# Development of the scientific requirements of an Environmental Management System (EMS) for the pearling (*Pinctada maxima*) industry

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**OBJECTIVES:**

1. To determine relevant scientific requirements for a pearl industry EMS
2. To determine if the benthic physical / chemical or ecological variables beneath established pearl farms differ from the surrounding environment.
3. To develop the PPA's capacity to initiate and co-ordinate strategic research.

## OUTCOMES ACHIEVED TO DATE

This project has been a successful collaboration between pearl farmers, academic scientists and museum taxonomists and has given the scientific community greater access to remote regions of Australia, facilitating the description of new species to science. It has highlighted the inherent variability and abundant biodiversity of shallow water benthic communities in northern Australia. The study employed an exhaustively designed sampling regime incorporating three spatial scales (10's of metres, 1-5 km, >100's km) and random sampling through time. A multi-control sampling strategy was undertaken to give an estimate of the natural variability of the region and to test for benthic impacts at three pearl farms that have been in use for up to 40 years. Multiple lines of evidence all conclude that the variability in benthic conditions at the farms is within the bounds of the natural variability at the reference locations. The main mechanisms that influence the impact of shellfish aquaculture are considered to be; the farming method, the density of the cultivated shellfish (or stocking rate), the water depth of the farm area and the hydrographical conditions in the area (Danovaro et al 2004). All these factors favor the northern Australian cultured pearl industry and would contribute to the lack of a benthic footprint documented by this study.

The conclusion drawn from these studies is that current pearl oyster culture techniques in northern Australia have no detectable effect on the sediments of the lease sites. As ongoing or frequent benthic monitoring is logistically challenging and expensive in context of northern Australian pearl farms and cannot be expected to observe anything but natural variability it would not be a wise use of scarce industry funding to include benthic monitoring protocols in the standard EMS for this industry. If major changes to farming practice creates uncertainty in the future on this issue, or political climate requires revalidation of these findings, a further study such as this, conducted as corporate industry research, such as this project, could again test the issue.

**NON TECHNICAL SUMMARY:**

The pearl oyster (*Pinctada maxima*) aquaculture industry in the Kimberley region of Western Australia has been established for decades. However, the potential environmental impact of this aquaculture had not been investigated for this region before this study. Other aquacultures (such as some finfish and other shellfish) have caused eutrophication (nutrient enrichment) of coastal systems and caused changes to benthic macrofauna and sediments (e.g. mussel culture; Grenz et al 1990, Stenton-Dozey et al 1999, Mirto et al 2000). Prior to this study it was not known through evidentiary research whether or not pearl oyster aquaculture in the Kimberley had the potential to foul the benthic layer under the farms through the deposition of faeces and pseudo-faeces from the cultured oysters and fouling organisms, and the fallout of debris from the long lines that suspend the pearl oysters (O'Connor et al 1999, Yokoyama 2002, Gifford et al 2004).

Our investigation has found this does not occur in pearl oyster aquaculture in the Kimberley region. Over the past two and a half years we have sampled the sediments below three *Pinctada maxima* pearl oyster farms in remote regions of the Kimberley coast each of which had been in continuous use for up to 40 years and were selected on the basis of their long history of continuous use. Sediment core samples were taken to measure physico-chemical parameters and grab samples collected the benthic macrofauna (>1mm in size). The physico-chemical parameters measured included the redox potential, nutrients 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 (Hargrave et al 1997). Each farm was compared to 4 control locations (total = 12 control locations) within the same region selected on the basis of being at least 1 km outside the boundaries of the lease area and having comparable depths, current regimes and sediment types. There was no indication of eutrophication (nutrient enrichment) at any of the three pearl farms. There were also no consistent differences in the benthic macrofauna below the pearl oyster farms when compared to control locations.

Tests were also carried out to assess the effect of closing down a pearl farm on the sediments and associated benthic fauna. A pearl farm that has been in continuous operation for >50 years (Otama pearl farm, Kuri Bay) was scheduled for closure and samples of sediments were taken from under the longlines before the farm was closed and two further sampling periods conducted after closure (1 year and 2 years after). For each sampling period, three reference locations were also sampled. This allowed a Before-After-Control-Impact (BACI) analysis to be performed. Results indicate that the sediments under the longlines before and after the farm closure were not different to those of the reference locations.

The international literature reviewed through this project suggests that the main mechanisms that influence the impact of shellfish aquaculture seem to be the farming method, the density of the cultivated shellfish (or stocking rate), the water depth of the farm area and the hydrographical conditions in the area (Danovaro et al 2004). All these factors, passive farming, low stocking densities, high current flows, naturally high sediment loads and relatively deep lease sites, favor the northern Australian cultured pearl industry and would contribute to the lack of a benthic footprint documented by this study.

These results suggest that, in terms of pearl industry expenditure on their Environmental Management Systems (EMS), the monitoring or attempt at management of benthic impacts should be a low priority, and even of no priority, unless the practices referred to above change dramatically. If needed at all in the future, monitoring for benthic impacts in this industry can be appropriately handled by periodic studies conducted as corporate industry research, such as this one, conducted every 10-20 years, or if industry practices change radically in terms of stocking density, or conceivably because in time the industry feels the results presented here need re-validating. If the issue of benthic impacts is shown to have become an issue in the future the industry can adapt their EMS to respond.

**KEYWORDS:** ***Pinctada maxima*, culture, benthic impact**

# Background

## The Potential for Benthic Impacts from Farming Bivalve Molluscs

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 (Prince 1999, Fletcher et al 2006). No artificial feed or chemicals are required in the culture of pearl oysters. The primary potential impact of this industry was thought to be the deposition of faeces and pseudofaeces from the cultured oysters and fouling organisms, and the fallout of debris from cleaning fouling growth from the long lines that suspend the pearl oysters in panels (O'Connor et al 1999, Yokoyama 2002, Gifford et al 2004).

Pearl oysters and other bivalve aquacultures are suspension feeders that feed on suspended particles from the water column. They then produce biodeposits in the form of faeces and pseudofaecal 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 based on studies into other shellfish aquaculture industries, it was unknown whether these biodeposits and shell debris might accumulate in the sediments below the long lines, potentially leading to organic enrichment and even eutrophication (a detrimental increase of nutrients such as carbon and nitrogen). Although using only high pressure water and brushing (no chemicals are used) the industry practice of cleaning the biofouling organisms off the oysters and longlines during the culture process potentially may have resulted in accumulation beneath the lease.

From experience with other types of aquaculture it is known that accumulation of biological debris below aquaculture leases can change the substrates by reducing oxygen content (Hatcher et al 1994), increasing nutrient loads and alter dependant benthic macrofaunal communities (Pearson and Rosenberg 1978, Kaspar et al 1985, Chamberlain et al 2001). Benthic macrofauna refers to the animals (greater than 0.5 or 1mm in size) that live or are associated with the sea floor and mostly comprises of worms, molluscs including snails, crustacea (e.g.

crabs and shrimps), echinoderms (seastars and brittlestars), fish, and other small animals.

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 macrofauna communities (e.g. Pearson and Rosenburg 1978, Grant et al 1995, Harstein and Rowden 2004). 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 2002). Numerous studies on shellfish aquaculture have demonstrated that a change in benthic macrofauna communities is one of the most sensitive measures of organic enrichment (Gibson et al 2000, Krassulya 2001, Crawford et al 2002, Dernie et al 2003, Thompson et al 2003, Barnes et al 2006).

In some parts of the world, mussel farms have been found to alter the characteristics of the seabed sediments (Grenz et al 1990) in sheltered sites where biodeposits and shell debris have built-up at rates of up to 10cm/year resulting in changes to the seabed up to 20m beyond farm boundaries (Dahlback and Gunnarsson 1981, Mattsson and Linden 1983). This build up of mussel biodeposits can organically enrich the sediments under mussel farms (Castel et al 1989, Grenz et al 1990, Gilbert et al 1997) alterating the macrofaunal assemblages in the sediments (Mattsson and Linden 1983, Tenore et al 1985, Stenton-Dozey et al 1999, Mirto et al 2000, Christensen et al 2003, Giles et al 2006, Callier et al 2007). This alteration of benthic macrofauna can include a decrease in the number of individuals and lower species richness (Mattsson and Lindén 1983, Kaspar et al 1985, Chamberlain et al 2001, Callier et al 2007). It can also involve a 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).

In contract, other studies have found no effect on sediment nutrients from bivalve aquaculture, nor any change in benthic macrofauna (Hatcher et al 1994, Grant et al 1995, Crawford et al 2003, Miron et al 2005, Goncalves da Costa and

Cunha Nalesso 2006). A study of cultured mussels at Twofold Bay, Eden NSW found there was no evidence of any ecological impact on the benthic macrofauna below the longlines (Lasiak and Underwood 2002). They attributed their findings to the large, relatively open coastal area of Twofold Bay and suggested that mussel farms located in sheltered, poorly flushed areas where there is little opportunity for the dispersal of wastes away from culture sites can create nutrient enrichment and associated sediment changes (Lasiak et al. 2006). Other studies that have detected no significant impacts of mussel farms have also suggested that oceanographic characteristics are responsible for the lack of impacts (Chamberlain et al 2001, Hartstein and Rowden 2004, Miron et al 2005, Goncalves da Costa and Cunha Nalesso 2006). Chamberlain et al (2001) demonstrated that for mussel cultivation, the site with tidal flushing had negligibly impacted benthos, yet the benthos at a site with little tidal flushing had 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).

In a study investigating the effects of different hydrodynamic regimes on biodeposits from mussel aquaculture Hartstein and Rowden (2004) found that macroinvertebrate assemblages only differed between farm and reference locations at low energy sites. No differences were observed between farm and reference locations at the high-energy sites. The physico-chemical parameters of total organic matter and the amount of mussel shell debris best explained the pattern of changes in the macroinvertebrate assemblage composition in the two low-energy study sites (Hartstein and Rowden 2004). They deduced that there is a relationship between the hydrodynamic regime and organic enrichment of seabed sediments by mussel biodeposits which can then result in the modification of the macroinvertebrate assemblage.

In general, the differences between studies may be attributed to difference in site hydrodynamics, 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). 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, making necessary this study of the sediments below pearl farms in northern Australia.

## The Ecologically Sustainable Australian Pearling Industry

Public awareness and government policies regarding Ecologically Sustainable Development (ESD) in the marine environment have been evolving rapidly over the last two decades. An industry of long standing, the *Pinctada maxima* pearling industry developed most of its practices well prior to this interest in the management of the marine environment becoming widespread. In line with changing public perception and government policy with regard to the environment, the Pearl Producers Association Inc (PPA) has long recognized the need to pro-actively address and demonstrate the industry's environmental responsibilities and practices. In 1998 the PPA commissioned the report: "The environmental impact of pearling (*Pinctada maxima*) in Western Australia" (Enzer MEC 1998). That report described the general environment in which pearling occurs and the pearling activities that might potentially modify the environment and concluded that the environmental effects of the pearling industry were likely to be minor and the industry environmentally benign. The report also made suggestions regarding the implementation of environmental monitoring programs to formally assess the conclusions and advised on the possible components of an environmental code of practice for the pearling industry. It suggested that the objectives of a code of practice should include:

- Establishing procedures that enhance Australia's reputation for producing high quality pearls through the application of ESD principles;
- Ensuring that pearl farms operate in a manner acceptable to the public and other users of the marine environment; and
- Providing guidelines for use by industry to ensure best practice techniques are adopted.

The Enzer MEC report provided an important benchmark summary of the current industry. It highlighted what was known within the industry and provided the R&D subcommittee of the PPA with an opportunity to review current environmental issues for the industry.

In 2001, funded through the WA Fishing Industry Council (WAFIC) Industry Development Unit (IDU) and the Fisheries Research and Development Corporation (FRDC), the PPA commissioned the environmental risk assessment consultancy, International Risk Consultants – Environment (IRCE), to conduct an environmental audit and risk assessment of pearl culture in WA (Jernakoff 2002 – FRDC 2001/099).

The consultants undertook an;

1. Evaluation of current Pearl Industry practices and procedures,
2. Ecological Risk Assessment on pearl culture including a workshop,
3. Environmental information gap analysis, and an
4. Environmental management gap analysis.

They concluded that the key environmental issue for the industry is whether or not there are long-term environmental impacts from pearl culture (Jernakoff 2002). In keeping with the conclusions of Enzer MEC (1998) they found that the available evidence suggests the environmental impact of pearling is low, observing however, that there was scant scientific evidence to prove this point. Jernakoff recommended that a study should be undertaken to document whether this is in fact the case, and to quantify the extent to which pearling might change the natural environment and recommended initially focusing on four components:

1. The composition of the fouling growth cleaned from cultured shell;
2. The potential for modifying benthic habitat below pearl farms;
3. The disposal of grey water from vessels and shore camps; and
4. Monitoring interactions with protected fauna.

In terms of direct assessment of the potential impact of pearl aquaculture on marine benthos, comparatively fewer investigations have been undertaken to date. In 1998, Enzer MEC suggested that the major environmental effect of pearl aquaculture in the region was the returning to the sea of marine growth cleaned from pearl oysters. However, Enzer MEC suggested that because no chemicals are used in the cleaning process and the material returned is of marine origin, the impact is temporally and spatially widely dispersed. In general, Enzer MEC found the industry to be environmentally benign. However this report did not directly test these assumptions by collecting field data.

Prince (1999) conducted a sampling program inside and outside a pearl lease to investigate the effects of *Pinctada maxima* aquaculture in the Montebellos Islands in WA and found no impact of the pearl farms on the abundance and diversity of the benthic macrofauna community. Despite this finding, there was great variability in the fauna among individual sites, and control sites were not at comparable depths to lease sites. This study was also limited both spatially and temporally as it compared two sites within pearl farms to three nearby reference sites at only one period in time (March '99).

Another study was undertaken in Port Stephens, NSW (O'Connor et al 2003), which examined the effects of a *Pinctada imbricata* pearl farm on sediment physico-chemical characteristics (sediment carbon, nitrogen and phosphorus). This study was temporally replicated (n=6 sampling times), and compared five reference sites to one farm site. Sediment variables examined beneath the pearl lease (including total organic carbon, nitrogen and phosphorus) did not differ significantly from the reference sites over the sampling times examined. Despite these findings, the authors acknowledged study limitations and called for future assessments of pearl aquaculture to incorporate benthic faunal community analyses and a Before/After, Control/Impact or "BACI" design whereby the sampling starts before the establishment of a farm.

Yokoyama (2006) compared the impacts of pearl farming and fish cages (yellowtail and seabream) in Gokasho Bay, Japan. The pearl farms in this region use rafts of *Pinctada martensii* (not longlines as in Australia) which covered

79000 $m^2$ of the bay and produced 800 kg of pearls in 1995 when this study was undertaken. They sampled the sediments under the pearl and fish farms and within reference sites for 18 months at monthly intervals. They compared the macrobenthic fauna as well as the sediment nutrient loads (carbon, nitrogen sulphur and dissolved oxygen) in these sites and found that fish farming created a large impact on the macrobenthic fauna and sediments, whereas pearl farming caused fewer effects. The community structure at the pearl farm site was similar to that at the control site, although there were lower densities and species diversity at the pearl farm site. There were also more seasonal changes in the dominant species at the pearl farm compared to the control sites.

Fletcher et al (2006) compiled a comprehensive report on the contribution of the pearl oyster *Pinctada maxima* fishery to ecologically sustainable development (ESD) in Western Australia. This assessment examined the economic, social and environmental benefits and costs of the pearl oyster fishery but did not empirically test any potential environmental costs. Similarly, Environment Australia produced an assessment of the ecological sustainability of the management of the Western Australia pearl oyster fishery in 2003, revised and renewed in 2008, against guidelines set out in Commonwealth legislation (Environment Australia 2003 and 2008). However this did not undertake any monitoring or assessment of the potential impacts of the aquaculture operations.

Collectively, few studies with sufficient temporal and spatial replication have been conducted to date to reliably assess the potential effects of pearl aquaculture operations on marine benthos. For an industry of such importance to the Australian economy, this lack of evidence has been a direct threat as there has been an Increasing level of interaction between competing coastal resource users. While government and industry are generally supportive of pearl culture due to its expected low environmental impact, community opposition to other forms of aquaculture has been increasing nationwide, placing political pressure on decision makers. High quality scientific information about the actual level of impact by the pearling industry in the Kimberley was deemed essential for informing rational coastal management into the future. The importance of this information is highlighted by the fact that at the time of initiating this project the WA Fisheries Department's Business Plan highlighted the key objective of the pearling subprogram as ensuring ecological and environmental sustainability, while Strategy 4 of Program 1 in the FRDC R&D plan was 'increasing and applying knowledge of the effects of non-fishing activities, including the effects of aquaculture, on marine ecosystems.'

In 2003 the PPA became one of two industry association partners in the NHT funded Seafood Services Australia Ltd (SSA) pilot program for developing Environmental Management Systems (EMS). Through that project SSA and the PPA worked closely with the MG Kailis Group to develop and implement a cost effective EMS template that can be implemented generally across the pearling industry. Of central interest to that process was the relative necessity to implement benthic monitoring programs as a routine element of a Pearl Industry EMS. The environment in which pearl culture takes place typically involves, extremely remote locations accessed only by air or sea, high tidal flow and high turbidity which increases the difficulty, costs and risks associated with first sampling benthic sediments and faunas, along with the expense of freighting samples, analysis, evaluating and reporting. The permanent impost of routine benthic monitoring often associated with an aquaculture EMS would not be borne lightly by the pearling industry. A central aim of this project was to inform the content of Environmental Monitoring Systems for pearl farms off Northern Australia with regard to the relative priority for incorporating benthic monitoring as a standard part of environmental monitoring in the pearl industry.

This project has resulted in a comprehensive study undertaken by a research team from University of Newcastle examining the influences of pearl farming practices on the benthic sediments and macrofauna of the surrounding marine environment of the Kimberley coast of northern Western Australia. The project aimed to redress the limitations of previous studies of this kind by including greater spatial and temporal replication of both farms and reference sites. Furthermore, when one of the oldest continually used lease sites (>50 years of use) that was an initial part of the sampling program was closed for logistical reasons, the project was able to undertake a Before/After, Control/Impact or "BACI" study to test the effect of *removing* a pearl farm on benthos. It was impossible in a project like this, with its limited 3 year time frame, to sample these pearl farms before they were established but closure of this farm enabled investigation of the effects of removing an established pearl farm for 2 years after its removal.

The current study represents the most comprehensive assessment of the effects of pearl aquaculture on benthic physico-chemistry and benthic macrofauna communities undertaken internationally to date. It represents a proactive collaboration between individual pearling operators, the Pearl Producers Association and scientists to redress this knowledge gap to ensure best practice environmental management of pearl leases of the Kimberley coast, North Western Australia.

## Need

The pearl oyster culture industry needs to operate in an environmentally sustainable manner and have the supporting science for communication of this fact to the public at large. The PPA has been developing an Environmental Management System (EMS) for industry and has found the specific scientific requirements to underpin an EMS for this industry have been difficult to define due to the general lack of basic documented knowledge about the environment in which it operates. Both Enzer MEC (1998) and Jernakoff (2002) explicitly highlighted the general lack of information about the environment and ecosystems on which the pearl industry depends, and a paucity of knowledge about how the practices involved with pearl culture interact with the environment. In a climate of increasing interest over the use of the coastal zone, this lack of documented knowledge is a direct threat for an industry of such importance to the Australian economy. While it was considered likely that this study would produce similar results to other studies of bivalve culture which found little or no benthic impact (Crawford et al. 2003, Gifford et al 2004), the distinct nature of the pearling industry (*P. maxima*) in the Kimberley limited the usefulness of making generalizations based on the results of studies of temperate systems.

Thus the need addressed by this project was to study the Kimberley pearling industry mariculture practices with the aim of producing evidence based information about the industry's interaction with the environment upon which it depends so heavily to produce the world's best pearls. The PPA's longer term need was to continue developing its capacity to initiate, manage and complete programs of corporate research with the aim of enhancing environmental management, pearl production and status within the market and the community.

# Objectives

1. To determine the relevant scientific requirements for a pearl industry EMS.
2. To determine if the benthic physical / chemical or ecological variables beneath established pearl farms differ from the surrounding environment.
3. To develop the PPA's capacity to initiate and co-ordinate strategic research.

# Methods

## Aims and Objectives of the Scientific Study

This study investigated the influence of culture of the pearl oyster *Pinctada maxima* on the benthic assemblages and sediment physico-chemistry of the Kimberley coast, Western Australia. As detailed in Appendix 4 samples of the benthic macrofauna communities under the pearl long lines were compared with samples from communities from independent reference locations. Physico-chemistry of the sediments was measured such as the redox potential, nutrients 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 (Hargrave et al 1997).

As described in Appendix 4 three pearl farms were selected that have been in continuous operation for between 10-40 years and located in separate embayments around the Kimberley coast. The pearl oysters are suspended in multiple pocket panels at 2-3m depth, held in place by a drop line attached to surface floating long lines. The sediments under these long lines were sampled and compared to the sediments taken from four reference locations within the same embayment or area (total of 12 reference locations). Investigators hypothesised that if the pearl farms are having an impact on the natural environment then there should be differences in the sediments characteristics (physico-chemistry and macrofauna communities) between the reference and farm locations.

Tests were also carried out on the effect on the sediments and associated benthic fauna of closing down a pearl farm. A pearl farm that has been in continuous operation for almost 50 years (Otama pearl farm, Kuri Bay) was scheduled for closure for logistics reasons. Sediment samples were taken under the longlines before the farm was closed and for two sampling periods after closure (1 year and 2 years after) and for each sampling period, samples of the sediments were taken from three reference locations. This allowed completion of a Before-After-Control-Impact study (BACI). Investigators hypothesised that if the farm was having an environmental impact on benthic conditions, it would be expected that the sediments under the farm would change after removal of the farm, relative to the condition of the reference locations.

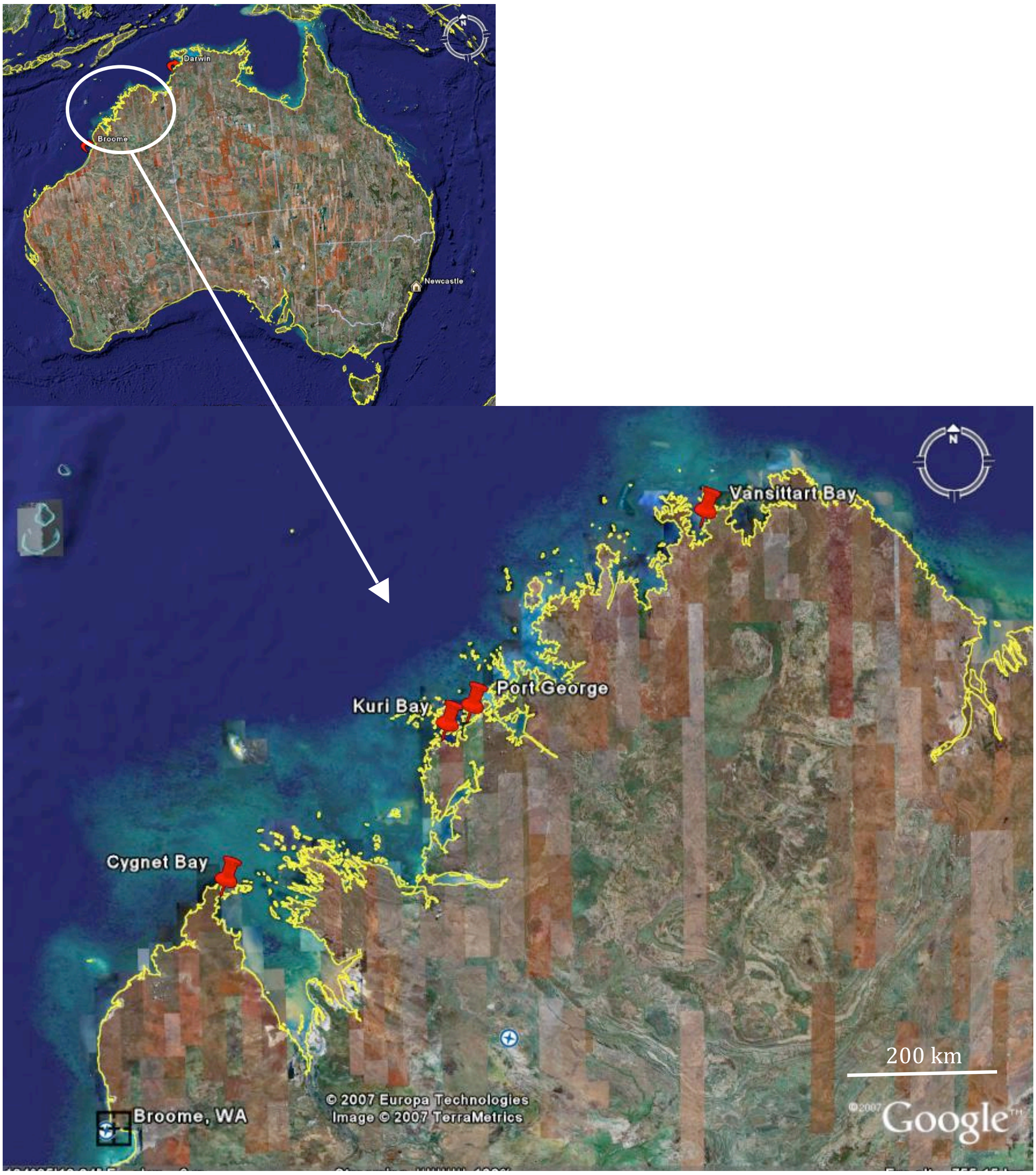


**Figure 1:** Map of Australia showing the Kimberley region and the study areas. The main study was conducted in Cygnet, Port George and Vansittart Bays and the BACI study was conducted in Kuri Bay (Image taken from Google Earth © Europa Technologies http://earth.google.com/).

## Study locations

As detailed in Appendix 4 the four pearl farms studied were located in the remote Kimberley coast of North Western Australia within the bays of Cygnet Bay (16°28'S, 123°02'E), Port George (15°23'S, 124°40'E), Kuri Bay (15°27'S, 124°31'E) and Vansittart Bay (14°01'S, 126°11'E) (Figure 1).

## Sampling design for the main study

As described in Appendix 4 the main study investigated the pearl farms in three bays, Cygnet Bay, Port George and Vansittart Bay over 10 sampling times. The bays were separated from each other by 100's of kilometres. The sampling occurred over 2 years (October 2006 to November 2008). At each bay, the condition of the benthos within the pearl lease (farm) was compared to four reference locations selected on the basis of being located at least 1km from the pearl lease boundary (and 2-8 nautical miles from the longlines), in similar water depths and having similar sediment types and current regimes. The design of this study was asymmetrical with the benthic conditions under three pearl farms compared to twelve reference locations. At each of these locations, there were 3 study sites that were spaced 50 metres apart (similar to the spacing of the pearl farm long lines). Within each site, 3 grab and 3 core samples were collected; a total of 9 grabs and cores for each location, and 45 for each farm. The grab and cores samples were collected ten times during the study (Grabs: Oct. '06, Jan., May, Sept. and Nov.'07, Feb., April, May, Aug. and Nov. '08. Cores: Oct. '06, Jan., Mar., May, Sept. and Nov.'07, Feb., April, May, Aug. '08). There were some exceptions to this sampling regime as some samples were lost in transit and the omission of some redox readings on two farms due to the temporary malfunctions of the redox probe during the study.

## Sampling design for BACI (Before, After Control, Impact) study

As described in Appendix 4 this study investigated the effects of removing a pearl farm (Otama pearl farm, near Kuri Bay) on the benthic conditions under the farm compared to nearby reference locations. This farm was closed down in November 2006 and all of the adult shell was removed from the longlines (some juvenile shell remained for a few months). The design of this study included three sampling periods; before the pearl farm was closed down (1-6 months before), 6-12 months after removal of the shell and 18-24 months later. These three periods are referred to as; before, one year after, and two years after. Within each sampling period there were two sampling times (nested). This study was asymmetrical with the benthic conditions under one pearl farm compared to three reference locations located at least 1km from the pearl lease boundary (and 2-8 nautical miles from the farm), in similar water depths and with similar sediment types and current regimes. At each of these locations, there were 3 study sites that were spaced 50 metres apart (similar to the spacing of the pearl farm long lines). Within each site, 3 grab and 3 core samples were collected, which is a total of 9 grabs and cores for each location, and 36 in total per sampling time. The grab and cores samples occurred six times during the study: before- May and Oct. 2006, 1 year after- January and May 2007, and 2 years- May and Nov. '08.

## Sediment grabs for Benthic Macrofauna

A Van Veen grab was used to collect the top layer of sediment (area = $0.1m^2$, depth=10cm) which was gently sieved through a 1mm mesh on site. The material retained on the sieve was preserved in 5% formalin-saline containing Rose Bengal that stained the fauna pink. The sample was then sieved again back at the laboratory and sorted for the macrofauna that were then preserved in 70% ethanol.

The benthic fauna was then identified to the highest possible taxonomic level, usually genus or species although some fauna were identified only to order level. A low power dissecting microscope was used to count and identify the macrofauna. Among Crustaceans, the most numerous group; the decapods, were identified to the species or genus level. Amphipods, isopods and tanaids were identified from the species to family level and the ostracods, stomatopods, mysids, and cumaceans were identified to order level. The polychaetes (segmented worms) were identified to the family level while the molluscs (including the bivalves) were identified to genus or species level. The echinoderms were identified mostly to genus level; the fish were identified to family level and the few sea spiders collected were identified to genus level. A small percentage of the benthic fauna included worms (flat, ribbon and acorn worms) sipuncilids, sponges, cnidarians and large forams which were not identified, however they were counted.

## Sediment cores for physico-chemical analysis

A universal gravity corer (68mm in diameter, Aquatic Research Instruments, Idaho USA) was used to collect the sediments for physico-chemical analysis. The corer collected over 20cm of sediment but only the top 5cm of sediment was used. The redox potential of the sediment was measured immediately after collection using a handheld pH-mV-Temp. meter (TPS Pty Ltd, Brisbane, Australia). The pH of the sediment was concurrently measured using pH indictor sticks. The sample was then placed into a sealed container, frozen and transported back to the laboratory where they were oven dried at 40°C and then ground. The physico-chemistry parameters measured in the laboratory from the sediment core samples were total organic matter, carbon, nitrogen, phosphorus, and carbonates.

The total organic matter was measured using the loss on ignition (LOI), furnace method (400°C, 16 hours). The total nitrogen and carbon content was measured using a LECO *Tru-spec*® CNS induction furnace analyser. Total phosphorus was determined photometrically after converting the organic phosphorus to inorganic phosphorus (furnace method: 550°C, 2 hours). The sample was then analysed using the ascorbic acid method for phosphorus analysis (Kuo 1996).

The carbonates were measured using the sequential loss on ignition method (Dean 1974).

## Univariate statistical analysis for the main study

The main aim of this study was to compare three farm locations with 12 reference locations so an asymmetrical analysis of variance (ANOVA) was used, the detail of which is provided by Appendix 4. The variables compared were the number of benthic species/families and individuals per grab and the sediment redox potential, total organic matter, total nitrogen, total phosphorus, total carbon and carbonates. The detailed design of this analysis is shown in Table 1 of Appendix 4. This type of asymmetrical ANOVA calculation has been previously employed by others when undertaking environmental impact assessment (e.g. Glasby 1997, Roberts et al 1998, O'Connor et al 2003).

## Univariate statistical analysis for the BACI study

As described in Appendix 4, a similar asymmetrical analysis of variance (ANOVA) was used to compare the sediments (and associated benthic fauna) over 3 sampling periods; before a pearl farm was closed down, soon after closing (within a year) and a longer time later (between 18-24 months later). The variables compared were the number of benthic species/families and individuals per grab and the sediment redox potential, total organic matter, total nitrogen, total carbon and carbonates. The detailed design of this analysis is shown in Table 2 of Appendix 4.

# Results / Discussion

## Main study: Benthic macrofaunal comparisons

As detailed by Appendix 4, more than two years of benthic sampling demonstrated that there was no evidence of any consistent change in the total number of benthic macrofauna taxa or individuals within soft sediments that might be directly attributed to pearl oyster longlines compared to reference locations. This outcome is particularly robust because of the rigorous sampling design that was employed to detect changes in benthic macrofauna over three spatial scales (sites, locations, bays) using numerous reference locations (n=4) in each bay and ten random sampling events in time. Too often an environmental impact of shellfish aquaculture (notably mussels) is demonstrated by studies that have only one control (or reference site) or one sampling time (e.g. Kaspar et al 1985, Tenore et al 1985, Grenz et al 1990, Stenton-Dozey et al 1999). Limited spatial or temporal sampling designs are inadequate to demonstrate any potential impact reliably (Underwood 1992) and for these reasons our study sought to undertake the most rigorous sampling protocol to date for assessing potential impacts due to pearl aquaculture.

As might be expected there was considerable natural variability of the benthic macrofauna among all location. Differences were observed in the assemblages of benthic macrofauna in the different bays (separated by 100's of km), as would be expected of different geographical regions. Larger scale processes such as biogeography, climate, and history probably drive this variability and contribute to these differences. However, there were no consistent differences in the benthic faunal assemblage under the longlines (at farms) when compared to the reference locations for all times. The fluctuations in benthic macrofauna found under the longlines at farms were within the bounds of what occurred naturally among reference locations. The reference locations were as different from one another as they were from the farm locations. The number of benthic macrofauna taxa, and their relative abundances within sediments underlying the farms fell within the range of natural benthic macrofauna variation observed at the same spatial scales within reference sites. In fact, the greatest variability was observed at the within site level (50-150m distance) in comparison to the variability observed at the location level (1-5km distance). This can be typical of natural variability in benthic assemblages and corroborates other studies that show small scale variability in fauna can be greater than large-scale variability (Chapman et al 1995, Anderson et al 2005, Norén and Lindegarth 2005). This suggests that for the benthic species of this region, small-scale processes (such as competition between the species in the benthic assemblage, settlement and behaviour) may be more influential than other influences such as pearl farming activities. Therefore, in relation to small and large-scale processes, the farms had no detectable influence on the composition and abundance of benthic fauna in the soft sediments.

## Main study: Sediment physico-chemistry comparisons

When comparing among all bays (3 farms with 12 reference locations), the sediments under the pearl longlines did not exhibit the symptoms of nutrient enrichment or eutrophication observed in some other aquaculture industries (e.g. fish farms, Yokoyama 2002). Overall, the fluctuations of the sediment physico-chemistry under the longlines at the farms were within the bounds of what occurred naturally at the reference locations. Comparisons across all bays revealed no differences between what was observed at the farms compared to the reference locations. In fact, surprisingly very few of the samples taken from under the farms contained shell grit originating from the culture of pearl oyster. This is regardless of the fact that some of the farm sediment samples were taken soon after 'cleaning' of the longlines (removing epiphytic growth from oyster shells, panels and ropes).

## BACI study: Benthic macrofauna (effect of farm closure)

Despite the lack of 'before' monitoring in the main study, the project was however, afforded the opportunity to assess the potential effects of pearl aquaculture by monitoring before and after the *removal* of a pearl farm. The design of our Beyond BACI study (Underwood 1992) assumed that the removal of the oyster shell from the pearl farm longlines would cause sustained changes in the benthic fauna and conditions. This farm had been under constant operation for over 50 years so we would expect its removal to cause significant long-term changes *if* the farm had created some change or impact during its operation. The design of the Beyond BACI study allowed us to test for a 'pulse' disturbance, one that may occur soon after pearl oyster removal from the longlines.

The Beyond BACI study showed that the removal of the pearl oysters from the longlines did not have an effect on the underlying sediments and benthic fauna, when compared to the natural variability of the sediments at the reference locations. The changes observed between the benthic conditions six months before and then up to two years after the removal of the oyster shells were similar to the natural variability observed at the reference locations in this time. Although the assemblages of benthic macrofauna in this study changed significantly with time, there were no consistent changes in the benthic fauna assemblages that could be attributed to the removal of shell from the longlines.

## BACI study: Sediment nutrient levels (effect of farm closure)

The fluctuations of the sediment nutrient levels (total organic matter, carbon, nitrogen and carbonates) under the longlines at the farm were within the bounds of what occurred naturally at the reference locations, both before and after oyster shell removal. There were no differences between what was observed in the sediments at the farm compared to the reference locations, or any significant differences before and after shell removal at the farm. Similar to the main study, the sediments under the pearl longlines did not exhibit evidence of nutrient enrichment or eutrophication.

These results from the Beyond BACI study concurred with the results of the main study in suggesting that pearl lease had no impact on the sediments or benthic fauna of the lease site.

## No dominance of indicator species of organic enrichment

Similarly the composition of the benthic fauna observed during this study support the notion that pearl leases have no impact on the benthic fauna within pearl leases. Benthic fauna has been used as an indicator of organic enrichment (from anthropogenic sources) particularly the Capitellid polychaetes, some Spionid polychaetes and gastropod molluscs. In fact 17 polychaete and 7 mollusc groups have been historically used as indicators of organic enrichment (Pearson and Rosenberg 1978), however none of these studies were from the Indo-Pacific region and so direct comparisons with our study are limited. Yet we did find that the benthic assemblage in the Kimberley, both at the pearl farms and reference locations, was very diverse and not dominated by one species or one group of taxa. In other studies of sediments affected by nutrient enrichment (or other environmental impacts), one or a few species or groups of taxa tend to dominate the sediments (Pearson and Rosenberg 1978, Stenton-Dozey et al 1999, Callier et al 2007). In particular for shellfish aquaculture, the use of ropes, racks buoys and lines is expected to have an immediate effect on local hydrography and provide a new substratum upon which other epibiota can attach and grow (Goncalves da Costa and Cunha Nalesso 2006). This can then potentially lead to a new or changed benthic fauna occurring in the sediments underneath the longlines.

Changes to polychaete assemblages are recognised as one of the best indicators of environmental impacts from aquaculture (Pearson and Rosenberg 1978, Hutchings 1998). Therefore the presence or absence of specific polychaetes in marine sediments can provide an indication of the condition or health of the benthic environment (Pocklington and Wells 1992). For example, some polychaetes families, such as those belonging to the Capitellidae (i.e. *Capitella capitata*), Cirratilidae, and Spionidae families will dominate benthic communities in sediments experiencing excessive organic enrichment (Hutchings 2003, Giangrande et al 2005, Surugiu 2005, Cardoso et al 2007). Although some of these groups were collected in the sediments they were collected from the sediments of both farm and reference locations and potentially reflect a naturally occurring population of fauna. There were no differences in their numbers between farm and reference locations.

In contrast, some polychaete families can experience a decline in numbers during anthropogenic impacts. For example, the family Syllidae have shown to be a very useful indicator taxon in hard substrata as they are highly sensitive to pollution and disturbances, decreasing in numbers of species and individuals or completely disappearing in adverse conditions (Giangrande et al 2005). However in our study there were similar numbers of Syllids at the farms compared to the reference locations. Although we sampled in soft sediments and not hard substrata, the abundance of Syllids in the sediments under the longlines could suggest an absence of disturbance occurring under the pearl farms.

The mollusc species collected in our study reflected the normal fauna of tropical north Australia (Lamprell and Healy 1998, Lamprell and Whitehead 1992) and only one genus *Macoma* sp. was collected from the Kimberley that has been identified by Pearson and Rosenberg (1978) as an indicator of organic enrichment. However this mollusc was found in similar abundances at the pearl farms and reference locations.

## Comparison of our studies with other shellfish studies

In general, there is a lack of consensus regarding the environmental effects of shellfish aquaculture and this is not surprising given the different ecosystems and conditions that shellfish farms are located in.  Furthermore the husbandry practices of each farm may be very different, and these can, in turn, influence potential effects of the farm on the natural environment. There are numerous studies that suggest shellfish aquaculture can produce organic enrichment and alteration of benthic macrofauna (Mattsson and Linden 1983, Kaspar 1985, Tenore et al 1985, Stenton- Dozey et al 1999, Mirto et al 2000, Callier et al 2007) however half of these studies had limited spatial and temporal replication. In contrast, other studies suggest shellfish aquaculture to have little or no impacts (Hatcher et al 1994, Danovaro et al 2004, Goncalves da Costa and Cunha Nalesso 2006, Lasiak et al 2006) while others suggest that the conditions of the aquaculture and its environment can determine whether an impact occurs or not. For example, in Nova Scotia, one study found some biodeposition occurring under mussel lines compared to reference sites, but the sediments were not anoxic, and a diverse and active benthic community persisted regardless. They did find that the benthic community was influenced by the fallout of mussels from the farm lines, and this promoted the scavenger component of the benthic community. However, they did not find any enrichment of the sediment organic matter at the farm sites compared to reference sites (Grant et al 1995). Similarly, as mentioned previously, in New Zealand the influence of mussel farms was found to be dependant on variation in local current patterns (Chamberlain et al 2001).

Thus main mechanisms that influence the impact of shellfish aquaculture seem to be; the farming method, the density of the cultivated shellfish (or stocking rate), the water depth of the farm area and, as mentioned above, the hydrographical conditions in the area (Danovaro et al 2004). All these factors favour the northern Australian cultured pearl industry and could contribute to the lack of a benthic footprint documented by this study.

# Benefits and Adoption

The project reported here is the logical extension of two studies previously commissioned by the PPA; Enzer MEC (1998) WAFIC IDU project 00/05 and Jernakoff (2002) FRDC project 2001/099. These previous studies recommended that the PPA become pro-active in developing an ESD research capacity and a culture of constantly improving environmental monitoring and management protocols. The PPA through partnership with Seafood Services Australia Ltd (SSA) pilot program developed an Environmental Management Systems (EMS) which can be implemented at each pearl farm site in the form of an Environmental Management Plan (EMP). The specific scientific requirements of an EMS for the industry have remained ill-defined due to a general lack of documented knowledge about the environment in which the pearl leases operate.

The results of this project suggest that, in terms of pearl industry prioritizing expenditure on their Environmental Management Systems (EMS); monitoring or attempts to manage for benthic impacts should be of low priority, and if needed at all in the future, monitoring for this issue can be appropriately handled by periodic studies conducted as corporate industry research similar to this project.

## Further Development

If needed at all in the future, monitoring for this issue can be appropriately handled by periodic studies conducted as corporate industry research. Periodic studies could be conducted every 10-20 years to revalidate these results if needed, or if industry practices change radically in terms of stocking density. If results indicate benthic habitat impact is shown to have become an issue in the future the industry can adapt their EMS to respond.

## Planned Outcomes

The Planned Outcomes from this project were:

• To document the actual level of impact being caused by the activity rated as the most significant potential environmental impact.

• To trial and prove cost effective techniques for monitoring the benthic environment in and around pearl leases

- To publish results of this research in refereed and semi-popular literature

- To inform the development of an EMS for the pearling industry

- To develop an organizational capacity to initiate and co-ordinate strategic research

- To contribute to the development of a culture of best practice and self-improvement with regard to ESD issues.

- To have pearl farms that are operating, and are seen to be operating, environmentally responsibly by the general public, other users of the marine environment, and the involved government agencies;

It was expected that the immediate output of this project would be the results of a tightly focused project to determine whether or not change can be detected in the benthic environment beneath three pearling leases, which by Australian Pearl Industry standards, have been used on a consistent and intensive basis for decades.

In terms of adopting the results from this project it was predicted that this would be achieved by gauging whether they inform the EMS being developed by the PPA. The project was expected to inform the EMS process about the relative importance of ongoing benthic monitoring, the type of technique and relevant timing of future benthic studies. Informing the EMS process can be considered the first wave of adoption of the results from this study.

A second longer term process of adoption was expected to be the broader discussion of the results within industry and more broadly through education within the general community. This process of adoption would be driven by the presentation of this projects results at workshops, meetings and conferences and through publishing written accounts in a wide variety of scientific, trade and semi-popular literature. This broader community education would provide an opportunity for the PPA to advance its reputation as an environmentally progressive industry.

## Actual Outcomes

• To document the actual level of impact being caused by the activity rated as the most significant potential environmental impact.

This study has been exhaustive in the design of the sampling regime; and employed three spatial scales and random temporal sampling. We have used a multi-control sampling strategy, to give an estimate of the natural variability of the variables measured. We have also used a Beyond BACI approach to investigate the effects of removing a pearl farm that had been established for over 50 years. These multiple lines of evidence all conclude that variability in benthic conditions beneath farms in the region are within the bounds of natural variability at other locations. This final FRDC report with the attached University of Newcastle report (Appendix 4), along with the series of scientific papers in preparation (see below) thoroughly document that current pearl culture techniques in northern Australia produce no measurable impact on the benthic habitat of pearl leases.

• To trial and prove cost effective techniques for monitoring the benthic environment in and around pearl leases

This project successfully trialed proven cost effective sampling techniques, which were then deployed through the project by the staff of the pearl farms. If another study of this kind was ever considered a priority again, the same techniques could be easily re-used. The major expense of this project was sorting of the samples, which contained many poorly known taxa. In the context of monitoring of the environmental footprint of the pearl industry the lack of any detectable impacts means this level of expense to measure natural variability is not justified.

• To publish results of this research in refereed scientific journals and semi-popular literature

UoN has several draft scientific papers being prepared for publication with tentative titles as follows:

1. Jelbart, J.E. Schreider, M and MacFarlane, G. The lack of impacts of pearl oyster *Pinctada maxima* aquaculture on marine benthos in Western Australia. *Aquaculture.*
2. Dixon, K.L., Jelbart, J.E. and MacFarlane, G. A lack of impacts from pearl oyster *Pinctada maxima* aquaculture on polychaete assemblages of the north-west Australian coast. *Marine Biology.*
3. Jelbart, J.E. Schreider, M and MacFarlane, G. A "Beyond BACI" approach to detecting a lack of impacts from pearl oyster *Pinctada maxima* aquaculture on benthic conditions. *Marine Ecology Progress Series.*

Two oral presentations at the Annual Conference of the Australian Marine Science Association were given by Dr Jane Jelbart (Appendix 3).

1. 2009, Adelaide, SA. *What are the impacts of pearl oyster aquaculture on marine benthos in WA?*
2. 2007, Melbourne, Vic. *Monitoring for potential impacts of pearl oyster aquaculture on marine benthos*

One student poster was presented by Kylie Dixon at the 2007 Annual Conference of the Australian Marine Science Association in Melbourne (Appendix 3).

1. *Assessing the Impacts of Pearl Farms on Polychaete Assemblages.*

• To inform the development of an EMS for the pearling industry

The failure to detect any differences in the sediments below pearl farms suggests that expenditure on monitoring sediments within an EMS would be a waste of the industry's resources. This is because this study shows that current culture practices has no impact on the sediments or benthic fauna below the pearl leases, while the natural processes cause the sediments and benthic fauna of the Kimberley region to be highly variable in space and time. In this situation benthic monitoring programs run by pearl farms would monitor natural variation rather than the effect of the pearl leases, incurring an unnecessary level of expense for the farms.

• To develop an organizational capacity to initiate and co-ordinate strategic research

Through this project the PPA, supported by the expertise working for its member organisation, has demonstrated the capacity to engage and work with professionals and Universities to conduct field research in the difficult Kimberley marine environment.

• To contribute to the development of a culture of best practice and self-improvement with regard to ESD issues.

By pioneering the process of the PPA developing, implementing and completing corporate research projects into areas of corporate interest for the pearling industry this project has played a part in the PPA developing experience and expertise in applying a scientific approach to identifying issues and testing the basis of ESD issues for the industry. In this case existing practices have been vindicated as best practice in achieving the ESD outcomes required by the pearling industry and the community at large.

• To have pearl farms that are operating, and are seen to be operating, environmentally responsibly by the general public, other users of the marine environment, and the involved government agencies

The results of this study, vindicating existing practices as best practice with regard to the benthic habitat of the leases, fill a void in scientific information about this facet of pearl culturing in northern Australia and is being welcomed by the government agencies working with the industry in W.A., the N.T. and Commonwealth jurisdictions. Preliminary results from this project have already been used by Paspaley Pearl's Pty in negotiating the right for pearl leases to co-exist within Marine Parks in the Northern Territory. These final results should provide further support for continued 'no-footprint access' to areas on northern Australian coastal habitats which are likely be considered of increasing value for conservation.

In the longer term the extension of this project will build from the experience, processes and expertise built by the PPA R&D committee through developing and supervising this proposal. This experience will provide the basis for the PPA becoming more pro-active in developing and undertaking a broader research agenda, and for developing within the PPA membership a culture of best practice and continuous self improvement with regard to ESD issues. The scientific results demonstrating no change to the benthos below pearl leases will foster a dialogue within PPA, and between the PPA members, the broader community and government agencies, about the environmental credentials of the pearling industry and the relative priority for further research or monitoring of the benthos compared to research or monitoring of other ESD issues. The extension process included in this project will foster this dialogue through its reference group meetings, industry meetings and workshops. Discussions that take place during those meetings will enable the PPA R&D committee to develop priorities and proposals for future collaborative research.

## Evaluating Originally Stated Planned Objectives:

1. To determine the relevant scientific requirements for a pearl industry EMS.

This project successfully conducted a detailed and rigorous study that strongly suggests that monitoring the benthos below pearl farms should not be a part of the pearl industry's EMS. This study demonstrated that benthic monitoring programs run by pearl farms would incur considerable expense upon farms and simply monitor natural variation in the benthos rather than the effect of the pearl leases upon the environment.

2. To determine if the benthic physical / chemical or ecological variables beneath established pearl farms differ from the surrounding environment.

Over two and a half years this project exhaustively sampled the sediments below three *Pinctada maxima* pearl oyster farms in remote regions of the Kimberley coast. Sediment core samples were taken to measure physico-chemical parameters and grab samples collected the benthic macrofauna (>1mm in size). The physico-chemical parameters measured included the redox potential, nutrients loads (nitrogen, carbon, phosphorus and carbonates) and total organic matter. This project also tested the effect of closing down a pearl farm on the sediments and associated benthic fauna. These studies could find no consistent differences in the benthic macrofauna below the pearl oyster farms compared to independent control locations.

3. To develop the PPA's capacity to initiate and co-ordinate strategic research.

With this project the PPA has developed, implemented and completed a research project that addresses an area of corporate interest, the need for which, was identified and prioritised through ESD Risk Assessment Workshops (Jernakoff 2002). Through this project the PPA successfully developed the capacity to initiate and co-ordinate strategic corporate research, engaging and working with professionals and Universities to conduct field research in the difficult Kimberley marine environment. Through this process the PPA has developed experience and expertise in applying the scientific approach to identifying issues and testing their basis.

# Conclusions

Over the past two and a half years investigators sampled the sediments below three *Pinctada maxima* pearl oyster farms in remote regions of the Kimberley coast. Sediment core samples were taken to measure physico-chemical parameters and grab samples collected the benthic macrofauna (>1mm in size). The physico-chemical parameters measured included the redox potential, nutrients 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 (Hargrave et al 1997). Each farm was compared to 4 control locations (total = 12 control locations) within the same region. There was no indication of eutrophication (nutrient enrichment) at any of three pearl farms studied in the Kimberley region. There were also no consistent differences in the benthic macrofauna below the pearl oyster farms when compared to control locations.

Investigators also tested the effect of closing down a pearl farm on the sediments and associated benthic fauna. A pearl farm was sampled that had been in operation for almost 50 years (Otama pearl farm, Kuri Bay) but scheduled for closure for logistical reasons. Sampled sediments were taken under the longlines before the farm was closed and two further sampling periods were conducted after closure (1 year and 2 years after). For each sampling period, samples were taken of the sediments of three reference locations. This allowed a Before-After-Control-Impact (BACI) analysis to be performed. It was discovered that the sediments under the longlines before and after the farm closure were not different to those of the reference locations.

These studies found no indication of eutrophication (nutrient enrichment) on any of the pearl farms which were selected on the basis of having extensive histories of continual use. Nor could this study find any consistent differences in the benthic macrofauna below the pearl oyster farms compared to independent control locations.

This study has been exhaustive in the design of the sampling regime; and employed three spatial scales and random temporal sampling. We used a multi-control sampling strategy, to give an estimate of the natural variability of the variables measured. We also used a Beyond BACI approach to investigate the effects of removing a pearl farm that had been established for over 50 years. These multiple lines of evidence all showed that variability in benthic conditions beneath farms in the region are within the bounds of natural variability at other locations. In terms of observable impacts on benthic macrofauna and sediment physico-chemistry, current pearl farming practices in the Kimberley region can clearly be considered ecologically sustainable.

The main mechanisms that influence the impact of shellfish aquaculture seem to be the farming method, the density of the cultivated shellfish (or stocking rate), the water depth of the farm area and the hydrographical conditions in the area (Danovaro et al 2004). All these factors appear to favor the northern Australian cultured pearl industry and would contribute to the lack of a benthic footprint documented by this study.

The results of this project suggest that, in terms of the pearl industry prioritizing expenditure on their Environmental Management Systems (EMS) monitoring or attempts to manage for benthic impacts should be of low priority. If needed at all in the future, monitoring for this issue can be appropriately handled by periodic studies conducted as corporate industry research. Periodic studies conducted every 10-20 years could revalidate these results if considered necessary, or test the effect, if any, of a radical change to stocking density, in the unlikely event of that occurring. If results then indicated potential for benthic habitat impact to become an issue in the future the industry could then adapt their EMS to respond to that situation.

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# Appendix 1: Intellectual Property

The data collected, and the intellectual property developed this project's research, regarding sediment and benthic fauna of the Kimberley coast, are for public and scientific publication.

# Appendix 2: Project Team

**Project Team.**

| | |
|---|---|
| Brett McCallum | Executive Officer, Pearl Producers Association |
| Dr Scott Gifford | Post Doctoral Fellow, University of Newcastle |
| Dr Jane Jelbart | Post Doctoral Fellow, University of Newcastle |
| Ms Kylie Dixon | Honors Student, University of Newcastle |
| Dr Geoff MacFarlane | Senior Lecturer, University of Newcastle |
| Dr Maria Schreider | Lecturer, University of Newcastle |
| Dr Jeremy Prince | Marine Ecologist, Biospherics P/L |
| Dr David Mills | Paspaley Pearls P/L |
| Mr James Brown | Cygnet Bay Pearls P/L |

# Appendix 3: AMSA Abstracts

## Abstract for AMSA 2007

## Monitoring for potential impacts of pearl oyster aquaculture on marine benthos

**Jane Jelbart[1],** Scott Gifford[1], Kylie Dixon[1], Mary Greenwood[1], Maria Schreider[1], Jeremy Prince[2], Geoff MacFarlane[1]

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The pearl oyster (*Pinctada maxima*) industry in Western Australia has been well established for decades. However, there has been no investigation of its potential environmental impacts, until now. Pearl oysters have the potential to enrich the benthic layer under the farms through the deposition of faeces and pseudo-faeces. In addition, periodic husbandry practices remove epiphytic growth from the pearl shells on location, which may settle and accumulate under the farms. For these reasons, the benthos below three pearl oyster farms was compared to 4 control locations for each farm (total = 12 control locations). Sediment core samples were taken to measure physico-chemical parameters and grab samples collected the benthic macrofauna (>1mm in size).

At all three pearl farms, a preliminary investigation has found no significant differences between the benthic macrofaunal assemblages below the pearl oyster farms when compared to control locations. The macrofauna assemblage was also tested for a correlation with the sediment physico-chemical parameters to uncover any abiotic influences on community structure. The sediments at all three farms were not organically enriched as typical of some other shellfish aquaculture industries. This is of particular note as these farms are some of the longest operating in Australia (~50 years).

## Abstract for AMSA Poster 2007

# The impact of pearl aquaculture on polychaete assemblages in Western Australia

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Pearl aquaculture is well established on the northern west Kimberley coast of Western Australia, yet little is known in regard to the environmental condition of benthos below pearl leases. The principal environmental concern of shellfish aquaculture is the deposition of faeces and pseudofaeces produced by the cultured shellfish and the regular cleaning of associated fouling organisms from oyster shell. Biological waste may accumulate sufficiently to modify physico-chemical characteristics of the benthos below the pearl lease. This, in turn, may impact associated macrobenthic infauna. Benthic communities can influence surface productivity, alter the physical and chemical condition of the sediment and sediment-water interface, and transfer energy to higher trophic levels. Polychaete assemblages are widely employed as indicators of habitat condition and for the detection of human induced change. Three pearl leases were selected for this study as they have a relatively long history of farming activity. Specifically, the polychaete assemblage below each pearl farm was compared to 4 nearby control locations that were at a distance of 1 kilometre or greater from the lease location. Both uni- and mulitvariate analyses suggest that no consistent impact is evidenced at pearl leases in terms of polychaete assemblages. The farm locations exhibited similar abundance and diversity of polychaete taxa when compared to control locations.

## Abstract for AMSA 2009

# Does pearl oyster aquaculture have an impact on marine sediments and benthic fauna in Western Australia?

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The pearl oyster (*Pinctada maxima*) aquaculture industry in the Kimberley region of Western Australia has been established for decades. However, the potential environmental impact of this aquaculture has not been investigated for this region until now. Pearl oysters may also have the potential to enrich the benthic layer under the farms through the deposition of faeces and pseudo-faeces. Other aquacultures (such as some finfish and shellfish) have caused eutrophication of the marine sediments and a concurrent change in the benthic assemblages. However, our investigation has not found this to occur in pearl oyster aquaculture.

Over the past two and a half years we have sampled the sediments below three pearl oyster farms in remote regions of the Kimberley coast. Sediment core samples were taken to measure physico-chemical parameters and grab samples collected the benthic macrofauna (>1mm in size). Each farm was compared to 4 control locations (total = 12 control locations) within the same region. At all three pearl farms there were no indications of eutrophication. There were also no consistent differences in the benthic assemblages below the pearl oyster farms when compared to control locations.

In this presentation we describe the biodiversity of the region, including the natural variability and connectivity of the benthic assemblages. We also attempt to explain why some of this variability occurs in the region and the spatial scales of this connectivity. This project has increased our knowledge of the distribution and abundance of benthic fauna in the Kimberley region. It has been a successful collaboration between pearl farmers, academic scientists and museum taxonomists. The project has also given the scientific community greater access to remote regions of Australia and facilitated the description of new species to science.

## Appendix 4: University of Newcastle Report