are more climatically stable and cooler (average rainfall between 10 and 14 mm/month). The area is subject to diurnal (2 per day) tidal regimes with a maximum tidal range of 10.55 m (mean spring range = 7.75 m, mean neap range = 5.72 m). The area experiences strong bidirectional tidal velocities and as a result the water turbidity can be high. Turbidity measures in the region are recorded at 38,000 tonne of suspended sediment per tidal cycle or 35 mg/L (courtesy of Paspaley Pearls). During sampling, the average surface temperature of the water was 28.9 °C and surface salinity ranged from 30 to 35 psu. The sediment samples were taken from 10 to 16 m water depth depending on the tidal state.

2.2. Sampling design

The pearl farms were located in three bays: Cygnet Bay, Port George and Vansittart Bay, which were separated from each other by 100s of kilometers. There were ten sampling occasions over two years (October 2006 to November 2008). Within each bay, the abundance and composition of the benthos under the pearl lease (farm) was compared to four reference locations situated at least 1 km from the pearl lease boundary (and 2–8 nautical miles from the farm). All locations (farm and reference) were in sheltered bays with similar environmental features such as distance to land, shoreline topography, salinity, water depth and soft sediment type (sandy clay loam) with an absence of nearby river discharge or coral reefs. This asymmetrical study design compared the benthic conditions under each pearl farm (three in total) to four reference locations (twelve reference locations in total). Within each location there were three study sites spaced 50 m apart (similar to the spacing of the pearl farm longlines). Within