Department of
Primary Industries and
Regional Development

GOVERNMENT OF
WESTERN AUSTRALIA

We're working for
Western Australia.

Fisheries Research Report 330

Ecological Risk Assessment for the Western Australian Silverlip Pearl Oyster (*Pinctada maxima*) Resource

K.A Smith, S. Brown, A. Bissell and A.M. Hart.

January 2023

Correct citation:

Smith K.A., Brown S, Hart A.M and Bissell A. (2023). Ecological Risk Assessment for the Western Australian Silverlip Pearl Oyster (*Pinctada maxima*) Resource. Fisheries Research Report No. 330. Department of Primary Industries and Regional Development, Western Australia. 90 pp.

Enquiries:

WA Fisheries and Marine Research Laboratories,
PO Box 20,
North Beach, WA 6920

Tel: +61 8 9203 0111
Email: library@fish.wa.gov.au
Website: fish.wa.gov.au

A complete list of Fisheries Research Reports is available online at **fish.wa.gov.au**

Department of Primary Industries and Regional Development
Gordon Stephenson House
140 William Street
PERTH WA 6000
Telephone: (08) 6551 4444
Website: dpird.wa.gov.au
ABN: 18 951 343 745

ISSN: 2202-5758 (Online) ISBN: 978-1-921845-15-4 (Online)

Table of Contents

List of Acronyms

ARMA	*Aquatic Resources Management Act 2016*
B_{MSY}	Biomass at Maximum Sustainable Yield
DBCA	Department of Biodiversity, Conservation and Attractions
DPIRD	Department of Primary Industries and Regional Development (Department)
EBFM	Ecosystem-Based Fisheries Management
EPBC	*Environment Protection and Biodiversity Conservation Act 1999*
ERA	Ecological Risk Assessment
ESD	Ecologically Sustainable Development
TEPS	Threatened, Endangered and Protected Species
FRDC	Fisheries Research and Development Corporation
FRMA	*Fish Resources Management Act 1996*
FRMR	*Fish Resources Management Regulations 1995*
GPS	Global Positioning System
MOP	Mother of Pearl
MoU	Memorandum of Understanding
MPG	Ministerial Policy Guideline
MSC	Marine Stewardship Council
NT	Northern Territory
OOD	Oyster Oedema disease
PA	*Pearling Act 1990*
PPA	Pearl Producers Association
SAWG	Stock Assessment Working Group
SL	Dorso-ventral Shell Length, excluding growth ‘fingers’
TAC	Total Allowable Catch
TACC	Total Allowable Commercial Catch
VMS	Vessel Monitoring System
WA	Western Australia
WAFIC	Western Australian Fishing Industry Council
WTO	Wildlife Trade Operations

Executive Summary

In August 2022, the Department of Primary Industries and Regional Development (DPIRD) convened an ecological risk assessment (ERA) of the fishery and aquaculture operations that access the Western Australian (WA) Silverlip Pearl Oyster (*Pinctada maxima*) resource (Resource).

The ERA considered the potential ecological impacts of the WA commercial Silverlip Pearl Oyster Fishery and related aquaculture activities including hatchery and seeding operations. The assessment evaluated the impact of each activity on all relevant retained and discarded species; threatened, endangered and protected species; habitats and the broader environment. Risks associated with aquaculture activities were also considered, including genetic impacts on wild stock, and translocation of pests or diseases.

A broad range of external stakeholders including representatives of the commercial fishing and aquaculture sectors, State and Commonwealth Government agencies, the conservation sector, universities and DPIRD staff including Fisheries Management, Research, Compliance, Biosecurity and Aquaculture personnel, were invited to participate in the ERA workshop.

Risk scores were determined based on available scientific information and expert knowledge on species, fishing and aquaculture activities, fishery regulations and management. The assessment conforms to the AS/NZS ISO 31000 risk management standard, and to the methodology adopted by the Department which relies on a consequence-likelihood analysis for estimating risk.

Twenty six ecological components were scored for risk. The vast majority (25) of ecological components were evaluated as low or negligible risks, which do not require any specific control measures. There was one medium risk, which was assessed as acceptable under the current monitoring and control measures already in place. The ERA did not yield any high risks.

It is recommended that the risks be reviewed in five years.

1.0 Introduction

The Department of Primary Industries and Regional Development (DPIRD, Department) in Western Australia (WA) uses an Ecosystem-Based Fisheries Management (EBFM) approach that considers all relevant ecological, social, economic and governance issues to deliver community outcomes (Fletcher *et al.* 2010; 2012). Ecological risk assessments (ERA) form part of this management framework and are undertaken periodically to assess the impacts of fisheries on all the different components of the aquatic environments in which they operate. Outcomes of ERAs are used to:

- inform EBFM-based harvest strategies;
- prioritise DPIRD's monitoring, research and management activities (Fletcher 2015; Fletcher *et al.* 2016), and
- inform external processes such as Marine Stewardship Council (MSC) certifications and Wildlife Trade Operation (WTO) approvals.

This report provides background information relating to an ERA for the Western Australian Silverlip Pearl Oyster (*Pinctada maxima*) resource (Resource) that was conducted on 3 August 2022. The assessment considered the potential ecological impacts of the commercial fishery for this Resource and related aquaculture activities including hatchery and seeding operations.

The risk assessment methodology utilised a consequence-likelihood analysis, which involves examining the magnitude of potential consequences from fishing activities and the likelihood that those consequences will occur given current management controls.

The scope of the ERA is for the next five years (through to 2027). It is envisioned that ERA's for the Resource will be undertaken periodically (approximately every five years) to reassess any current or new issues that may arise. However, a risk assessment can also be triggered earlier if there are significant changes identified in fishery operations or management activities that may change current risk levels. Following implementation of the *Aquatic Resources Management Act 2016* (ARMA), anticipated to be in late 2023, DPIRD will review current risk levels against the revised management arrangements.

This report is intended be read in conjunction with the MSC Assessment Report for this resource (Hart et al. 2016) which provides a comprehensive overview of the WA pearling industry.

2.0 The Resource

In the context of this ERA, the Resource is the wild stock(s) of the Western Australian Silverlip Pearl Oyster (*Pinctada maxima)* in WA waters. The Resource is accessed by a single commercial fishery which harvests individual adult pearl oysters from the wild and also operates hatcheries that produce and rear juvenile pearl oysters derived from broodstock collected in WA waters. Both wild-caught and hatchery-reared oysters are grown-out together on farm leases in WA marine waters.

3.0 Aquatic Environment

The pearling industry operations in WA occur from Exmouth Gulf northwards to the Northern Territory (NT) border, encompassing two Bioregions (Figure 3.1). Most activity occurs in the North Coast Bioregion along the Pilbara and Kimberley coasts. Wild pearl oysters are mainly collected off Eighty Mile Beach and in a channel between the mainland and the Lacepede Islands at approximately 10 to 20 m depths. The remainder of activity occurs in Exmouth Gulf within the Gascoyne Coast Bioregion.

3.1 North Coast Bioregion

Coastal waters of the North Coast Bioregion are generally low-energy in terms of wave action, but are heavily influenced by macro-tides and are seasonally (December to March) influenced by intense tropical cyclones, storm surges and associated rainfall run-off. These cyclone events generate the bulk of the rainfall, although the Kimberley section of the coastline also receives monsoonal rainfall over summer.

Significant river run-off and associated localised coastal productivity can be associated with cyclone events, with run-off ceasing during winter. Despite localised areas of high productivity, the Bioregion is generally oligotrophic and large areas of the coastline receive no riverine input. The entire North Coast Bioregion is subject to very high evaporation rates (3 metres per year). The Pilbara coastline is more arid than the Kimberley due to lower rainfall. Ocean temperatures range from 22°C to 33°C, with localised higher temperatures in coastal waters, particularly along the Pilbara coast.

The macro-tidal regime is a result of the wide continental shelf and the convergence of ocean currents. Spring tides range from more than 2 metres in the West Pilbara to more than 11 metres along the Kimberley section of the coast.

The generally tropical low-nutrient offshore waters can, in the few small locations with large adjacent rivers, be significantly influenced by rainfall run-off and tidal mixing to generate varying water quality in different sections of the North Coast Bioregion. Along the Kimberley coastline, waters are turbid and in areas locally productive, while the Pilbara Coast with its lower run-off and lesser tidal influence has the clear, low productivity waters more typical of the tropics.

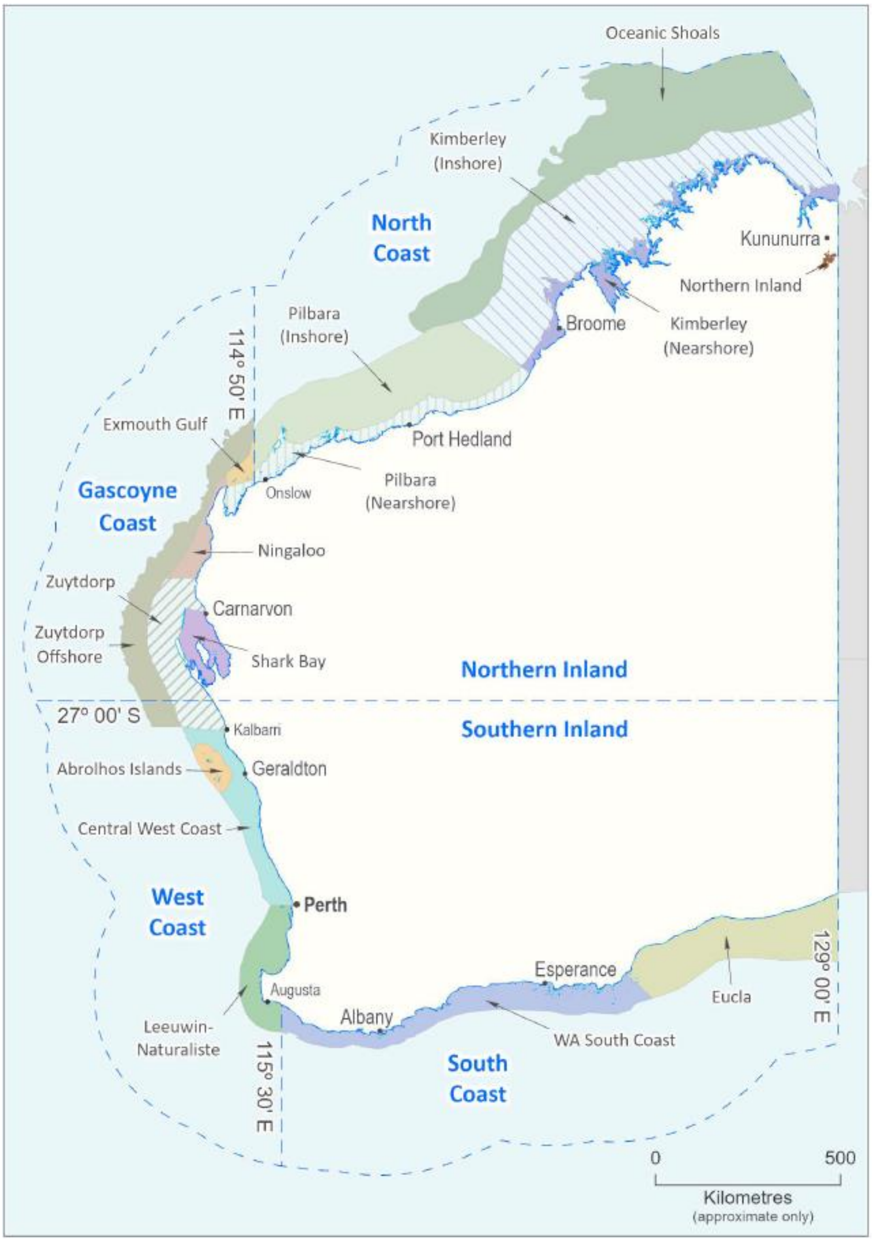


Figure 3.1. Map of WA Bioregions and Integrated Marine and Coastal Regionalisation of Australia (IMCRA) ecosystems.

The coastal geography of the Kimberley Coast is complex, with bays and estuaries backed by a hinterland of high relief. The large tidal amplitudes and the extensive and complex coastline combine to produce ecologically diverse and highly productive intertidal areas including wide expanses of mud flats, sand banks, coral and algal reef flats, mangrove forests and beaches. Subtidal habitats include macroalgal reefs, corals, seagrasses and filter-feeding communities. Mangrove communities are well developed along the Kimberley coast. Extensive and diverse intertidal seagrass meadows occur around islands in the western Kimberley. Filter-feeder communities (e.g., sponge beds) are patchily distributed and vary in spatial extent, diversity and cover, but generally appear to be associated with stable, hard substrates overlain by sand veneers in areas of gently shelving bathymetry. Coral communities are not well developed in the western Kimberley. Coral communities become well developed in nearshore environments north and east of Cape Leveque, except within King Sound due to high water turbidity.

Coastal and shallow water habitats along the Pilbara coast include mangrove forests, macroalgae and seagrass beds and fringing coral reefs around some of the nearshore islands. In addition to clear-water coral reefs, the Pilbara coast also hosts turbidity-adapted hard coral communities in nearshore environments, notably those in the Dampier Archipelago. The eastern Pilbara Coast is more exposed than the Kimberley, with few islands and extensive intertidal sand flats. Softer sediments and mangroves occur around the river entrances. The western Pilbara coastline is characterised by a series of significant but low-relief islands including the Dampier Archipelago, Barrow Island and the Montebello Islands. Nearshore coastal waters include rocky and coral reef systems, creating significant areas of protected waters. West Pilbara shorelines also include areas of soft sediment and mangrove communities.

Integrated Marine and Coastal Regionalisation of Australia (IMCRA) ecosystems in the North Coast Bioregion are illustrated in Figure 3.2, and current and proposed marine protected areas in the North Coast Bioregion are provided in Figure 3.3.

For a detailed description of benthic habitats in the North Coast Bioregion, particularly those in pearling areas, refer to Section 12.1 in Hart *et al.* (2016).

3.2 Gascoyne Coast Bioregion

The Gascoyne Coast Bioregion represents a transition zone from the warm, tropical waters of northern WA and the cooler, more temperate waters in the southwest. Offshore ocean temperatures range from about 22°C to 28°C, while the inner areas of Shark Bay regularly fall to 15°C in winter. Rainfall averages ~300 mm annually, with rain experienced in winter and summer because of the influence of tropical cyclones, the incursion of warm, moist air from the Kimberley region and mid-latitude depressions. Tropical cyclones with wind speeds more than 40 – 50 knots occur in the north around Exmouth Gulf every three to five years, with less intensive systems occurring annually from January to March (Fletcher *et al.* 2006).

The Gascoyne coastline is characterised by high cliffs in the southern half, changing to fringing coral reefs in the north. Coastal waters generally experience high wave energy due to the strong trade wind system. Exmouth Gulf is seasonally influenced by extreme tropical summer cyclones, while Shark Bay receives infrequent cyclones, but is affected at times by river outflows from inland cyclone-based summer rainfall. The sea floor of Shark Bay and the continental shelf are typically sandy compared to Exmouth Gulf, which has more mud areas and greater turbidity. Ningaloo Reef in the north of the Bioregion is the largest continuous reef in WA and is one the most significant fringing reefs in Australia. The Bioregion has areas of mangroves, mostly in Exmouth Gulf, and seagrass beds also occur in some areas.

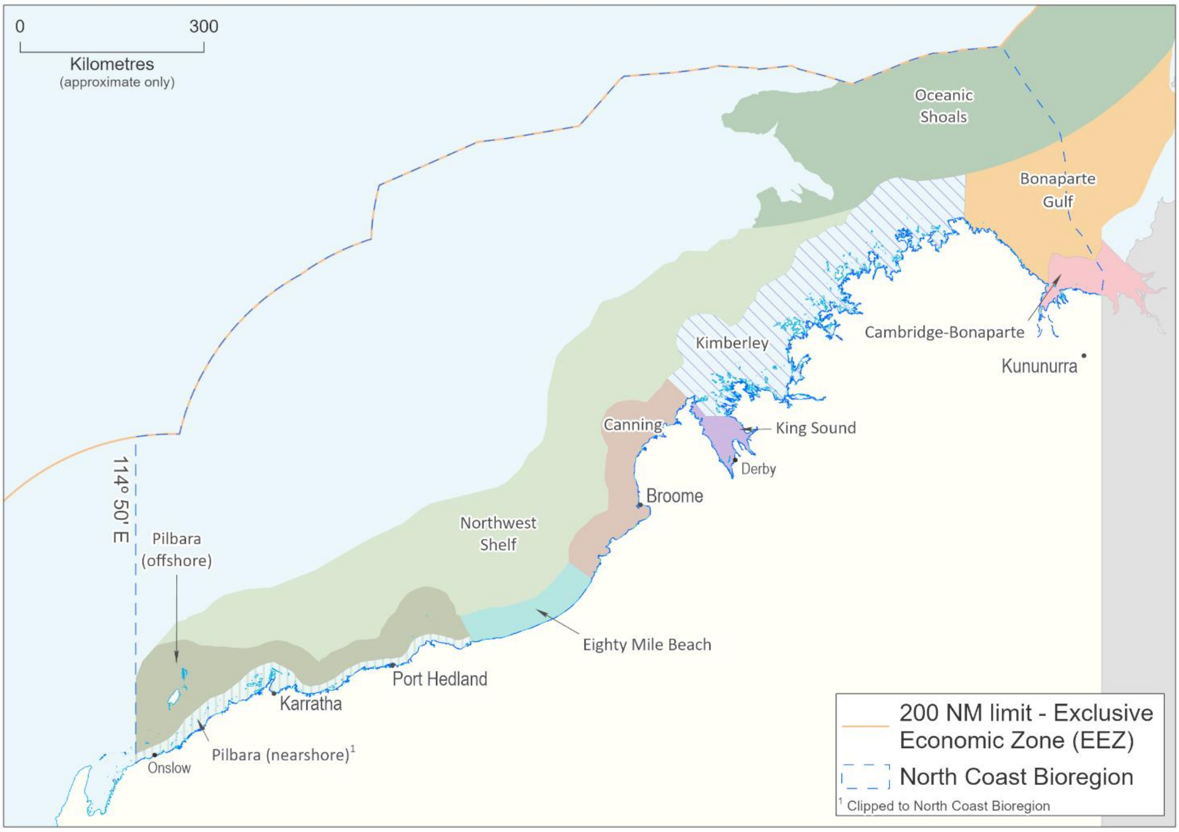


Figure 3.2. Integrated Marine and Coastal Regionalisation of Australia (IMCRA) ecosystems in the North Coast Bioregion.

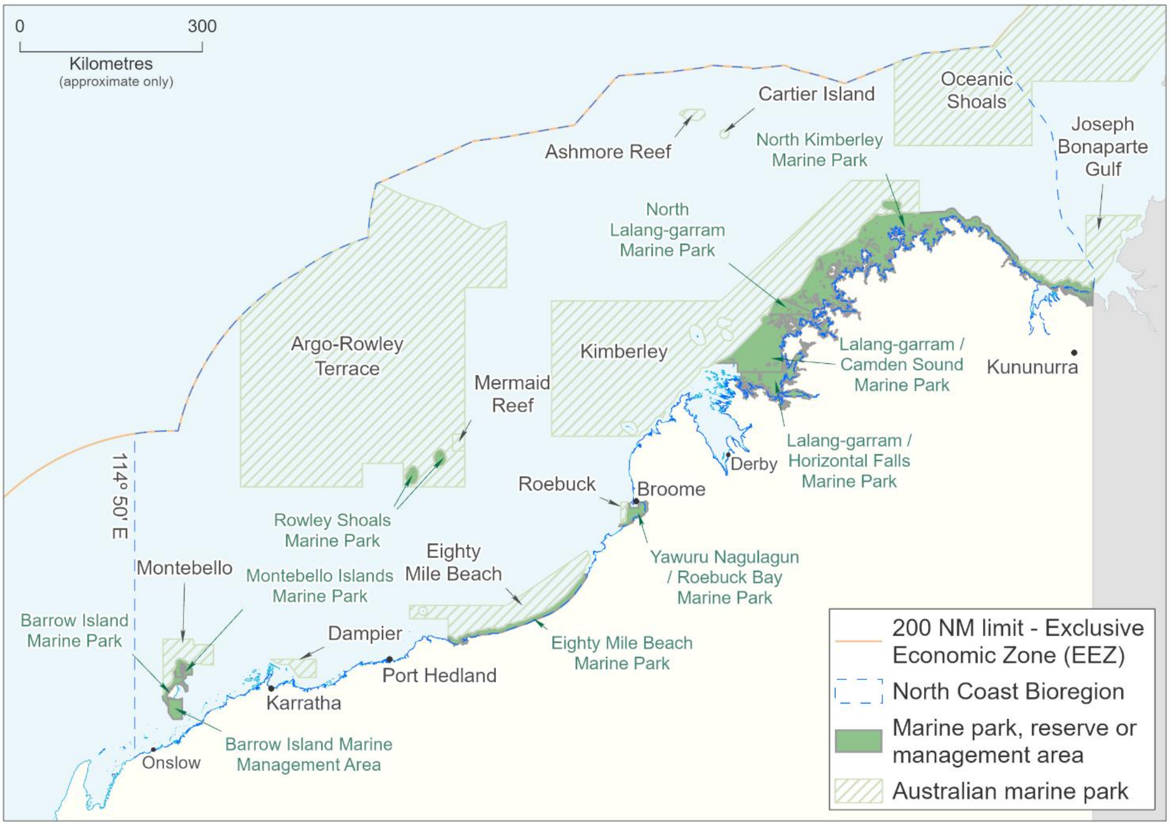


Figure 3.3. Current and proposed North Coast Bioregion State and Commonwealth marine parks and reserves.

4.0 WA Pearl Oyster Managed Fishery

4.1 History of Development

For further information about the history of the WA pearling industry refer to Section 2.1 of Hart *et al.* (2016). A short summary is provided below.

Pinctada maxima was discovered in WA near Nickol Bay in the 1860s, and a fishery harvesting this species for Mother of Pearl (MOP) developed shortly after. *P. maxima* pearl culture activities began in Kuri Bay in the Kimberley region during the 1950s and by the end of the 1970s, most of the pearling industry had moved into cultured pearl production. In the 1980s it was agreed that the prime use of pearl oysters would be for pearl culture, with MOP production a secondary objective, and quotas and minimum size limits were implemented to protect the breeding stock. Due to these changes, many deeper historical fishing beds were no longer harvested.

Prior to the development of hatchery technology in the 1990s, the WA pearling industry relied on the capture of live pearl oysters from the wild, which were seeded to stimulate pearl formation, then moved to pearl leases for the grow-out of pearls. In recent decades, pearl oysters produced from hatcheries has become an important source of pearl oysters for seeding, providing an alternative stock source to the wild stocks and allowing producers to selectively breed for specific characteristics.

4.2 Current Fishing and Aquaculture Activities

The WA pearling industry is the world's top producer of highly prized, silver-white 'Australian South Sea Pearls', which are cultivated within the Silverlip Pearl Oyster (*P. maxima)*. The pearls produced in WA are well regarded in the industry worldwide, with the value of cultured pearls and other related products estimated to be AUD $64.5 million in 2021. In addition to pearls, which are supplied to a global market, pearl meat and Mother of Pearl (MOP) for watch faces, buttons and inlay work are sold nationally and internationally.

The WA pearling industry is comprised of three vertically integrated components (Figure 4.1):

1. Collection of pearl oysters from the wild.
2. Production and grow-out of hatchery-produced pearl oysters, and initiation of cultured pearl production within wild or hatchery oysters via a seeding operation. The seeded oysters are then grown-out on pearl oyster farm leases to produce cultured pearls (aquaculture)
3. Pearl oysters collected from the wild, as well as hatchery-produced pearl oysters, used for MOP and pearl oyster meat.

Fishing of the Resource mainly occurs on the Northwest Shelf of Australia, primarily off the southern Kimberley Coast, at Eighty Mile Beach in water depths of 10-35 metres. Fishing has also historically occurred in Zone 1 and Zones 3 (Lacepede Islands) (Figure 4.2).

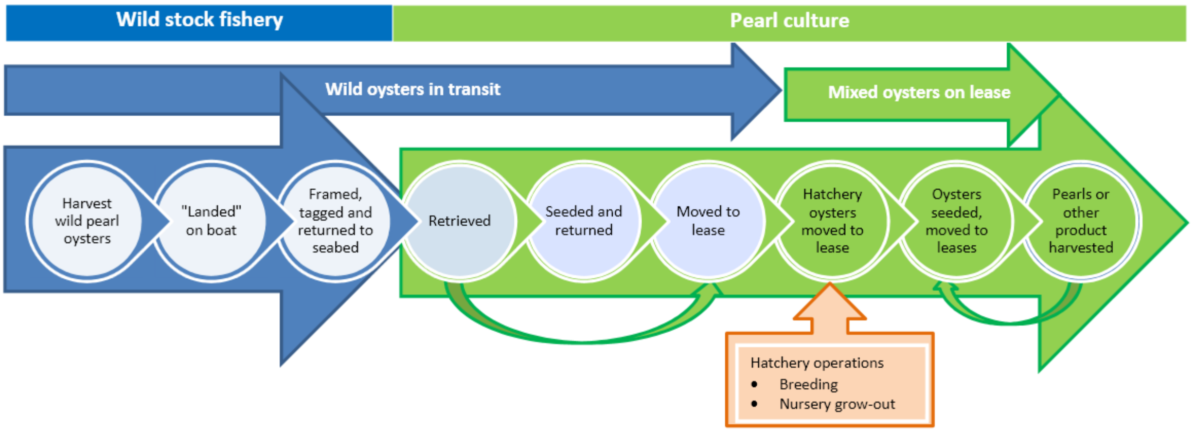


Figure 4.1. Overview of the pearling industry, which integrates capture of wild oysters with hatchery-produced stock for pearls, mother-of-pearl, and oyster meat production

The WA Pearl Oyster Managed Fishery currently comprises 15 wild stock licences that are permitted to take *P. maxima* from Exmouth Gulf to the NT border in three of the four management zones (Figure 4.3).

The number of active vessels in the fishing fleet has been slowly reducing from a peak of 16 in 1997, mostly due to increased fleet efficiency and high densities of wild stock populations. The number of vessels fishing in 2021 was three. Most vessels presently operate 10-14 crew for the fishing of pearl oysters between March and August each year. These vessels also support other pearl production activities throughout the year. The WA pearling industry currently employs about 300 full time equivalent (FTE) positions (Hart *et al.* in prep.).

Highly trained divers collect *P. maxima* while being towed behind large (~ 35 m long) boats that are often custom designed for the pearling industry (Figure 4.4).

Collection activities generally occur for three to four months per year, usually over the winter season. Fishing for pearl oysters generally involves the extension of booms outwards from each side of the vessel (Figure 4.4), with several weighted ropes hung vertically from each boom to a height of approximately one to two metres above the seabed. Currently, most boats use four lines per boom, which allows eight divers to work simultaneously. Divers operate on hookah with air supplied from a surface compressor. Coded signals are used by the head diver to communicate with the crew on the boat to control factors like the speed and direction of the boat and height of the weights, etc. Since water clarity is paramount to divers being able to identify pearl oysters on the sea floor, significant effort is made to ensure the weight does not strike the sea floor. Therefore, the diver will signal to the vessel to raise the weight according to the sea floor height to avoid bottom disturbance.

During fishing activities, the vessel begins “drifting” (towing) at one end of a pearl oyster patch and moves slowly across the patch at a rate of about one knot. The engine remains in gear to maintain steerage of the vessel, but even at minimum speed, the boat moves too fast for the divers, and so a stern drogue is deployed to act as a sea anchor and slow the boat. Ropes attached to the drogue can be manipulated to open the drogue fully and slow the boat or partially close it to increase speed.

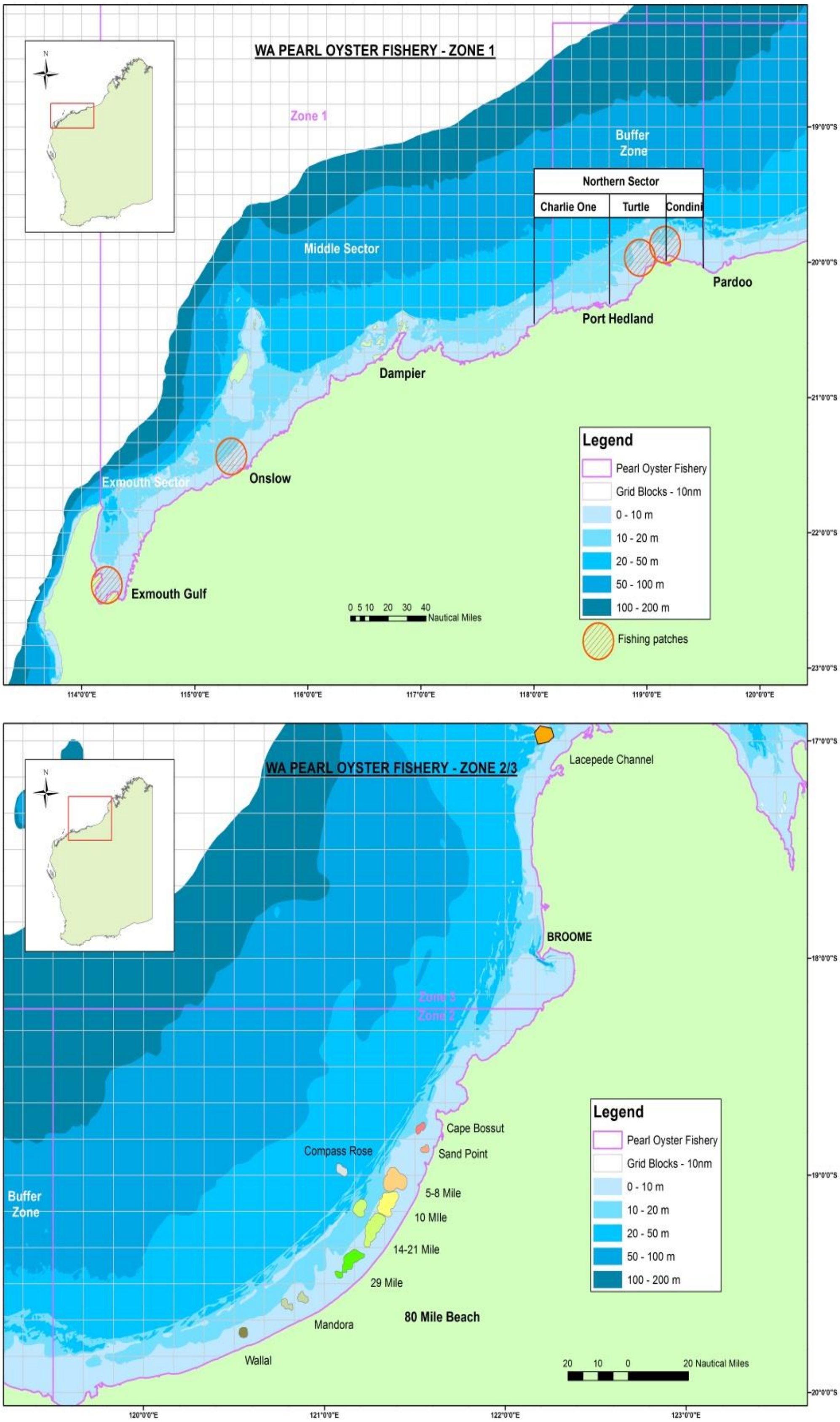


Figure 4.2. Western Australian Pearl Oyster Fishery main 'fishing patches' (hatched areas) in Zone 1 (top) and (coloured areas) in Zones 2/3 (bottom). Water depth indicated in blue.

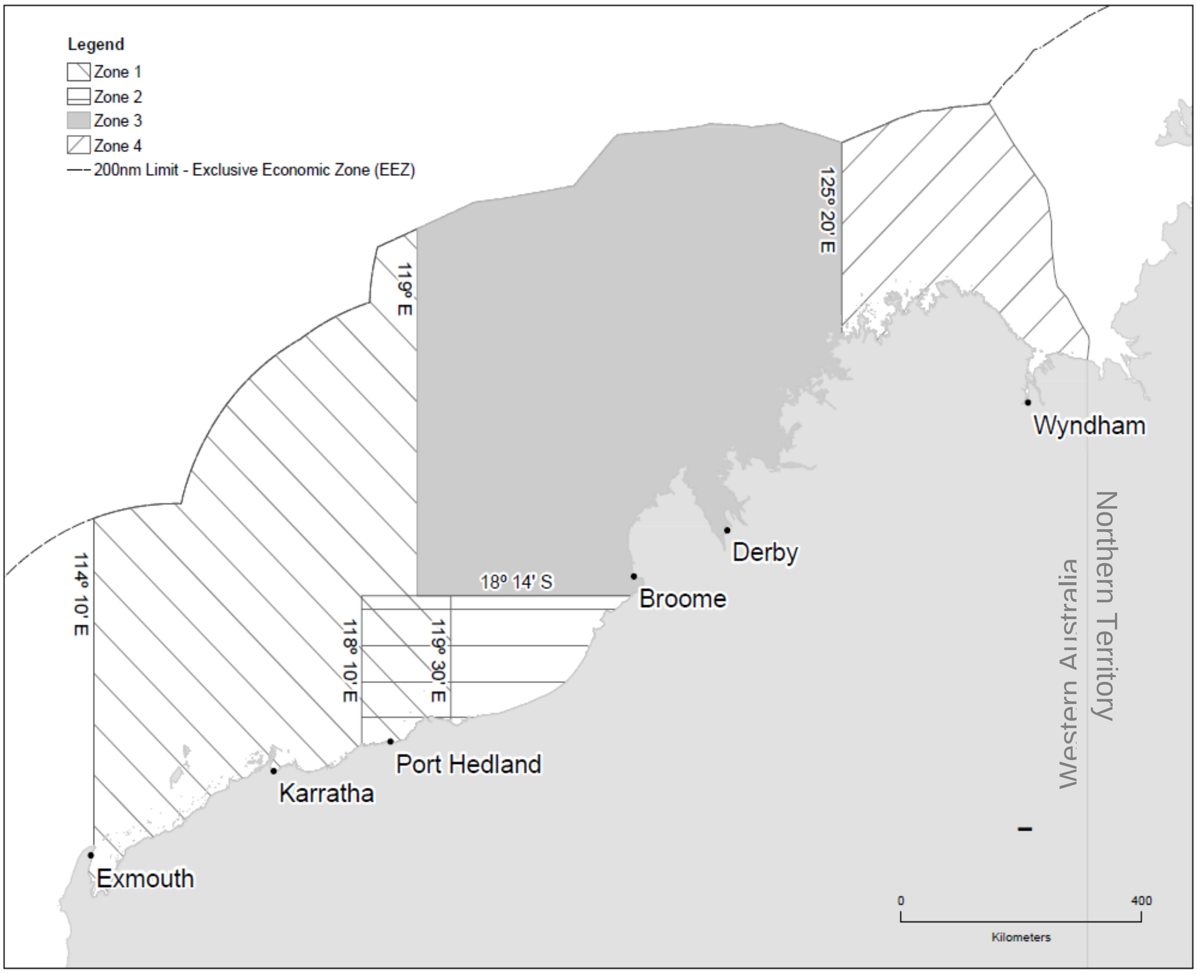


Figure 4.3. Western Australian Pearl Oyster Fishery fishing boundaries and zones.

Each diver wears a neck bag during the dive (Figure 4.4), and as pearl oysters are collected, they are stored in the neck bag. Only pearl oysters deemed appropriate size and shape are collected. Once the neck bag is full, the collected oysters are transferred to a holding bag at the end of the diver's weighted rope. Divers swim about 1.5 metres off the seabed to obtain maximum field of view (Figure 4.4). Even in murky water, when divers swim closer to the bottom, they are still above the bottom substrate. Each diver makes an average of eight to ten dives per day (Fletcher *et al.* 2006).

Larger oysters (i.e., >175 mm SL) are not suitable for pearl production but may be specifically harvested for MOP shell.

At the end of the dives, collected pearl oysters are brought on deck and graded. Pearl oysters that do not meet size or shape criteria are returned immediately within the vicinity of where they were taken. Encrusting organisms are scraped off the shells of retained oysters and returned to the ocean. A hose is then used to rinse the pearl oysters; no chemicals are used in the process. If the pearl oysters are to be used for culturing purposes, they are placed in transport panels on the boat that hold up to 16 animals each, and every panel is individually tagged to indicate which company has collected the pearl oysters. Serially-coded lockable tags are issued to licensees by the Department annually based on quota allocations. If the pearl oysters are to be used

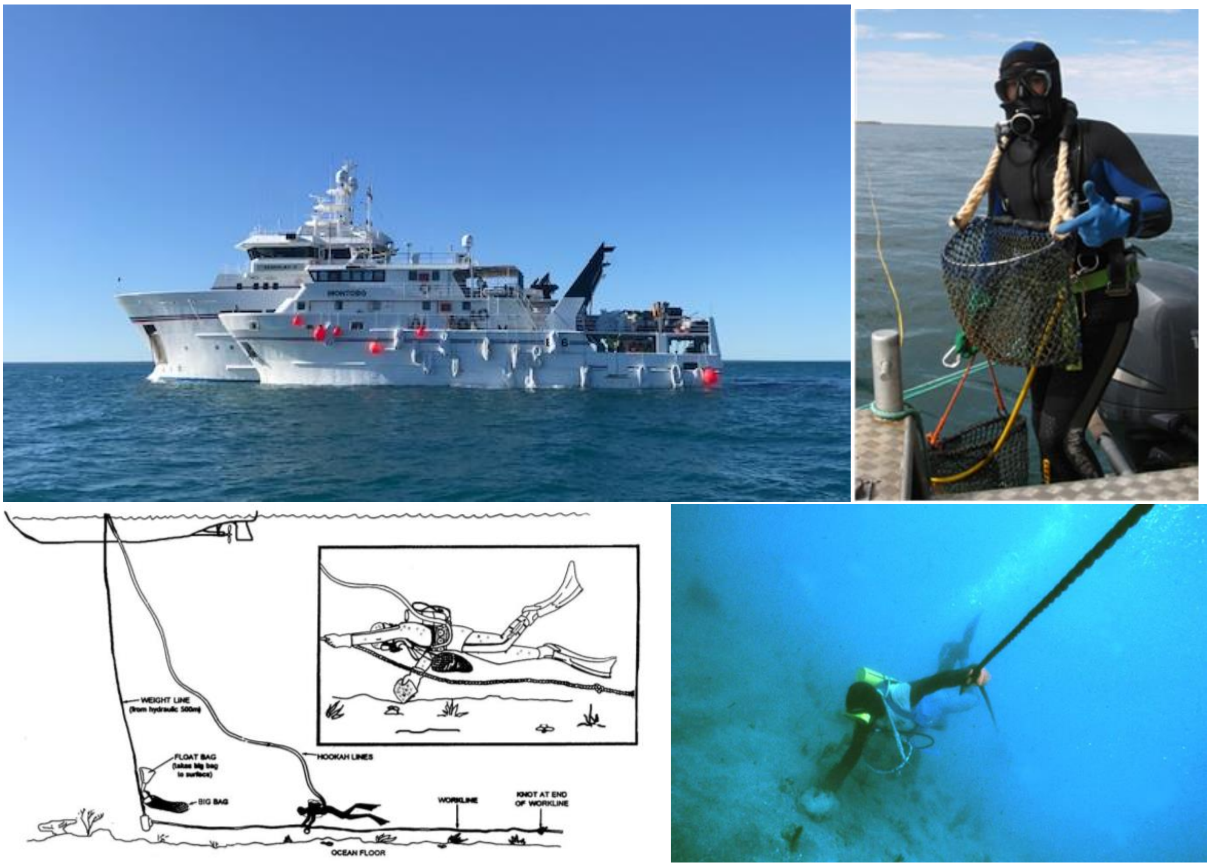


Figure 4.4. Pearl oyster industry vessels and diver (top); schematic of pearl oyster diving operations (bottom left) and photo of diver collecting a pearl oyster (bottom right). Source: PPA (2008a)

for MOP purposes they will be placed in an approved container (as approved by pearling inspectors) and also tagged.

Once all pearl oysters have been placed in the panels, they are taken to a resting site (and subsequently moved to a holding site) or are moved directly to a holding site (generally located near the fishing grounds), where they are placed on the seabed in a marked area by divers for later collection. Pearl oysters are moved from fishery areas to the resting and/or holding sites in accordance with Regulation 42 of the WA *Pearling (General) Regulations 1991* and Part 13A of the WA *Fish Resource Management Regulations 1995* (FRMR).

At the holding site, the panels are attached at 900 mm intervals to lines, which may be several hundred metres long. Resting sites are used on a temporary basis and are marked with surface buoys to allow relocation.

The sea floor at resting and holding sites is deliberately selected to be very similar to the fishing grounds. Thus, they are mostly sand bottom with occasional sponges, soft corals, sea fans, and other fauna present, including some *Turbinaria* corals (Fletcher *et al.* 2006). The seafloors in these areas must be sufficiently hard that the panels do not sink into the sediment.

Applications for holding sites are considered under *Ministerial Policy Guidelines* (MPG) *17*, with a holding site typically gazetted for a three-year term (under Section

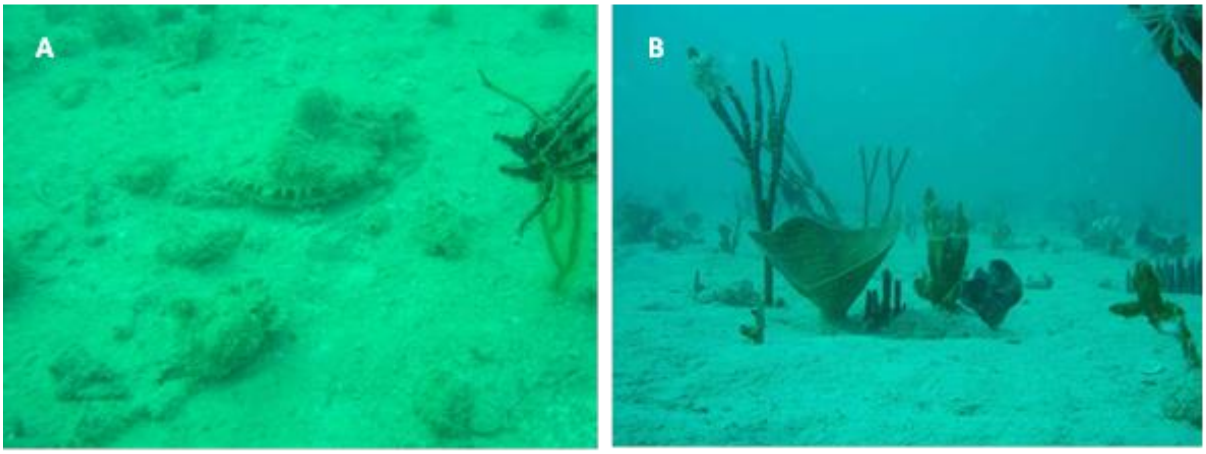


Figure 4.5. Example of the two main benthic habitat types encountered in the WA Pearl Oyster Fishery: (a) 'potato' bottom (with pearl oyster) and (b) 'garden' bottom

19 of the PA). In practice, pearling companies generally re-apply to use the same holding sites, and the same sites are used for decades.

Use of holding sites to store shell is strictly seasonal. Operators are required to remove all shell from holding sites by 31 December each year (unless otherwise specified) and anchoring infrastructure at these sites must be removable.

Individual holding sites must not exceed 4 nm^2. In 2021 there was a total of 28.34 nm^2 of pearl holding sites. All holding sites occur in waters of less than 30 m depth.

Pearl oysters seeded on holding sites are 'rested' at the site for 2-3 months and are turned by divers every 2-5 days to ensure proper pearl development. The panels of seeded pearl oysters are then transported by boat to a pearling lease.

The pearling industry recognises a variety of bottom types within the fishing grounds and has developed names for them, including:

- 'Potato' bottom areas (Figure 4.5a) are dominated by low, round, densely packed ascidian species, which live attached to the bottom. The seafloor has a flat plate of underlying rock, overlain with a few millimetres of sand. In areas of heavy 'potato' bottom, the ascidians are almost completely dominant. Sponges are the next main group, with a large variety of vase-shaped, basket and massive sponges up to 0.5 metres high interspersed with smaller sponges only a few centimetres high. Other taxa may occur at low densities. Total species diversity is low, with very few corals present. Bare sand patches can be interspersed between areas of 'potato' bottom, and faunal density rapidly decreases in areas where sediment is 2 – 3 cm deep.
- 'Garden' bottom (Figure 4.5b) is a very diverse assemblage dominated by hydroids. The hydroids grow rapidly up to one metre in height and quickly become encrusted with a variety of organisms. Distance between hydroids is variable, but on average, they grow about one metre apart. Other than hydroids, a variety of sponges are present. Ascidians are also present but are a larger species than that found on 'potato' bottom. Other fauna present include soft corals, sea pens and crinoids. Hard corals are generally absent.
- 'Stone' bottom areas are comprised of stone and coral rubble of various sizes covered by coralline red algae and rounded by the rolling effect from tides and currents. A

mixture of whips corals, sea fans, sponges and coloured corals can be attached (Daume *et al.* 2009).

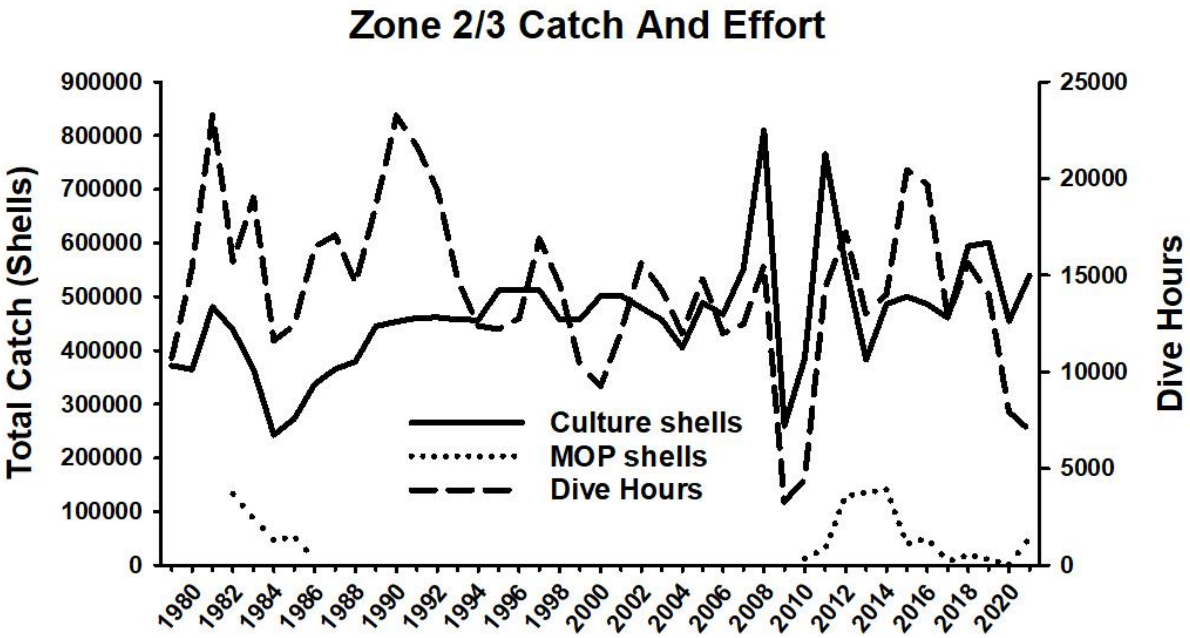


Figure 4.6: Total annual pearl shell catch (all areas) and effort (Zone 2/3) from 1980 to 2021. 'Culture shells' are pearl oysters ≥100 and <175 mm shell length, 'MOP shells' are pearl oysters ≥175 mm.

4.2.1 *Formal Harvest Strategy*

The Harvest Strategy for wild-caught *P. maxima* employs a constant exploitation approach, whereby the same proportion of the stock is harvested each year (DPIRD 2022). It is operationalised through an annual total allowable catch (TAC), divided into individual transferable quotas (ITQs). The TAC is set in proportion to overall stock abundance.

The sustainable harvest level and TAC are determined from predicted recruitment to the fishery, estimated from fishery-independent spat surveys and fishery catch rates.

Harvest Strategy control rules ensure that the catch is reduced when predicted recruitment is low, which provides increased protection to the stock, but also allows the catch to be raised in years when the predicted abundance is high.

In 2021, the overall TAC for the fishery was 863,860 pearl oysters. This was comprised of a Zone 1 TAC of 54,970 pearl oysters and a Zone 2/3 TAC of 808,890 pearl oysters. The Zone 2/3 TAC was further broken down into an industry maximum harvest level of no more than 776,900 pearl oysters between 100–175mm and 31,990 MOP oysters.

4.2.2 *Catch and effort*

Total catch and effort in the WA pearl oyster fishery have followed relatively stable long-term trends (Figure 4.6).

In 2021, the total commercial catch was 590,064 oysters and the total effort was 8,175 dive hours. The effort in 2021 was relatively low because pearl oyster abundance is currently high.

4.3 Hatchery Operations

Hatchery propagation techniques for *P. maxima* were pioneered by Rose and Baker in the 1990s (Rose and Baker 1994).

After carefully selected broodstock complete spawning, the fertilised eggs are stocked into tanks of filtered seawater. After approximately 24 hours, metamorphosis from egg to free-swimming larvae is complete, and cultured microalgae are added to the rearing tanks. Gentle aeration is supplied to mix the suspension within the tank, and algal concentrations are increased during the culture period. Water changes are conducted every two to four days, at which time culling and size grading of the larvae also take place (PPA 2008a).

Larvae begin to metamorphose into spat (juvenile pearl oysters) on day 24. Settlement substrates are placed in the larval rearing tanks to collect the settled spat, otherwise they will settle on the tank floor. In the hatchery, newly settled spat are treated in a similar manner to larvae. As they grow, the feeding rates and water circulation are increased to ensure that attached spat have sufficient access to food and oxygen. Spat are commonly held in the hatchery until they are large enough to be placed into mesh cages or other structures. Once spat attain about 20 to 50 mm in shell height, they are generally transferred to small mesh panels on surface longlines in the ocean. As the spat size increases, they are transferred to panels with progressively larger panel pockets and mesh sizes (PPA 2008a).

Spat take two to three years to grow to a sufficient size to be seeded for pearl production. Most farms have personnel specialising in maintenance of the spat to seeding size (PPA 2008a).

The *Pearl Oyster Translocation Protocol* (Appendix A in Hart *et al.* 2016) reflects the translocation and hatchery requirements under the WA *Pearling Act 1990*, the WA *Pearling (General) Regulations 1991* and *Fish Resources Management Act 1994 (Part 13A)*, as well as additional mandatory protocols for commercial pearl oyster hatcheries in WA. This includes annual inspections to ensure hatcheries are meeting minimum standards for filtration of incoming seawater, cleaning and disinfecting procedures, health testing, sterilisation of effluent seawater and record keeping (see Section 7).

Additionally, there are several criteria for establishing a quarantine site for translocated hatchery-produced pearl oysters due to the potential for these pearl oysters to carry pathogens (see Part 7C of the *Pearling (General) Regulations 1991* and *MGP No. 17* for details).

Hatcheries are land-based and the location of each hatchery is specified on the licence. Hatchery licences are issued for the purpose of either producing spat (two licences in 2022), or hatchery nursery licences for growing out spat (nine licences in 2022) or undertaking both activities (six licences in 2022).

Any new land-based aquaculture or support facilities require planning approval from the relevant local government authority (LGA). LGAs may seek advice on potential environmental impacts from other government agencies as part of their approval process. If there is the likelihood of significant environmental impact, the proponent and LGA have an obligation to refer the proposal to the EPA for formal environmental impact assessment. Such proposals require additional information to ensure all aspects of nutrient and waste management are considered. The EPA may recommend that an aquaculture site can be operated only under certain specified conditions.

There are two pearl oyster hatcheries in WA, at Willie Creek near Broome and at Cygnet Bay on the Dampier Peninsular.

4.3.1 *Broodstock selection*

WA legislation requires the use of WA-origin, wildstock pearl oysters for all hatchery broodstock (i.e., broodstock must be taken from Zone 1, 2 or 3 of the Fishery or have originated from WA stock).

In general, broodstock oysters are sourced from the pool of production oysters (used for pearl production) that have produced quality pearls. These oysters are kept in a location separate from the bulk of the juvenile and production oysters. In the hatchery, a number of these oysters are selected based on phenotypic and genetic criteria and used either in mass or family line spawnings. During grow-out, juveniles from each batch are kept separate at the farm. They retain their batch identity at least for the first two cycles of pearl operations (approximately 6-7 years).

To manage the genetics of the hatchery stock for both broodstock and production purposes, records of broodstock sources are maintained to track family lines and genetic pools. To maintain appropriate levels of genetic diversity, the genetic diversity of the hatchery-produced animals are carefully monitored, and the selective breeding programs are conducted in accordance with company specific protocols that have been developed with expert input and oversight.

Production pearl oysters that are seeded and grown out on leases may include individuals of generations ranging from F0 to F4.

4.4 Seeding

Cultured pearl production is initiated with the surgical implantation of a mantle tissue graft (tissue from another oyster) and a spherical ‘nucleus’ (an inert foreign object) into the gonad of a host pearl oyster, in a procedure known as ‘seeding’. The mantle graft (known as ‘saibo’) proliferates around the nucleus to form an enclosed cyst - known as the ‘pearl sac’ – which becomes incorporated into the host oyster’s tissues. Upon formation, the pearl sac resumes the functionality of the source tissue (the mantle) and begins to secrete shell materials (primarily nacre) onto the nucleus. Consistent deposition of nacreous materials onto the nucleus throughout the culture period (generally, two years for Australian South Sea pearls) results in the production of a cultured pearl.

The most common type of pearl nucleus is made of shells from freshwater bivalves (Bivalvia: Unionidae) from the USA, although other materials may also be used.

Seeding is generally undertaken either on a purpose-built vessel or at a shore-based facility by a skilled seeding technician. Pearl oysters from the fishery are seeded at either the holding sites or at the pearl leases, while those from hatchery-produced stocks are seeded on nearby pearl leases and may then be moved, depending on the preferred location for pearl production. The technician’s surgical instruments are sterilised between sites and cohorts, according to a protocol developed by the PPA. This practice is intended to eliminate the risk of transmitting microbial disease between different production sites or cohorts via the seeding procedure.

Australian pearl producers routinely produce sequential pearls from individual pearl oysters by a process known as ‘re-operation’. This is achieved by surgically extracting the first pearl from the established pearl sac, before replacing it with an equivalently sized nucleus. The pearl sac heals around the new nucleus and resumes nacre deposition to form another cultured pearl (Joll 1996).

4.5 Translocation

After seeding, the pearl oysters are returned to the ocean in panels at the holding site or pearl lease and undergo post-operative recuperation husbandry, before being transported to surface lines at a pearl farm for cultivation. Pearl oysters seeded on holding sites are transported by boat to a pearl lease after two to three months of resting. All pearl oysters must be cleared from the holding site by 31 December each year. During transportation, the pearl oysters are maintained in running seawater in holding tanks on the vessel. No feeding or chemicals are used in this process. Each vessel is capable of transporting 20,000 – 25,000 animals on a single trip.

All transport approvals and health certificates required for movement are outlined in Regulation 42 of the *Pearling (General) Regulations 1991* and Part 13A of the *FRMR*. The *Pearl Oyster Translocation Protocol* reflects this legislation and provides further guidance on:

- Movement of hatchery-produced pearl oysters.
- Movement of all pearl oysters between farm lease areas [1].
- Movement of pearl oysters into WA.
- Reporting of hatchery-settled pearl oyster spat (via a *Pearl Oyster Settlement Form P9*).
- Requirements for spat leaving a hatchery and the testing of hatchery spat by a fish pathologist.
- Requirements for pearl oyster spat transported from a hatchery to a pearl lease (including submission of required log sheets).
- Translocation and handling procedures when unusually high mortality levels indicate there may be a disease risk.
- Requirements and procedures for health testing and the destruction of pearl oyster spat that has failed health testing.
- Minimum standards required for hatchery accreditation, including the cleaning/disinfecting schedule and the disinfection of hatcheries when a batch fails health certification.

4.6 Pearl Oyster Grow-Out

Pearl oyster leases in WA are located between the NT border and Exmouth Gulf, including the Montebello Islands, the Dampier Peninsula, King Sound, the northern Kimberley coast.

Most leases occur in the Kimberley region (see Figure 4.7). This region is a very high-energy environment, with tidal amplitudes up to 10 m and strong tidal currents. These currents constantly renew the available phytoplankton, which nourish the pearl oysters and reduce the potential for localised impacts from pearl farms by dispersing biodeposition material. Leases also occur in the Pilbara region (Figure 4.8)

[1] Note the *Pearl Oyster Translocation Protocol* does not apply to the initial movement of wildstock pearl oysters sourced from the fishing beds within WA to a resting site/holding site within WA. However pearling activity and transport approvals under the *Pearling Act* are still required.

The process of obtaining pearl leases is outlined in *MPG 17* and *Administration Guideline No. 1*. In granting a new lease, the Department considers the applicant's requirement for lease area based on an industry-agreed formula of quota (or stock) holding versus lease area. Essentially, a larger holding will require a larger leased area. Under *MPG 17*, an applicant should not be granted an additional lease area if it exceeds their requirements. Leases are issued for a period of 21 years.

In 2022, the total area of pearl oyster leases in WA was 176.33 nm^2, which represents the total area of leases granted since 1998 (Table 4.1). Most leases are in depths less than 30 m, with all farms located in depths less than 40 m.

Pearl leases are separated from each other, usually by 5 nm, to counter disease transfer. However, if the holder of an existing pearl lease agrees, a new pearl lease can be established within 5 nm (but not closer than 2 nm) of the existing lease and if the lease is owned by the same legal entity a new pearl lease maybe established within 2 nm. Pearl leases occur in sheltered habitats. The location is chosen based on protection from cyclones and sediment characteristics. Mud-bottom areas are preferred, as mud provides the best holding ground for the longline anchor system used in pearl culture activities. Estuarine areas and submerged reefs are avoided as they act as reservoirs for problematic fouling organisms, such as barnacles, other oysters, and *Clionid* boring sponges (PPA 2008a).

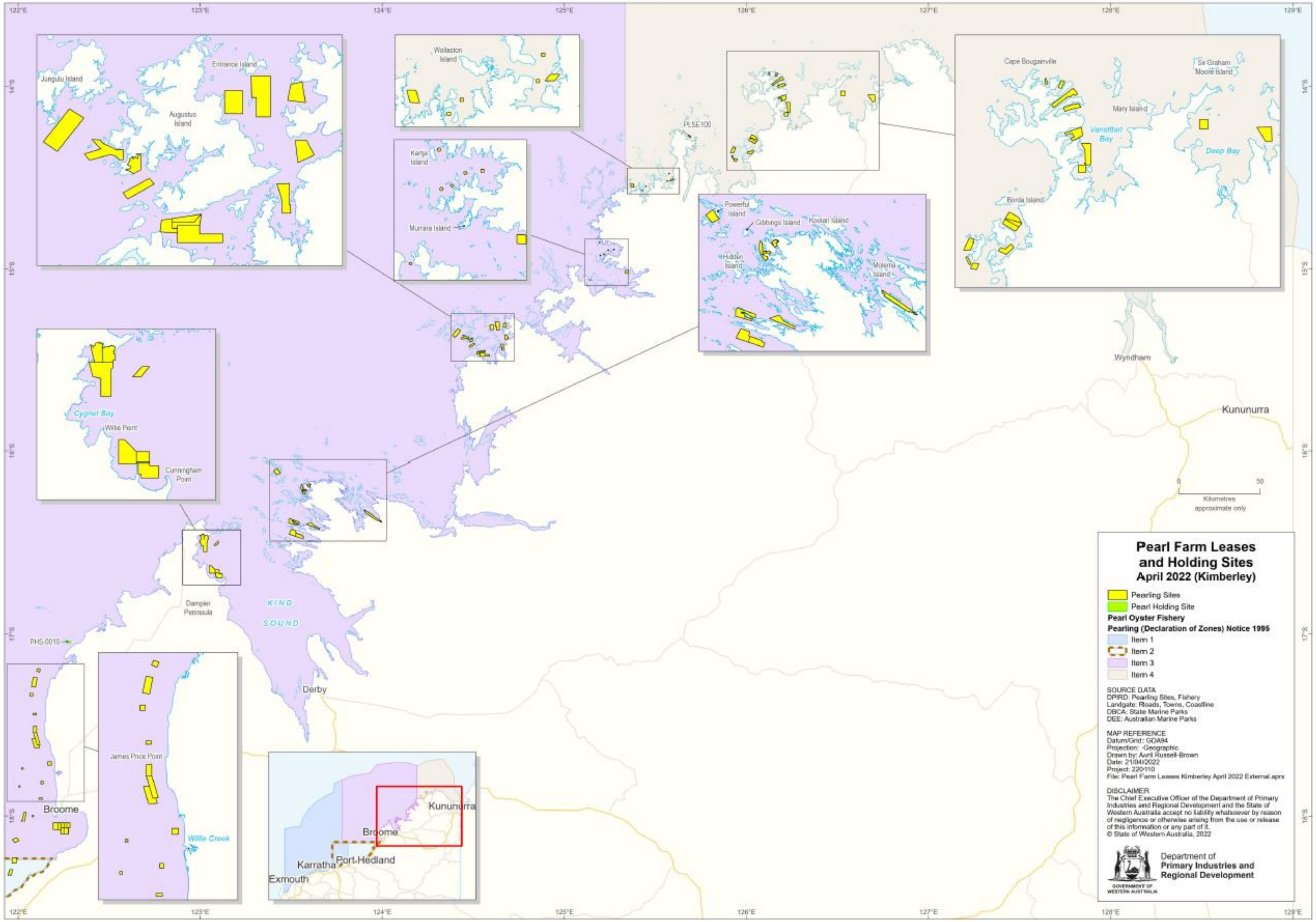


Figure 4.7. WA Pearl Oyster Fishery holding sites and farm leases in the Kimberley region in 2022.

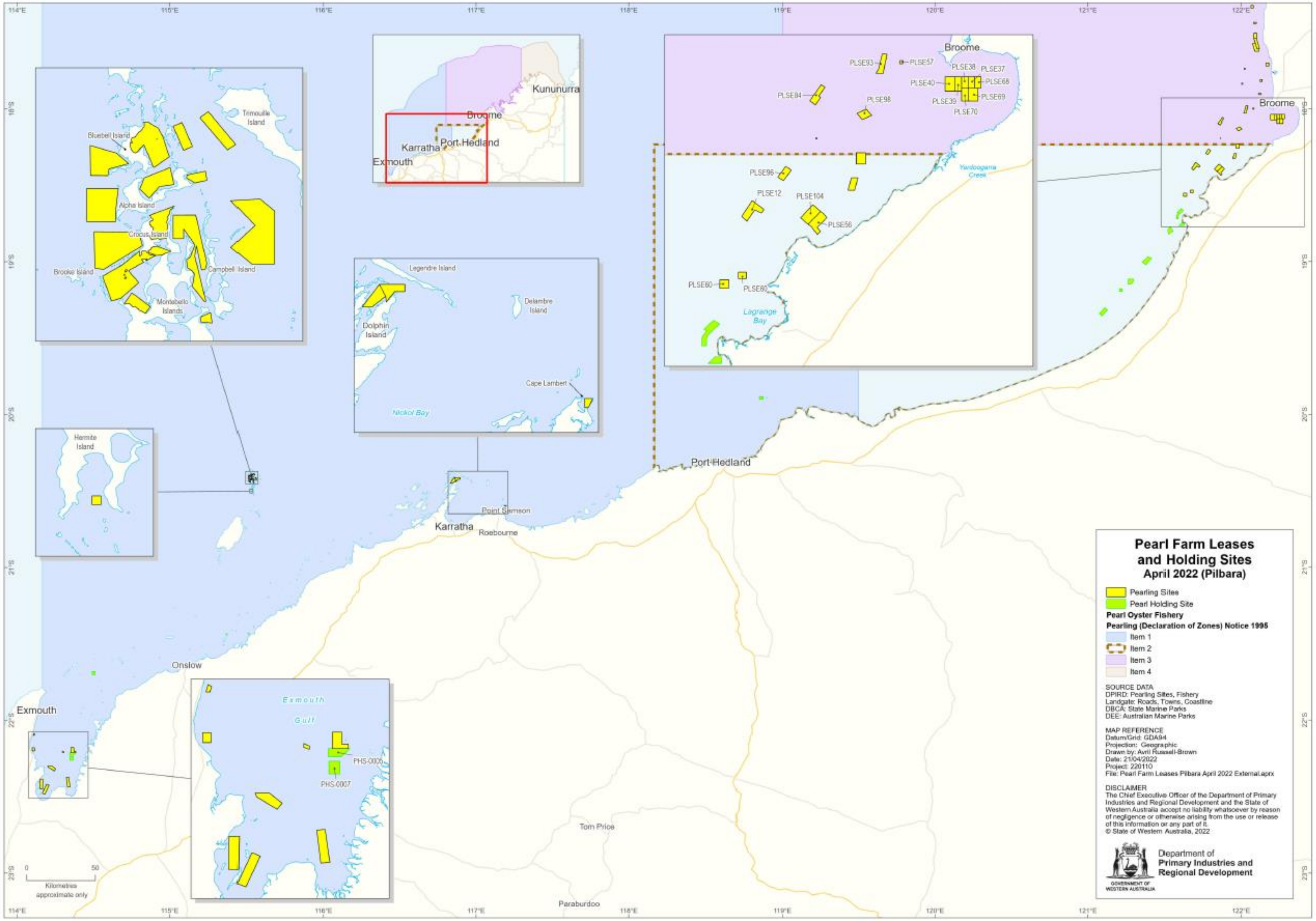


Figure 4.8. WA Pearl Oyster Fishery holding sites and farm leases in the Pilbara region in 2022.

Table 4.1. Total area of WA pearl oyster farm leases granted per year from 1998 to 2022.

Year lease granted	Number of leases granted in year	Total lease area granted (nm^2)	Lease expiry year
1998	1	0.0094	2029
1999, 2000	0		
2001	1	1.054	2025
2002	2	2.863	2023
2003	1	0.498	2024
2004	4	2.26	2025
2005	2	4.788	2026
2006	0		
2007	3	8.239	2028
2008	14	13.8151	2029
2009	2	5.049	2030
2010	15	25.7275	2031
2011	20	43.6032	2032
2012	14	30.9362	2033
2013	5	9.1225	2034
2014	0		
2015	3	9.112	2036
2016	2	2.886	2037
2017	6	5.4574	2038
2018	3	6.577	2039
2020	1	0.238	2041
2021	0		
2022	3	4.093	2043
TOTAL	**102**	**176.3283**	

Farm leases (see example in Appendix D in Hart *et al.* 2016) are subject to conditions, including:

- The lease does not confer exclusive use of the waters by the lessee in respect of purposes other than hatchery or pearling activities permitted under the pearling or hatchery licence held by the lessee;
- Access shall be maintained through and within the farm lease at all times for other legitimate uses, including native title holders;
- The farm lease shall be marked (as outlined in the *Guidance Statement for Evaluating and Determining Categories of Marking and Lighting for Aquaculture and Pearling Leases/Licences*);

- Any flotation buoys used on the longlines must be purpose built, securely attached to the lines and black in colour, or as otherwise approved by the Department;
- No anchors and bottom structures shall be placed on, or within swinging distance of, corals and seagrass beds;
- The lessee shall undertake monitoring of the benthic habitat at the farm lease and any deleterious impacts shall be reported to Department of Biodiversity, Conservation and Attractions (DBCA);
- Any injury or entanglement to rare or protected fauna that occurs within the lease area shall be reported immediately to DBCA;
- The lessee shall not deposit any rubbish or permit any rubbish or discarded equipment to remain on site, nor dispose of any rubbish or discarded equipment at sea or on adjacent beaches;
- The lessee shall bait for rodents at all times on all vessels associated with the pearling operations; and
- On decommissioning, all operational equipment and associated infrastructure must be removed from the site (note this condition is not listed on all lease instruments).

On delivery to a pearl lease, the panels of seeded pearl oysters are placed onto surface longlines consisting of a rope backbone with attached surface floats anchored at each end in the thick mud bottom by specially designed anchors (up to 2 m deep). Panels are attached to longlines by short lengths of rope ('droppers') at regular intervals. Vertical lines with panels containing pearl oysters are hung from the buoys and are maintained off the bottom to avoid fouling. The lines are at least 100 m offshore and are 20 – 30 m apart to avoid entanglement if a line breaks. An average line is 100 m long, with panels every metre for a total of ~600 oysters per line (PPA 2008a).

The pearl oysters and their holding panels are cleaned regularly to remove fouling organisms, which weigh down the farming infrastructure and can inhibit the filter feeding of the pearl oysters. Lines and floats are also cleaned. Cleaning occurs on specially designed boats equipped with cleaning machines, which clean the panels of oysters using high pressure seawater jets. Hard fouling species, such as barnacles or other oysters, are removed manually with stainless steel chisels. No chemicals are used in the cleaning process (PPA 2008a). Material removed is largely algae, with a variety of other organisms such as sponges, molluscs, crustaceans, polychaetes and ascidians. Removed organisms are discarded into the water.

Pearl oysters remain in panels on the farming lines for two years. Pearls are generally harvested during winter (July – August; Scoones 1991). To undertake the pearl harvest, panels of seeded oysters are delivered to the harvest vessel or a land site where the pearl oysters are propped opened and given to technicians, who surgically remove the pearl from the sac (PPA 2008a). If the quality of the pearl is appropriate and the pearl oyster is in good condition, a new nucleus is then inserted into the pearl sac. Following reseeding, the pearl oyster is placed back into the panel and returned to the pearl lease where, over the next two years, the pearl cultivation process is repeated. As many pearl oysters as possible are reseeded; approximately 40-50% of the pearl oysters can be re-operated to produce a second pearl, and 40-50% of these can be used to produce a third pearl (Wells and Jernakoff 2006).

Pearl oysters that have not produced a pearl of sufficient quality are not reseeded and are processed to produce saleable end products (pearl oyster meat and MOP).

4.7 Management

For further information about the management of the WA pearling industry refer to Section 2.4 of Hart *et al.* (2016). A short summary is provided below.

The WA pearling industry, which includes the wild collection, translocation of pearl oysters to pearl leases, hatchery and seeding components, is managed in accordance with the following legislation, subsidiary instruments and documents:

- *Pearling Act 1990* (will be replaced by ARMA once enacted)
- *Pearling (General) Regulations 1991* (will be replaced by ARMA)
- *Fish Resources Management Act 1994* (will be replaced by ARMA)
- *Fish Resources Management Regulations (FRMR) 1995* (will be replaced by ARMA)
- *Administration Guideline No. 1 Assessment of Applications for Authorisations for Aquaculture and Pearling in Coastal Waters of WA.*
- *Ministerial Policy Guideline No. 17.*
- Regulatory notices
- Pearling and hatchery leases and licences, other licences and permits and licence conditions
- Harvest Strategy
- *Guidance Statement for Determining Categories of Marking and Lighting for Aquaculture and Pearling Leases/Licences.*
- *Translocation Protocol.*

Fishers must also comply with relevant requirements within:

- Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC)
- *Marine Safety (Domestic Commercial Vessel) National Law Act 2012*
- Western Australian *Marine Act 1982*
- Western Australian *Biodiversity Conservation Act 2016*
- Western Australian *Conservation and Land Management Act 1984*
- Other legislation governing the use of the marine environment in which fishery activities occur.

WA pearling legislation and management arrangements are currently being transitioned to ARMA, which is scheduled to be implemented in 2023. New management documents will be developed for the industry as part of the transition to ARMA, including an Aquatic Resource Management Strategy and Aquatic Resource Use Plan. These documents will be developed with the intent to streamline and improve management of the pearling industry, but significant changes to the management system are not expected.

There is a Memorandum of Understanding (MoU) in place between the WA Minister for Fisheries and NT Minister for Primary Industry and Resources regarding management of the *P. maxima* pearling industry in WA and NT. This MoU has been developed to ensure that:

1. Consistent standards of management and compliance exist within the WA and NT pearling industries; and

2. Efficiencies and synergies in pearling management and compliance are achieved through cooperative arrangements.

Companies producing hatchery-reared pearl oysters must hold appropriate hatchery licences and must hold relevant seeding quota to seed pearl oysters. Other important management controls include:

- A limit on the number of hatchery-produced pearl oysters that can be seeded each year (enforced by quota licence conditions and compliance monitoring).
- The use of WA-origin, wildstock pearl oysters for all hatchery broodstock (i.e. broodstock must be taken from Zone 1, 2 or 3 of the Fishery or have originated from WA stock).
- Legislation that controls the movement of pearl oysters into and throughout WA.

Table 4.2. WA pearl oyster industry management measures and instruments relevant to harvesting the wildstock.

Control	Description	Instrument
Licence requirements	• Managed Fishery Licence - commercial pearl oyster fishing in WA • Pearling Wildstock Licence – pearl oyster collection • Pearling or hatchery permit – pearling or hatchery activity for research • Pearl Diver's Licence – diving for pearl collection • Pearl Boat Licence – for pearling vessels • Pearl Boat Master's Licence – licenses master of pearl fishing boat.	*Pearling Act 1990*
Species restrictions	*P. maxima* is the only pearl oyster species managed under the *Pearling Act 1990* as it is the only species collected in the Fishery or used for pearl cultivation by the WA pearling industry.	*Pearling Act 1990*
Size limits	*P. maxima* collected from the wild are to have a minimum shell length of 120 mm[2] (i.e. 3 – 4 year old animals). A trial to reduce the minimum shell length to 100 mm has been in place since 2011.	Harvest Strategy
Zone restrictions	The WA pearling industry is separated into four zones (see Figure 4.3) to manage wild stocks and translocation: • **Zone 1** extends from the Northwest Cape (including Exmouth Gulf) to 119° 30' E longitude and includes 115 wildstock quota units. There are currently five wildstock licences with permanent quota units in Zone 1; • **Zone 2** extends east of Cape Thouin (118° 10' E) and south of 18° 14' S and includes 425 wildstock quota units. There are currently eight wildstock licences with permanent quota units in	*MP Guideline 17.*

[2] Note the harvest of pearl oysters 100 to 119 mm in shell length was approved in 2011 for an initial three years, and was extended for another three years in 2013. This approval was subject to the harvest level of pearl oysters of this size being less than 15 % of the TAC.

	Zones 2/3 (note these licensees also have full access to Zone 3). • **Zone 3** extends west of 125° 20' E and north of 18° 14' S and includes 32 wildstock quota units. There are currently two wildstock licences with permanent quota units in Zone 3; these licence holders also have access to Zone 2. • **Zone 4** extends east of 125° 20' E to WA/NT border. All licensees have access to this Zone, although no TAC is set and no fishing occurs in Zone 4. Pearl leases occur in Zone 4.	

TAC Quota system	The Fishery is managed through output controls in the form of a total allowable catch (TAC), which is divided into individually transferable quotas. There are 572 total quota units, allocated between 15 wildstock licences[3] across management Zones 1 – 3. The value of these quota units varies depending on the status of pearl oyster stocks and the annual TAC (as set by the CEO of DPIRD, based on advice from the Pearling Stock Assessment Working Group [SAWG] and DPIRD).
	Each operator has an annual quota of pearl oysters, based on the number of quota units (on each licence). The 2022 TAC and associated quota unit values were as follows:
	• **Zone 1:** TAC of 54,970 pearl oysters, which equated to 478 pearl oysters per unit.
	• **Zones 2/3:** TAC of 839,966 pearl oysters, which equated to 1838 pearl oysters per unit. Within the TAC there was a voluntary agreement between industry and DPIRD that:
	  ◦ 776,900 pearl oysters 100 to 175 mm SL could be taken, equating to 1700 pearl oysters per unit;
	  ◦ 63,066 pearl oysters >175 mm SL could be taken, equating to 138 pearl oysters per unit.
	• **Total 2022 TAC:** 894,936 pearl oysters.
		Harvest Strategy

Table 4.3. WA pearl oyster industry management measures and instruments relevant to aquaculture activities.

Control	Description	Instrument
Licence requirements	Pearling Seeding Licence – pearl oyster seeding Pearling Hatchery Licence – hatcheries activities Pearling or hatchery permit – pearling or hatchery activity for research.	*Pearling Act 1990*
Seeding Quota system	Each operator has an annual seeding quota, based on the number of quota units (on each licence). The 2022 seeding quota unit values were as follows: *Zone 1* – 1000 pearl oysters per wildstock quota unit. This is consistent with a 2002 agreement between DPIRD and PPA,	Annual TACC BN from Minister.

[3] Note that some licences have quota in more than one Zone of the POF.

	that the seeding value be at least 1000 pearl oysters per unit. The additional 522 pearl oysters for seeding, above the wildstock unit value of 478, can only be hatchery-produced or previously collected pearl oyster. *Zone 2/3* – 1700 pearl oysters per wildstock quota unit. This is equivalent to the voluntary harvest level of pearl oysters from 100 to 175 mm within the TAC. *Hatchery* – 1000 pearl oysters per hatchery quota unit. *Pearl Production Quality Supplement* - an additional 15% of the seeding (wildstock and hatchery) quota.	
Holding sites	Seeding can occur on a holding site. Holding Sites used to be given effect under Section 19 of the Pearling Act.	*Pearling Act 1990*
Translocation	Regulation 42 of the *Pearling (General) Regulations 1991* and Part 13A of the FRMR regulates the movement of pearl oysters. *Pearl Oyster Translocation Protocol* – provides detailed guidelines on the translocation of pearl oysters.	*Pearling (General) Regulations 1991* *Pearl Oyster Translocation Protocol*

5.0 Indigenous fishery

Pearl oyster shell is an important resource of cultural significance to Australian Aboriginal people and has been harvested for at least 20,000 years (Yu and Brisbout 2011). Aboriginal Australians of the West Kimberley harvested pearl oyster shells from shallow waters and had well established traditional trading networks that extended throughout Australia (Akerman and Stanton 1994). Aboriginal communities ate the pearl meat, used the shell for decoration and other cultural purposes, and the pearl shell has important cultural significance. The shells were collected, cleaned, shaped and often decorated with designs that were worn for ceremonial occasions. The *P. maxima* pearling industry was initiated in 1861 through trade between early explorers and Aboriginal Australians (Southgate and Lucas 2008).

Pearl oyster shell continues to be of important cultural significance and customary fishing activities for *P. maxima* have been recognised in Native Title determinations and negotiated agreements. The size of the customary catch is unknown, as DPIRD does not record nor quantify customary catch.

6.0 Recreational fishery

No authorised recreational fishing of *P. maxima* is permitted under the *Pearling Act 1990*. Incidental collection of dead beach-strewn pearl oyster shell by the general public does occur.

7.0 Compliance system

The long-term sustainability of wild *P. maxima* stocks is primarily managed through the setting of an annual TAC which is divided into ITQs and allocated to licensees based on permanent quota units held.

Quotas are monitored through a combination of quota tags and a paper audit trail using logbooks, forms and transport approvals. Serially coded lockable tags are issued to licensees by DPIRD annually, based on quota allocations. The following forms/log sheets are also used in the tracking and enforcement of quota:

1. *Notice of Pearling or Hatchery Activity* (Form P2), must be completed prior to any pearling activity associated with collecting, transporting or operating on pearl oysters.
2. *Pearl Oyster Fishing Daily Logsheet*, captures daily records of pearl oysters collected by each diver and vessel and the tags used.
3. *Pearl Seeding Logsheet* (Form P8), records pearl oysters that are received or held on board a boat or in any other place for the purpose of being subjected to pearl seeding operations, and/or when pearl seeding operations are carried out.
4. *Transport Logsheet* (Form P6), required for the transport of wildstock pearl oysters from resting sites to holding sites and from holding sites to pearl leases.
5. *Diver's Catch Record* (Form P4), completed by the catcher boat by 2200 hours of each day that pearl oysters are taken, summarising each dive made from that boat.

Compliance strategies and activities include pre-season briefings of pearling company staff and pearling vessel crews, in-port inspections of pearling vessels and at-sea inspections of pearl oysters to ensure they are appropriately tagged by fishers, as well as inspections of pearl leases and pearling equipment.

Some vessels operating within the fishery are voluntarily fitted with Automatic Location Communicators (ALC). ALC can be used to track the location of the vessel by transmitting the geographical position, course and speed of the vessel to Vessel Monitoring System (VMS) compliance officers at the Department. VMS allows the Department to monitor fleet movement in real time, provides intelligence for inspections and investigations, and provides information and analysis to research and management branches on vessel activities and patterns. As VMS is voluntary in the pearling industry, DPIRD does not currently monitor pearl vessels, However, it is intended that VMS will become mandatory in future.

Management arrangements for the fishery are enforced under an Operational Compliance Plan (OCP). The OCP is informed and underpinned by a compliance risk assessment conducted for the fishery. The OCP is reviewed every 1-2 years. A summary of compliance activity for the fishery since 2012 is provided in Table 4.4.

Each hatchery is inspected at least annually by DPIRD Pearling Inspectors. Inspections are conducted without notice. A Standard Operating Procedure (SOP) (Appendix 2) is followed by Pearling Inspectors when conducting Hatchery Inspections.

Table 4.4. Number of annual compliance contacts and offences for the Pearl Oyster Fishery from 2012 to 2021.

Year	Contacts	Offences
2012	12	8
2013	23	3
2014	17	1
2015	14	0
2016	13	0
2017	29	5
2018	27	1
2019	31	1
2020	9	0
2021	10	0
Total	**185**	**19**

The pearling industry routinely provides compliance and research information to the Department about fishing, hatchery and farm operation via the following reporting forms:

P1 – Annual Notice of Intent
P2 – Notice of Pearling or Hatchery Activity
P3 – Pearl Oyster Fishing Daily Log Sheet
P4 – Diver's Catch Record Log Sheet
P5 – Dump Record Log Sheet
P6 – Transport Log Sheet
P7 – Transport (seeding) Log Sheet
P8 – Pearl Seeding Log Sheet
P9 – Tag Allocation form
H1 – Nursery Site Stock Report
H2 – Pearl Oyster Settlement Log
H3 – Vet Examination Certificate (Health Certificate)
H4 – Destruction of Spat
H5 – Hatchery Manager's Certificate

7.1 Industry Initiatives

In 2007, NT and WA pearling industries adopted a *Pearling Environmental Code of Conduct* (PPA 2007), which outlined the environmental responsibilities of license holders. The Code stipulates that the pearling industry will work in conjunction with government and other stakeholders to ensure it is managed sustainably (ecologically and economically) and that social, economic and environmental benefits are maintained. In 2008, the pearling industry implemented a *Whale Management Policy and Protocol* (PPA 2008b), which included an overview of industry instructions for preventing whale entanglements and interactions at the pearl leases, an overview of local whale species and identification guides and a response protocol should an interaction or entanglement occur.

8.0 Research and Monitoring Activities

8.1 Monitoring of wild stock

For further information about the research monitoring of *P. maxima* stocks in WA refer to Section 7.4 of Hart *et al.* (2016). A short summary is provided below.

There is a statutory obligation for commercial fishers in the WA Pearl Oyster Fishery to provide logbook data (recorded in 10 x 10 nm statistical reporting blocks), which includes information on daily catch by numbers of the two size classes (i.e. 100 – 175 mm SL and >175 mm SL), effort in dive hours, depth fished, statistical reporting block, visibility, quota record and tag numbers for the panels where oysters are stored. This information has been collected since the 1980s, although catch information is also available dating back to the 1890s.

Monitoring of wild *P. maxima* stocks is undertaken by DPIRD to better estimate stock abundance and fishing impacts. Regular monitoring activities include:

- <u>Annual length-frequency monitoring</u>: Research observers take measurements of pearl oysters during approximately three of the 5 – 10 discrete fishing trips that occur each year, with 4,000 – 13,000 pearl oysters measured from 100 – 200 sites per year. Data collected include length frequency information, spatial location and incidence of bio-eroding sponge infestation, which is a general measure of the health of the pearl oyster.
- <u>Population surveys</u>: Population surveys have been undertaken annually since 2007 and provide an independent time series of stock abundance to compare against fishery catch rates. Population length-frequency data are collected by spatial location (GPS) and depth, with 3,000 – 5,000 pearl oysters measured from 30 – 150 sites per year. These surveys provide both an index of pre-recruitment abundance, which can be compared with earlier predictions from the recruitment spat surveys, and an index of breeding stock abundance (pearl oysters + 175 mm SL), which can be compared over time.
- <u>Recruitment monitoring</u>: Recruitment monitoring is used to measure the abundance of each year class using a 'piggyback' spat recruitment index (Hart and Joll 2006). The index involves counting juvenile pearl oysters (spat) that have recently settled on adult pearl oysters ('piggybacked'). The annual change in recruitment strength measured by this index is one of the primary tools used to forecast future stock abundance and consequently, the annual TAC. Spat samples are obtained during 200 – 800 drift dives per fishing year, and are counted, measured, and separated into two age classes (age 0+ or age 1+) based on their size frequency. 30,000 to 155,000 adult pearl oysters are inspected each year.
- <u>Environmental monitoring</u>: The environmental monitoring program consists of two components:
    1. On-board vessel monitoring for three key environmental factors: depth, water visibility, and habitat type.
    2. Long-term monitoring of broad environmental factors such as sea surface temperature, rainfall, frequency of cyclones, wind components and the Southern

Oscillation Index, which are obtained from independent environmental monitoring programs implemented by various Government agencies and other organisations.

Environmental factors have a relatively large influence on both pearl oyster abundance and fishing efficiency. Significant negative relationships have been found between pearl oyster abundance and rainfall. While there are positive relationships between abundance and temperature for both spat settlement and fishery catch rates at appropriate lags (Hart *et al.* 2011).

8.2 Monitoring of other ecological impacts

None undertaken by DPIRD.

8.3 Other Research

- DPIRD's Fish Health Unit provide the WA pearling industry with a comprehensive disease-testing program.
- Other research projects conducted by the WA pearling industry focusing on environmental management, improved health and safety for pearl divers and pearl oyster health, including investigating aspects of oyster oedema disease (OOD) in *P. maxima* to assist in mitigating the impacts and understanding pathways to disease and disease response.

9.0 Ecological Impacts

9.1 Retained species

9.1.1 *Western Australian Silverlip Pearl Oyster (Pinctada maxima)*

For further information about the biology of *P. maxima* refer to Section 3 of Hart *et al.* (2016). A short summary is provided below.

P. maxima (Phylum Mollusca, Class Bivalvia, Family Pteriidae) is the largest of four *Pinctada* species found in WA. *P. maxima* is widespread throughout the Indo-West Pacific, including across tropical northern Australia (Figure 9.1). In WA, this species has been recorded as far south as Shark Bay, but it is not commercially collected south of North West Cape (Exmouth).

P. maxima populations within WA waters are considered a single genetic stock, with the possible exception of Exmouth Gulf. The genetic connectivity of *P. maxima* populations across WA, NT and Indonesia has been investigated using microsatellite markers (Benzie and Smith-Keune 2006). Results indicated high levels of gene flow and connectivity among populations at the Lacepedes, Eighty Mile Beach (both shallow and deep-water areas), Port Hedland and Exmouth Gulf. However, there was some genetic differentiation between Exmouth Gulf and the more northern WA populations, as well as between WA and NT (Darwin) populations. A pattern of isolation by distance was observed between Exmouth Gulf and Darwin. Indonesian populations are significantly different to all Australian populations, suggesting little or no direct recruitment to WA or NT from Indonesian sources (Benzie and Smith-Keune 2006).

At Eighty Mile Beach (the main fishing ground), there is evidence of high levels of gene flow among of *P. maxima* at inshore and offshore sites (separated by ~40km) and no differences in genetic diversity between depths (Thomas and Miller 2022).

P. maxima has been reported to occur at depths up to 120 m but is more typically found in shallow (5-50 m) subtidal habitats with strong tidal currents (Wada and Temkin 2008). A recent survey using towed video off Eighty Mile Beach, the main fishing ground in WA, observed *P. maxima* at depths up to 76 m, but with 92% of individuals located at depths <40m (Whalan *et al.* 2021).

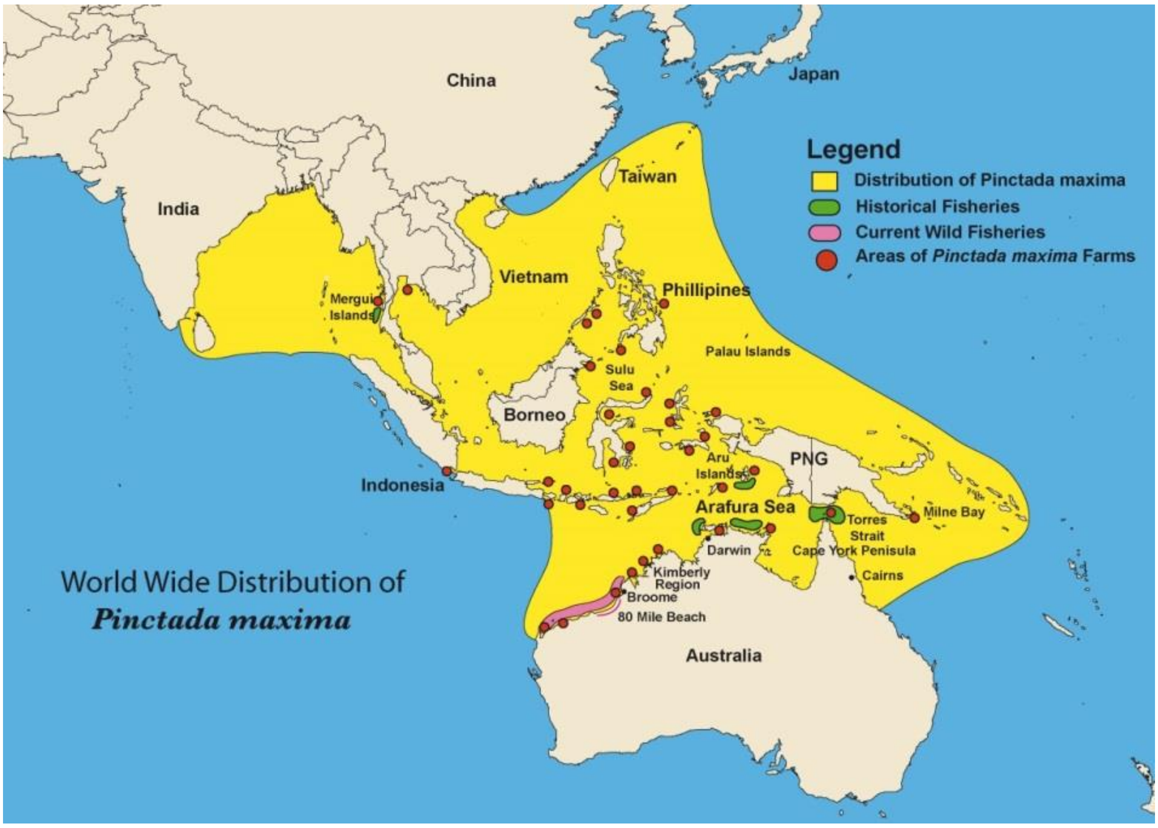


Figure 9.1. Distribution of Silverlip pearl oysters (*Pinctada maxima*) and areas of historical and current wild capture fisheries and pearl oyster farm leases.

P. maxima is a protandrous hermaphrodite, i.e., individuals mature first as males at approximately 3 - 4 years of age and at a size of 110 to 120 mm SL, then undergo a sex change and become female, with majority female by 190 mm SL. *P. maxima* is also a rhythmic hermaphrodite and individuals can have more than one sex reversal during their lifetime (Saucedo and Southgate 2008).

P. maxima can reach 270 mm SL (Rose and Baker 1994) and live for 15 – 20 years (Joll 1996). The instantaneous rate of natural mortality is relatively low and varies from 0.1 to 0.18 y^{-1}, depending on habitat, equivalent to an annual mortality of 10 to 16.5% (Hart and Friedman 2004).

P. maxima is a broadcast spawner, with individual females capable of producing between 20 million to 50 million eggs per year (Hart and Friedman 2004). Spawning occurs between September and May each year, with a peak during October-December and a smaller, secondary spawning event in February-March (Rose *et al.* 1990; Rose and Baker 1994). Fertilised eggs develop into planktonic veliger larvae.

A planktonic phase of about four weeks allows larvae to disperse and colonise new areas. Larval dispersal is dictated by physical oceanographic processes, such as wave action, prevailing winds and currents. Modelling of *P. maxima* larval dispersal in the Eighty Mile Beach region suggests that large tidal currents in the region move larvae back and forth across the shelf, while lower frequency currents influence their net transport, which was mostly alongshore (Condie *et al.* 2006). Modelled larvae were sometimes advected >60 km but more typically <30 km.

Recruitment success is determined by a combination of factors including favourable larval dispersal and the availability of suitable juvenile habitat. Juveniles are commonly found in areas where the seabed has crevices that allow the young animals to settle into a protected environment. Environmental conditions (e.g. ocean temperature, rainfall) during the spawning and larval periods also appear to affect recruitment success (Hart *et al.* 2011).

At settlement, larvae attach to hard substrate with byssal threads and so the presence of suitable hard substrate is an important determinant of successful larval recruitment. This habitat requirement is reflected in the type of seabed found on pearl oyster fishing grounds, which is typically a flat basement rock covered with a layer of sediment obscuring the underlying rock, with very little relief. A variety of organisms attach to the rock surface and provide a vertical relief of up to one metre off the bottom (Fletcher *et al.* 2006; Daume *et al.* 2009).

P. maxima is a filter feeder, using its gills to filter small food particles from the water.

9.1.2 *Depletion of biomass in wild populations*

While there are many local subpopulations of *P. maxima* in WA waters, they are all highly connected and considered to belong to a single genetic stock, with the possible exception of those in Exmouth Gulf.

Annual weight-of-evidence assessments of population status are conducted for the wild populations of *P. maxima* in Zones 1-3 (where harvesting occurs). Zone 4 is not assessed. For detailed information about the data and methods used to assess the status of *P. maxima* populations in WA refer to Sections 6 and 7 of Hart *et al.* (2016).

The outcomes of the most recent assessments (Hart *et al*. in prep.) are as follows:

Zone 1 – LOW RISK. The low risk reflects the negligible levels of fishing mortality in this zone. The overall weight of evidence assessment indicates the Zone 1 pearl oyster stock is adequate and that current management settings are maintaining the level of risk at acceptable (low) levels.

Zone 2 - MEDIUM RISK. The medium risk reflects the controlled levels of fishing mortality. Current lines of evidence show an increasing abundance due to above-average recruitment, catch rates are above the threshold level, and the size-structure of harvested oysters has returned to the long-term average. Overall, the weight of evidence assessment indicates the status of the Zone 2 pearl oyster stock is adequate and that current management settings are maintaining the level of risk at acceptable (medium) levels.

Zone 3 – LOW RISK. The low risk reflects the negligible levels of fishing mortality in this zone. The overall weight of evidence assessment indicates the Zone 3 pearl oyster stock is adequate and that current management settings are maintaining the level of risk at acceptable (low) levels.

Zone 4 – not assessed.

9.1.3 *Genetic impacts due to translocation of wild populations*

The pearling industry translocates pearl oysters between zones, and between onshore hatcheries and oceanic leases, which has the potential to alter the genetic structure of receiving wild subpopulations if they are genetically different to translocated animals.

Studies undertaken by Johnson and Joll (1993) and by Benzie and Smith-Keune (2006) concluded that WA populations of *P. maxima* were genetically different to those in NT. Benzie and Smith-Keune (2006) noted that this regional population structure had been maintained despite substantial historical translocation of *P. maxima* from WA into NT, suggesting that previous translocation had been insufficient to homogenise wild stocks.

P. maxima within WA is assumed to be a panmictic population and is managed as a single stock. This is based on evidence of high connectivity (high gene flow) between *P. maxima* subpopulations within WA waters, with the possible exception of Exmouth Gulf which may host a genetically distinct subpopulation (see Section 2.1).

Genetically different, locally adapted subpopulations can still occur due to strong local selection, even where there is high gene flow. This type of fine scale genetic structure has been reported in subpopulations of *P. maxima* from three neighbouring geographic regions in Indonesia (Nayfa and Zenger 2016).

9.1.4 *Genetic impacts on wild populations due to hybridisation with reared stock*

High genetic diversity within a population increases its ability to withstand environmental perturbations and disease outbreaks. Selective breeding and other cultivation practices used in aquaculture typically result in reared populations with substantially less genetic diversity than the wild populations from which they are derived, and these effects can occur in a single generation. Stock enhancement, restocking and sea ranching activities pose a risk to natural populations because hybridization between hatchery-reared and wild individuals can lower the genetic fitness of natural populations (Grant *et al.* 2017).

Reduced genetic diversity and a reduced effective population size has been observed in hatchery-produced populations of *P. maxima* in Indonesia, relative to wild populations (Lind *et al*. 2009).

9.1.5 *Translocation of pests or diseases affecting wild populations*

See Section 9.5.2

9.2 Bycatch species

The WA Pearl Oyster Fishery is a highly selective hand collection fishery that exclusively targets pearl oysters and no bycatch is taken. However, pearl oyster shells are encrusted with fouling/commensal organisms that are harvested together with the pearl oyster and are then scraped off the pearl oyster shell and discarded overboard.

Within WA, the primary pearl oyster fouling organisms include coralline algae and sponges, as well as ascidians, fire coral and other algae. Predatory sponges, boring annelids, gastropods and algae can also infest pearl oysters.

Commensal species use pearl oyster shells as substrate and the removal of oysters results in a loss of habitat for these organisms.

Two commensal species - a pea crab (*Nepinnotheres villosulus,* formerly *Pinnotheres villosulus*) and a pontoniine shrimp (*Conchodytes maculatus*) - are commonly found living inside the shell of *P. maxima* across Australia and are collected with the oysters as minor secondary species (Dix *et al.* 1973, Humphrey *et al.* 1998, Bruce 1989). The pea crabs are common within pearl oysters at shallow (<20m) depths, whereas the shrimp are common at deeper (>20m) depths (Humphrey *et al.* 1998).

The hosts of *N. villosulus* include a range of bivalve molluscs including *Pinctada* and *Pinna* species (Ayhong and Brown 2003; Ayhong and Ng 2007), whereas *P. maxima* is the only reported host of *Conchodytes maculatus.*

9.3 Threatened, Endangered and Protected species (TEPS)

TEPS that occur in the pearl oyster fishing area and so could potentially be impacted by the fishery include whales, dolphins, turtles, crocodiles, sharks and rays, sea snakes, seabirds and syngnathids.

In this ERA, a TEPS 'interaction' is defined as an incident when a listed species is injured/killed as part of the fishing operation or requires human intervention to be removed from fishing gear. This includes accidental capture in the fishing gear, entanglements, boat strikes, observed dropouts of dead/injured animals. It does not include observations, attendance or feeding behaviour, or provisioning (e.g., feeding birds).

In addition to these interactions, fishing and aquaculture can generate multiple forms of pollution (noise, light, plastic rubbish, oil spills, etc) that can potentially impact on TEPS (see Section 9.6).

Commercial fishery license holders are required under their license conditions to report all interactions with Threatened, Endangered or Protected species (TEPS) listed under the FRMA, ARMA, EPBC, BCA or subsidiary legislative instruments.

Pearl lease holders' requirements for TEPS reporting and impact mitigation are set out their individual lease conditions. Negative TEPS interactions must be reported to the WA Department of Biodiversity, Conservation and Attractions (DBCA).

There is potential for various TEPS to collide with the hull or propeller of moving vessels during pearling fishing and aquaculture activities. There is also potential for various TEPS to become entangled in ropes and hookah air-hoses used during fishing operations and at holding sites, or culture lines and moorings used on leases.

Pearl leases have semi-permanent underwater infrastructure and floating lease boundary markers, moorings, and culture lines, which could potentially entangle TEPS. Netting is not used. The layout of the pearl leases and use of surface longlines reduces the number of lines in the water compared to many other types of aquaculture. Culture lines are typically 20 – 30 m apart and about 100 m long, with panels hung every metre.

9.3.1 *Whales*

Under the Commonwealth EPBC Act all cetaceans (whales, dolphins and porpoises) are protected in Australian waters. Over thirty species of whales and dolphins have been recorded along the Gascoyne, Pilbara and Kimberley coasts.

This area is an important migratory pathway for fin (*Balaenoptera physalus*), minke (*B. acutorostrata*) and pygmy blue whales (*B. musculus brevicauda*). The region is particularly important for the WA population of humpback whales (*Megaptera novaeangliae*), which have breeding and calving grounds in the area from Camden Sound in the Kimberley to at least North West Cape in the Pilbara (Irvine *et al.* 2018).

Humpbacks are the whale species considered most likely to interact with the pearling industry due to their WA migration patterns overlapping with fishing activities. The WA humpback whale population is currently estimated to be significantly more than 30,000 individuals, which is regarded as fully recovered, and is no longer listed as threatened under the EPBC Act (DAWE 2022).

Some pearling leases in WA overlap with humpback whale migration paths along the WA coastline.

One whale boat strike associated with the pearling industry is known to have occurred in the past few decades, with the whale surviving the encounter and swimming away.

In WA, DPIRD and DBCA staff jointly maintain a database of known whale entanglements in WA waters. Since 1990, there have been four humpback whale entanglements with pearl oyster leases in WA. These occurred in 1998 (2 entanglements), 2004 (1) and 2008 (1).

In 2008, the pearling industry implemented a *Whale Management Policy and Protocol* (PPA 2008b), which includes an overview of industry instructions for preventing whale entanglements and interactions and a response protocol should an interaction or entanglement occur.

9.3.2 *Dolphins*

Dolphins regularly seen in the inshore waters of the region include Australian snubfin dolphins (*Orcaella heinsohni*), Indo-Pacific humpback dolphins (*Sousa chinensis*), common bottlenose dolphins (*Tursiops truncatus*), Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) and spinner dolphins (*Stenella* spp.). The distribution of each species varies, but all have localised and fragmented populations reflecting the limited availability of appropriate habitat and prey throughout the region (DSEWPaC 2012a).

There are currently no major conservation concerns for *Tursiops* or *Stenella* species.

Australian snubfin and humpback dolphins are both IUCN listed as Vulnerable due to their small population sizes and cumulative exposure to human activities. Both species occur in the operating area of the WA pearling industry.

Australian snubfin and humpback dolphins are endemic to the tropical waters of northern Australia and southern Papua New Guinea. In WA, snubfins are recorded as far south as Exmouth Gulf while humpbacks range to Shark Bay. Both species are typically found in shallow coastal waters (<20 m) and usually near rivers (Hunt *et al.* 2020; Bouchet *et al.*, 2021). The biology of the snubfin dolphin is particularly poorly known.

Available evidence indicates that each species forms small (<250 mature individuals), genetically isolated subpopulations with limited gene flow and high site fidelity. Recent estimates suggest subpopulations in Cygnet Bay and Roebuck Bay contain about 50 and 130 individuals, respectively (Brown *et al.* 2016). Roebuck Bay is the largest known subpopulation of snubfin dolphins. Snubfin dolphins in Roebuck Bay are known to be vulnerable to boat strikes and entanglements with fishing gear (Thiele 2010). However, there are no reported incidents of dolphin boat strikes or entanglements associated with the pearling industry.

There is evidence that some dolphins may actively avoid pearl leases because of the equipment, human activities or other factors, which would reduce the risk of entanglement but result in displacement from the area and loss of habitat for the dolphins (Watson-Capp and Mann 2005).

9.3.3 *Turtles*

The following six species of marine turtles, each listed under the EPBC Act as either Endangered (E) or Vulnerable (V), have been reported in the waters along the north coast of WA:

- Green (*Chelonia mydas*) V
- Loggerhead (*Caretta caretta*) E
- Hawksbill (*Eretmochelys imbricata*) V
- Flatback (*Natator depressus*) V
- Leatherback (*Dermochelus coriacea*) E
- Olive ridley (*Lepidochelys olivacea*). E

Turtle breeding areas throughout northern WA include:

- Ashmore Reef (green, hawksbill and loggerheads)
- Browse Island
- Lacepede Islands
- North West Cape
- Barrow Island
- Muiron Islands
- Montebello Islands (Prince 1994).

Turtle nesting occurs from October to February each year, and large turtle rookeries in the region include the Dampier Archipelago, Port Hedland's Cemetery Beach, Eighty Mile Beach, Broome's Reddell Beach and Eco Beach in the Kimberley.

Marine turtles can suffer serious injury or death if they become entangled in fishing gear or are hit by the hull or propeller of a vessel. The risk of 'boat strike' increases with vessel speed. For example, a study of green turtles estimated that small boats would need to travel at very low speeds (<4 km/h) to ensure turtles and vessel operators had enough time to react and avoid a collision (Hazel *et al.* 2007).

There have been no reported boat strikes involving marine turtles by the WA pearling industry.

Individual turtles are likely to move through pearl leases from time to time and, as turtles are known to occasionally become entangled in lines in other fisheries, it is also possible that they may become entangled in lines on pearl leases. There have been no recorded entanglements of marine turtles in pearl culture lines in WA or the NT.

Artificial lights at night can potentially reduce breeding success of marine turtles by changing the behaviour of adult and hatchling turtles (see Section 9.6).

9.3.4 *Crocodiles*

Saltwater (*Crocodilus porosus*) and freshwater crocodiles (*C. johnsoni*) are protected under the EPBC Act. Both species can be found in the northern coastal waters of WA and NT. Saltwater crocodiles are natural inhabitants of coastal waters and estuaries of the Kimberley, and can be found in tidal rivers, coastal floodplains and channels, billabongs and swamps up to 150 km inland from the coast (Webb *et al.* 1987). Freshwater crocodiles are endemic to

Australia and only occur in the tropics (Webb and Manolis 1989). They prefer upstream freshwater areas and can be found in lakes, rivers and billabongs.

In the history of the pearling industry, there have been no known boat strikes or entanglements involving crocodiles, or any reported concerns about these events occurring.

9.3.5 *Sharks and Rays*

Protected elasmobranch species found in the North Coast Bioregion include grey nurse sharks (*Carcharias taurus*), whale sharks (*Rhincodon typus*), mako sharks (*Isurus* spp.), river sharks (*Glyphis* spp.) and sawfish (*Pristis* and *Anoxypristis* spp.).

The coastal waters of the Pilbara and western Kimberley are a global hotspot for sawfish diversity, with four of the world's five species found there, including the largetooth sawfish (*Pristis pristis*), dwarf sawfish (*Pristis clavata*), green sawfish (*Pristis zijsron*) and narrow sawfish (*Anoxypristis cuspidata*). Populations of sawfish species in northern WA are regarded as nationally and globally significant. Sawfish are particularly vulnerable to entanglement in fishing gear or marine debris due to their rostrum. Sawfish generally inhabit inshore coastal and estuarine environments which puts them in close proximity to human activities including those of the pearling industry.

Largetooth, dwarf and green sawfish are listed as Vulnerable under the EPBC Act and Critically Endangered (green, largetooth) or Endangered (dwarf) under the IUCN Red List. Areas used by the WA pearling industry overlap with known pupping grounds for these three sawfish species, including Roebuck Bay and Eighty Mile Beach (CoA 2015a).

There have been no recorded entanglements of sharks or rays (including sawfish) in pearl oyster culture lines in WA or NT.

9.3.6 *Sea snakes*

Under the Commonwealth EPBC Act all sea snake are protected in Australian waters. Sea snakes are generally long living and slow growing, with small broods and high juvenile mortality. These traits make populations slow to recover if depleted.

Numerous sea snake species are found in the North Coast Bioregion. Areas in the North Coast Bioregion that are particularly important for sea snake species include:

- Sahul Shelf (important for short-nosed, leaf-scaled, turtle-headed and slender-necked sea snakes)
- Pilbara coast (for brown-lined and north-western mangrove sea snakes)
- Kimberley coast (for brown-lined, Stokes', black-ringed and northern mangrove sea snakes).

Most species in the bioregion are not threatened, with the exception of the short-nosed sea snake (*Aipysurus apraefrontalis*) and the leaf-scaled sea snake (*A. foliosquama*), which are both listed as Critically Endangered under the Commonwealth EPBC Act and IUCN Red List. Both of these species are endemic to WA and are mainly known from Ashmore and Hibernia Reefs, but they also occur in coastal waters (D'anastasi *et al.* 2016).

Threats to sea snakes include environmental factors causing habitat degradation, boat strikes and disruption of feeding behaviour by boating traffic, pollution (e.g. oil spills) and fishing (particularly trawling).

There have been no recorded entanglements of sea snakes in pearl oyster culture lines in WA or NT.

9.3.7 *Seabirds*

Pearling industry areas of operation include two coastal areas of international significance for migratory birds, Roebuck Bay and Eighty Mile Beach, both covered by the Ramsar Convention. Both sites have large intertidal mudflats, containing a high density of invertebrates and are the primary feeding grounds and over-wintering areas for Palaearctic shorebirds on their annual southern migration. The region is also important for many other seabird species including terns, petrels, shearwaters, tropic birds, frigatebirds and boobies. The Lacepede Islands host internationally significant numbers of migratory and non-migratory seabirds, including relatively large breeding colonies of brown boobies, and roseate terns (Rogers *et al.* 2011).

Thirty seven migratory bird species regularly visit Australia along the East Asian-Australasian Flyway during their non-breeding season, and are listed under the EPBC Act as ‘migratory’ (CoA 2015b). About 30 of these species visit the north-west marine region. The majority of migratory shorebirds will be present in Australia between October and March.

Significant regional declines have been identified in at least 18 species that use the East Asian-Australasian Flyway (CoA 2015b). Four migratory bird species that visit the north-west marine region are currently listed as Critically Endangered under the EPBC Act, and others are listed as Endangered or Vulnerable.

Migratory shorebirds will feed throughout day and night and are only limited by the high tide covering feeding grounds. If birds are disturbed as they are feeding, or while roosting, there may be an energetic cost to the birds resulting in reduced ability to gain condition or be sufficiently rested to undertake their migration back to the northern hemisphere to breed. Buffer zones with widths of 165-255 m have been recommended to avoid bird disturbance (CoA 2017).

There is potential for the pearling industry to interact with seabirds, including undertaking activities that occur on or near the shore that may disturb migratory birds.

Seabirds can be found feeding on and around pearl leases; however, there have been no known entanglements or reported interactions with seabirds by the pearling industry.

9.3.8 *Syngnathiform species*

Syngnathiformes species are protected under the EPBC Act. A number syngnathids (seahorses, pipefish) and solenostomids (ghost pipefish) can be found throughout the Northwest Shelf region. Syngnathid species have diverse characteristics, ranging from rare and localised species to widely distributed and very common. Syngnathids are usually found in shallow, coastal waters living among seagrasses, mangroves, coral reefs, macroalgae-dominated reefs or sand/rubble habitats (Dawson 1985; Vincent 1996; Lourie *et al.* 1999, 2004).

The semi-permanent underwater infrastructure at pearling leases may increase the availability of habitat for some seahorse species which are known to attach to artificial structures.

There have been no recorded interactions with seahorses or pipefish in the pearling industry.

9.3.9 *Dugongs*

Internationally, dugongs (*Dugong dugon*) are listed as Vulnerable under the IUCN Red List. In Australia, dugongs are protected under the EPBC Act, which lists them as ‘marine’ and ‘migratory’, but there is no formal Australian conservation listing advice for this species. Globally, threats to dugongs include entanglement in fishing gear and marine debris, loss and degradation of key habitat such as seagrass meadows, unsustainable traditional harvest and collisions with boats (DSEWPaC 2012b).

Dugongs are found across the Indo-Pacific and typically occur in shallow, warm waters over seagrass meadows. In WA they occur from Shark Bay northwards, including along the Pilbara and Kimberley coasts and around the offshore islands of the North West Shelf (Prince 2001). Shark Bay hosts the largest and most well studied population in WA (e.g. Holley *et al.* 2006). Other WA populations are relatively poorly understood.

Dugong populations are known to occur within the area of operation of the pearling industry, including Exmouth Gulf, Eighty Mile Beach and Roebuck Bay.

There have been no recorded interactions by the pearling industry with dugongs.

9.3.10 *Other TEPS*

There have been no recorded interactions by the pearling industry with any other TEPS.

9.4 Habitats

Fishing activities have the potential to impact on the structure of local aquatic habitats. Habitats may include substrates like sand or rock, but also include sessile biota that provide essential habitats for many other species.

Pearl lease conditions stipulate that the lessee should undertake monitoring of the benthic habitat at the farm lease and any deleterious impacts shall be reported to DBCA.

9.4.1 *Unconsolidated sediments*

Unconsolidated sediments include mud, sand and gravel in subtidal and intertidal zones. They provide habitat for many marine species that live on or under the surface. Seemingly ‘bare’ sand or mud may host a diverse community of infauna (burrowing) and sessile epifauna (on the surface), including polychaete worms, small crustaceans, bivalves, gastropods, starfish, sea cucumbers and other small invertebrates. Soft sediments also host larger animals that embed themselves, such as crabs and flatfish.

Invertebrates in unconsolidated sediments provide ecosystem services including capturing and processing organic wastes in sediments, water filtration, bioturbating and oxygenating sediments, and stabilising sediments. Bacteria and microalgae in unconsolidated sediments also contribute substantially to primary production, nutrient cycling, oxygenation and sediment stabilisation. Many small invertebrates associated with unconsolidated sediments are important prey for larger species including fish, birds and macro-invertebrates.

Key threats to unconsolidated sediments include physical disturbances (such as from dredging or trawling) and bottom-water hypoxia (such as from nutrient pollution).

Fishing for pearl oysters typically occurs over benthic habitats comprised of soft sediments interspersed with sessile invertebrates. Hand collection methods result in minimal disturbance to benthic habitats, but there is the potential for weighted ropes and for divers and their equipment to accidently interact with benthic habitats. In practise, these interactions are rare because they increase turbidity, and water clarity is essential for divers to collect the oysters efficiently (i.e., identify the appropriate sized oysters). Divers will signal to the vessel to raise the weights according to sea floor height, preventing sea floor damage and disturbance.

Anchors have the potential to physically alter or damage benthic habitats where they are set. Pearl oyster vessels do not anchor during daily fishing but need to anchor at night when the crew and skipper are on standby. Pearl oyster vessels avoid anchoring in complex habitat to avoid fouling the anchor and prefer to anchor over sand or mud. Most anchoring occurs just outside fishing patches or holding sites in muddy or sandy areas.

There is the potential for the WA pearl oyster fishery to cause long-term, localised impacts to benthic habitats at holding sites and at leases because these sites are typically reused each year over extended periods (decades). In particular, there is the potential for changes to benthic habitats and communities under/around pearl oyster leases due to the increased deposition of organic material.

Pearl oysters feed by filtering organic matter from the water column and then release waste products in the form of faeces and pseudofaeces, which are deposited on the seafloor. These biodeposits are thought to be similar in composition to the natural sediments because they are derived from phytoplankton and suspended particles (Grant *et al.* 1995). These biodeposits and shell debris can accumulate in the sediments below leases and potentially lead to localised organic enrichment and eutrophication. Other fouling organisms growing on farms can also contribute to biodeposits. This process can be intensified through the cleaning of biofouling organisms from the pearl oyster shells, which also accumulate beneath the pearl lease.

Material can be dispersed by currents and so impacts depend on hydrodynamic conditions at the site as well as the scale of the cultivation process.

Pearling leases are mostly located over muddy sediments. The results of various studies suggest that pearling leases have minimal impact on sediment structure or chemistry, on the abundance and diversity of benthic fauna at these sites. Potential interactions between pearl leases and marine habitats, particularly seabed communities, have been studied at several locations around Asia and Australia, including:

- Beagle Bay, WA - survey of the seabed beneath longlines conducted by the WA museum found no measurable impact (WA Museum 1997);
- Montebellos Islands, WA - sampling program inside and outside a *P. maxima* lease found no impact of pearl leases on abundance and diversity of the benthic macrofauna community (Prince 1999).
- Gokasho Bay, Japan - compared impacts of raft pearl farming (*P. martensii*) and fish cages by measuring macrobenthic fauna and sediment nutrient loads (carbon, nitrogen, sulphur and dissolved oxygen) and found that fish farming created a large impact on macrobenthic fauna and sediments, whereas the pearl farming caused fewer effects. The community structure at the pearl farm was similar to that of the control site, although there were lower densities and species diversity at the pearl farm (Yokoyama 2002).
- Port Stephens, NSW, Australia - environmental impacts of pearl farming (*P. imbricata*) investigated using sediment samples with results indicating no significant changes in the sediments underneath the experimental pearl farm over time relative to the control sites (O'Connor *et al.* 2003).
- Kimberley region, WA - the impacts of pearl farming on benthic assemblages and the physico-chemistry of sediments were investigated in a comprehensive study conducted over multiple years at three pearl farms (McCallum and Prince 2009; Jelbart

et al. 2011). At each site there was no indication of eutrophication (nutrient enrichment), nor was there evidence of consistent change in the total number of benthic macrofauna taxa or individuals within soft sediments that may be directly attributed to pearl oyster longline compared to reference locations. There was considerable natural variability of the benthic macrofauna among all locations but especially among the reference locations, indicating the diversity of taxa and their relative abundances within the sediments underlying the leases fell within the range of natural variability found at these spatial scales (Jelbart *et al.* 2011).

- McCallum and Prince (2009) also studied the effects of removing a pearl oyster farm (Otama pearl lease, near Kuri Bay, WA) on the benthic conditions under the farm compared to nearby reference locations. There were no observed differences between the sediments at the farm and those at the reference locations, or any significant differences before and after pearl oyster removal. Results suggested that the lease had no impact on the sediments or benthic fauna at the site.
- Cygnet Bay, WA - Liu *et al.* (2016) examined sediment cores from a pearl oyster farm site at Cygnet Bay, WA, to reconstruct environmental changes over a 90 y period. They estimated approximately 2- to 3-fold increases in organic matter (total N and total C), 1- to 5-fold increases in silt proportion and 2- to 5-fold increases in biogenic silica concentrations after pearl oyster farming, in contrast to the control site.

9.4.2 *Sessile invertebrates (excluding hard coral)*

This habitat category includes any other habitat-forming species, including sponges, soft corals, anemones, tunicates, crinoids, bryozoans and bivalves/shellfish. Some of these sessile invertebrates form large colonies. Sessile invertebrates provide critical habitat to a wide range of other animals. Most of these habitat-forming species are also filter feeders that reduce turbidity and improve water quality. Some species, particularly those in deeper or cooler waters, are slow growing and colonies can take decades to recover from disturbance.

Fishing and aquaculture activities for pearl oysters typically occur over benthic habitats comprised of soft sediments interspersed with sessile invertebrates.

The hand collection methods of the pearl oyster fishery result in minimal disturbance to these habitats, but there is the potential for divers and their equipment, and for weighted ropes hung from booms, to accidently interact with benthic habitats. In practise, these interactions with the bottom are rare because they increase turbidity, and water clarity is essential for divers to collect the oysters efficiently. Divers will signal to the vessel to raise the weights according to sea floor height, preventing sea floor damage and disturbance.

Setting of anchors has the potential to physically alter or damage habitat-forming sessile invertebrates. Pearl oyster vessels do not anchor while fishing but need to anchor at night. Vessels avoid anchoring in complex habitat for fear of fouling the anchor and prefer to anchor over sand or mud. Most anchoring occurs in muddy or sandy areas just outside fishing grounds or holding sites.

There is the potential to cause localised impacts to sessile invertebrates at holding sites because these sites are reused each year.

9.4.3 *Hard coral*

Hard corals (Phylum Cnidaria, Order Scleractinia) are key habitat-forming species in tropical regions, supporting diverse ecological communities and providing many ecosystem services

(Fisher *et al.* 2015; Woodhead *et al.* 2019). The combined ability of hard corals to filter-feed and photosynthesise (via symbiotic algae known as 'zooxanthelllae') contributes to the high productivity of coral reef ecosystems.

Globally, coral reefs are threatened by climate change (especially ocean warming and acidification), and various other anthropogenic impacts including pollution, physical disturbances and exploitation (Hughes *et al.* 2017). Total coral cover in Australia is believed to have been declining since about 1990, although patterns differ greatly between regions (GCRMN 2020). The extent and frequency of heat-induced bleaching has been increasing since the 1980s, causing high levels of coral mortality, particularly in eastern Australia (Hughes *et al.* 2018a, 2018b). Until recently, WA corals had been less affected by elevated ocean temperatures and bleaching than those in eastern Australia, but there has been a noticeable increase in heat stress and bleaching in WA since 2010 (Gilmour *et al.* 2019).

Although pearl oysters may occur in coral reef areas, fishing activities do not generally occur in these areas as pearl oyster densities are too low to be commercially viable.

Fishing grounds, resting and holding sites do not occur in coral reef habitat but may contain low densities of individual hard corals.

Pearl oyster lease conditions stipulate that no anchors and bottom structures shall be placed on, or within swinging distance of, corals.

9.4.4 *Seagrass*

Seagrass meadows provide critical habitats and nurseries for many species, and act as substrate stabilisers. Seagrasses are a major food source for some animals, including protected species such as dugong and green turtles. Seagrass meadows enhance ecosystem productivity by capturing and recycling nutrients. They also store large amounts of carbon which helps to mitigate climate change.

Key threats to seagrass include nutrient pollution (that contributes to algal blooms) and suspended sediments, which smother seagrass and reduce light levels preventing photosynthesis. Fishing and boating activities may stir up sediment, reducing light levels for seagrass. Other threats to seagrass include physical damage to the leaves, stems and roots, such as by boat propellers, fishing gear and dredging. Some seagrass species are very slow growing and meadows may take decades to recover from disturbance.

WA hosts 25 species of seagrass, 12 of which occur in tropical areas.

Although pearl oysters may occur in seagrass beds, fishing activities do not generally occur in these areas as pearl oyster densities are too low to be commercially viable.

Pearl oyster resting and holding sites do not occur in seagrass beds.

Pearl oyster lease conditions stipulate that no anchors and bottom structures shall be placed on, or within swinging distance of, seagrass beds.

9.4.5 *Macroalgae*

Macroalgae refers to 'seaweeds' and other marine algae that are attached to substrate and visible to the naked eye. They encompass a wide diversity of morphologies, including foliose (leafy), filamentous, turfing and encrusting forms.

Macroalgae provide habitat for many species and are a food source for many herbivores. In tropical waters, macroalgal fields provide important habitat for various tropical species (Fulton *et al.* 2020). Macroalgae capture nutrients and contribute to primary production. They also sequester large amounts of carbon which helps to mitigate climate change (Krause-Jensen and Duarte 2016). Some macroalgal species produce calcium carbonate, which contributes to reef and sediment formation.

A small amount of macroalgae-dominated habitat occurs in pearl oyster fishing and aquaculture area.

9.4.6 *Mangrove*

Mangroves occur in intertidal zones in tropical and warm temperate areas. Mangrove forests are known to be highly productive ecosystems and provide habitat for a diverse array of vertebrate and invertebrate fauna, including those living within and on the mud, and on stems, roots and leaves of the trees themselves (Nagelkerken *et al.* 2008). Mangroves are key juvenile nurseries for fish and invertebrates, including important fishery species. Mangroves have the capacity to efficiently trap suspended material from the water column, which stabilises soft sediments and improves coastal water quality. Mangroves also store large amounts of carbon (Kristensen *et al.* 2008).

Globally, mangroves are threatened by land reclamation, rubbish and pollution, and climate change (Sippo *et al.* 2018, Goldberg *et al.* 2020). Following mortality events, mangrove forest recovery can be slow, potentially taking decades to regain their full canopy and ecosystem function (e.g., Adame *et al.* 2018; Connolly *et al.* 2020).

The WA pearling industry operates in areas where mangroves occur and therefore has the potential to impact on mangroves. Rubbish and debris from historical and recent pearling industry activities are sometimes found in local mangroves, especially ropes and floats, but also occasionally old boats, jetties and other infrastructure. Also pearl oyster hatcheries are located in, or adjacent to, mangroves.

The Department and the pearling industry work together to locate and remove rubbish from mangroves and beaches. DPIRD officers conduct an audit at least annually of each lease site, including those no longer operating, and of the nearby mangrove areas to check for rubbish. Indigenous Ranger Groups also search for and remove rubbish from their local areas.

9.5 Ecosystem Structure

9.5.1 *Trophic interactions*

9.5.1.1 *Removal of species*

Removal or addition of a species to the environment has the potential to alter key elements of the local ecosystem including trophic structure and function.

The only species retained by the WA pearling industry is *P. maxima*. For culture-sized pearl oyster collection – which comprises the majority of *P. maxima* fishing in WA - divers target a specific size range of *P. maxima* on the fishing grounds. Also pearl divers are limited to fish in shallower areas and calmer weather seasons for safety reasons, providing areas and times of refuge from fishing activities for pearl oysters populations. Total catch is limited by the annual TAC. Thus a limited proportion of the total *P. maxima* stock in a given area is removed.

In the wild, *P. maxima* comprise a small proportion of the total biomass of filter-feeders present in the ecosystem, thus removals of *P. maxima* by the fishery are unlikely to substantially alter this ecological function. There are no known obligate predators of pearl oysters. Therefore, removing pearl oysters at the current level is unlikely to result in significant trophic impacts.

Discarding of commensal/fouling species into the water following pearl oyster shell cleaning may have a trophic impact. However, harvested pearl oysters are young and generally have relatively little epiphytic growth and low infestation rates (Daume *et al.* 2009) minimising the quantity of discards. The boat is constantly moving during shell cleaning, and discards are dispersed over a wide area, rapidly dissipating into the ocean.

9.5.1.2 *Depletion of phytoplankton due to pearl oyster filtration at pearl leases*

Bivalves such as pearl oysters gain nourishment by filtering suspended particles, such as phytoplankton and detritus, from the water column. If phytoplankton consumption due to culture activities exceeds the combined reproduction rate and tidal replenishment rate of phytoplankton to a system (termed 'ecological carrying capacity'), changes to local ecological processes, species, populations or communities may occur.

Extensive research on bivalve and oyster culture indicates that while farms have potential to alter ecosystem structure, impacts vary depending on factors such as farm size, oyster density, water depth, currents and season. Large-scale effects of high densities of oysters in water bodies with limited water exchange were documented (Forrest *et al.* 2009). In lower-nutrient environments (lagoonal pearl farms), studies show that pearl oysters consume plankton at a low rate compared to planktonic fluxes and that their filter feeding activity does not markedly impact on primary productivity (e.g., Niquil *et al.* 2001; Souchou *et al.* 2001).

The northwest coast of WA is known for its high tidal regimes (high levels of water exchange) and seasonal productivity cycles (CoA 2007).

A reduction in phytoplankton abundance would reduce the quality of pearls being cultured; therefore, reductions in phytoplankton at pearl leases are avoided. For example, the pearling industry standard for stocking density of pearl oysters is no more than 16,250 shells per square nautical mile. This density is much lower than densities used in other bivalve aquaculture activities where significant ecosystem impacts have been reported (Jelbart *et al.* 2011).

Pearl leases are located throughout the northwest region, although the lease size and total area that a company can use is restricted. Pearl leases must be a minimum distance of 5 nm from other pearl leases (unless there is mutual consent with the pre-existing pearl lease owners or if the leases are owned by the same legal entity).

9.5.1.3 *Eutrophication*

Eutrophication (nutrient pollution) can result in macrophyte or phytoplankton blooms, structural habitat changes, turbidity and/or deoxygenation of the water column or sediments.

Pearl oysters release waste products in the form of faeces and pseudofaeces, which can accumulate in the sediments below leases and potentially cause localised organic enrichment and eutrophication. This process can be intensified through the cleaning of biofouling organisms from the pearl oyster shells, which also accumulate beneath the pearl lease. Available evidence from various studies (discussed in Section 9.4.1) suggests the deposition of organic material under leases is relatively low, and insufficient to result in any detectable trophic impacts.

Hatcheries release waste water into the environment, which could potentially contain nutrients.

9.5.2 *Pests and diseases*

Pests and diseases may be transferred via vessels in wet areas such as bilges, decks, anchor wells and sea chests and in niche areas of the hull. Fishing vessels may present additional areas including on wet fishing gear or holding tanks. Overall, fishing vessels are typically rated very low risk in terms of translocation of marine pests and diseases at an international scale but examples of local transmission of pest species such as *Undaria pinnatifida* can be identified (Bridgwood and McDonald 2014).

Given that commercial fishers are not permitted to use their boats or gear outside of Australian waters, the risk of international transmission of introduced marine pests and diseases is effectively zero.

The translocation of pearl oysters between zones within WA, or between WA and NT, has the potential to introduce diseases (due to viruses, bacteria, protozoans), pests or invasive species. Some diseases of oysters are host-specific while others have multiple hosts. The introduction of diseases or invasive species has the potential to result in mass mortalities of native species (including wild pearl oyster stocks) and severely disrupt ecosystems.

Industry and management protocols in place to reduce the risk of introductions include:

- Restrictions imposed on the transport of *P. maxima* under the WA *Pearling Act 1990*, the *Pearling (General) Regulations 1991* (Part 7) and the FRMR (Part 13A).
- The *Pearl Oyster Translocation Protocol* governs the movement of hatchery-produced pearl oysters and the movement of pearl oysters between pearl leases. The Protocol also applies to the movement of pearl oysters into and out of WA.
- All translocations require prior approval from a pearling inspector and may require a health certificate. If a health certificate is required, significant quantities of samples from the batch to be transported are required to be submitted to the Government fish health division (NT and/or WA) for health testing. This approval will be denied if there are disease concerns about a particular lease, hatchery or area.
- There are mandatory operating protocols for commercial pearl oyster hatcheries in WA, including minimum standards for filtration of incoming seawater, cleaning and disinfecting procedures, health testing, sterilisation of effluent seawater and record keeping. Hatcheries are inspected at least annually by DPIRD officers to ensure operating protocols are followed.

9.5.3 *Ghost fishing*

Hand collection of pearl oysters minimises ghost fishing risks. However, equipment used in fishing, such as bags or ropes, may still pose a ghost fishing risk if lost or discarded. Equipment and infrastructure used in holding and lease areas may present ghost fishing risks if detached or discarded.

9.6 Broader Environment

Australia abides by the International Convention for the Prevention of Pollution from Ships (MARPOL) which includes regulations aimed at preventing both accidental pollution and pollution from routine vessel operations. MARPOL is given effect through Commonwealth and state legislation to prohibit the disposal at sea of all types of pollution including gas emissions, sewage, plastics and other garbage, oil and other harmful substance.

9.6.1 *Air quality*

In the pearl industry, emissions are generated from the burning of fuel used to operate:

- Commercial fishing vessels.
- Vehicles and other machinery used at hatcheries.

9.6.2 *Water quality*

Pearl industry operations have the potential to impact water quality through:

- Unauthorised discharges from fishing vessels and/or hatcheries including accidental oil, fuel and other spills.
- Increased sediment disturbance due to potential interactions with the benthic environment from anchors, lease infrastructure, divers, etc.
- Nutrient enrichment around leases or hatcheries (discussed under 'Eutrophication' in Section 9.5.1.3).

9.6.3 *Litter*

The pearling industry has the potential to generate litter by abandoning old infrastructure or accidental loss of debris to the environment. Floats or other gear may occasionally escape from pearl leases, e.g., during cyclones.

Pearl leases include the following conditions to minimise litter:

- Infrastructure to be removed from leases when no longer in use.
- The lessee shall not deposit any rubbish or permit any rubbish or discarded equipment, to remain on site, nor dispose of any rubbish or discarded equipment at sea or on adjacent beaches.
- Flotation buoys used on longlines must be purpose built, securely attached to lines and black in colour, or as otherwise approved by DPIRD.

9.6.4 *Noise pollution*

Sound transmission is highly variable in the marine environment and can be dependent on acoustic properties of the seabed and surface, sound speed and water temperature and salinity (Richardson *et al.* 1995). For most marine animals, sound is important for communication; for locating prey and peers and for short and long-range navigation (Erbe *et al.* 2016; Hawkins and Popper 2017).

Noise from vessels, active sonar, synthetic sounds (artificial tones and white noise), acoustic deterrent devices, seismic surveys and noise from energy and construction infrastructure are all known to affect marine animals (Duarte *et al.* 2021). Both chronic and acute noise pollution can cause detectable effects on intra-specific communication, vital processes, physiology, behavioural patterns (e.g., larval settlement, predator avoidance), health status and survival (e.g., Di Franco *et al.* 2020). Depending on the level and duration of noise, effects on species may be temporary or permanent.

Little is known regarding specific effects of noise on most marine species in Australia. However, globally, there is strong evidence for noise impacts on marine mammals, and numerous studies have also found impacts to fish, invertebrates, marine birds and reptiles (Duarte *et al.* 2021).

Vessels used by the pearl industry generate intermittent, low level noise at fishing areas and leases which have the potential to impact local marine organisms. Vehicles and machinery used at hatcheries, have the potential to impact on terrestrial organisms.

9.6.5 *Light pollution*

Artificial light at night can adversely affect species and ecological communities (CoA 2020). It can alter behaviour and/or physiology, reducing survivorship or reproductive output, and can also have indirect effects such as changing the availability of habitat or food, or attracting predators.

For example, adult marine turtles may avoid nesting on beaches that are brightly lit, and adult and hatchling turtles may be unable to find the ocean in the presence of direct or indirect light (Thums *et al.* 2016, Price *et al.* 2018). Lights can disorient flying birds, causing them to divert from migratory routes or collide with infrastructure (Cabrera-Cruz *et al.* 2017). Migratory shorebirds may use sub-optimal roosting sites to avoid lights and may be exposed to increased predation where lighting makes them visible at night. Long-term exposure to artificial light at night may decrease survival growth and reproductive success in clownfish (Schligler *et al.* 2021). Exposure to light at night can reduce larval settlement in benthic invertebrates (e.g. Lynn *et al.* 2021).

10.0 External Factors

Previous ERAs conducted for the Resource identified and summarised external factors and associated issues that would potentially impact the WA pearling industry's performance.

While a number of external influences and activities (e.g., urban developments, dredging, climate change) have the potential to impact the productivity and sustainability of the resource and the broader ecosystem, these are not explicitly included within the scope of this current ERA (see Section 11.1).

11.0 Risk Assessment Methodology

Risk assessments are used to filter and prioritise the various fisheries management issues identified in Australia (Fletcher *et al.* 2002). The risk analysis methodology used for this risk assessment is based on the global standard for risk assessment and risk management (AS/NZS ISO 31000), which has been adopted for use in a fisheries context (see Fletcher *et al.* 2002; Fletcher 2005; Fletcher 2015). The broader risk assessment process is summarised in *Policy for the Implementation of Ecologically Sustainable Development for Fisheries and Aquaculture Within Western Australia* (Fletcher 2002) and Figure 11.1.

The first stage establishes the context or scope of the risk assessment, including determining which activities and geographical extent will be covered, a timeframe for the assessment and the objectives to be delivered. Secondly, risk identification involves the process of recognising and describing the relevant sources of risk. Once these components have been identified, risk scores are determined by evaluating the potential consequences (impacts) associated with each issue, and the likelihood (probability) of a particular level of consequence occurring.

Risk evaluation is completed by comparing the risk scores to established levels of acceptable and undesirable risk to help inform decisions about which risks need treatment. For issues with levels of risk that are considered undesirable, risk treatment involves identifying the likely monitoring and reporting requirements and associated management actions, which can either address and/or assist in reducing the risk to acceptable levels.

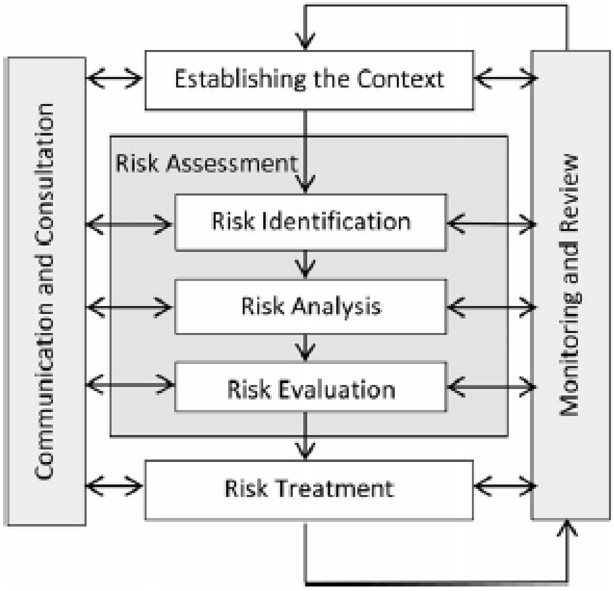


Figure 11.1. Position of risk assessment within the risk management process.

11.1 Scope

This ERA assessed the potential ecological impacts of harvesting and culturing the Resource within WA waters, as required to inform the harvest strategy for the Resource and meet MSC and EPBC Act assessment requirements.

Individual and cumulative risks of specific activities and their impact on each ecological component are scored across all relevant fishing sectors.

In WA fisheries, most primary retained species are managed under a harvest strategy against biologically based reference levels, and the risk of all fishing on the broader stock(s) has typically already been determined as part of their stock assessments. Thus there is no need to re-evaluate these scores in the ERA workshop. Instead, the ERA workshop focusses on assessing the risks of fishing and aquaculture impacts on bycatch and TEP species, benthic habitats and the broader ecosystem.

The calculation of risk in the context of a fishery is usually determined within a specified period, which for this assessment is the next five years (i.e. until 2027). It is envisioned that ERAs will be undertaken periodically (approximately every five years) to reassess new risks or changes to existing risks that may occur over that period. A new risk assessment may also be triggered if there are significant changes identified in fishery and aquaculture operations or management activities that may alter current risk levels.

For the purpose of this ERA, risk is defined as *the uncertainty associated with achieving a specific management objective or outcome* (adapted from Fletcher 2015). For DPIRD, 'risk' is the chance of something affecting DPIRD's performance against the objectives laid out in their relevant legislation. In contrast, for the commercial fishing industry, the term 'risk' generally relates to the potential impacts on their long-term profitability. For the general community, 'risk' could relate to possible impact on their enjoyment of the marine environment. The aim for each of these groups is to ensure the 'risk' of an unacceptable impact is kept to an acceptable level.

11.2 Risk Identification

The first step in the DPIRD risk assessment process is to identify ecological issues relevant to the Resource and fishery being assessed. Ecological issues are examined using a component tree approach (see Figure 12.1), where major components are deconstructed into smaller sub-components that are more specific to allow the development of operational objectives (Fletcher *et al.* 2002). Component trees are broadly similar for all WA aquatic resources assessed by DPIRD but are tailored to suit the individual circumstances of each Resource by adding and expanding some components and collapsing or removing others.

The component tree for the WA Silverlip Pearl Oyster Resource was based on:

- analysis of current fishing, cultivation and hatchery activities;
- previous risk assessments for the resource;
- previous Commonwealth assessments for the commercial fishery under Parts 13 and 13A of the EPBC Act;
- MSC assessments of the commercial fishery;

11.3 Previous Risk Assessments for the Resource.

Multiple risk assessments have been undertaken for the WA Silverlip Pearl Oyster Fishery over the years. A summary of components, issues and risk ratings for previous risk assessment is provided in Appendix 3.

The first comprehensive risk assessment involving external stakeholders was undertaken in 2004 in accordance with the *EPBC Act* to achieve WTO approval under Part 13A of the EPBC Act. The Fishery continues to be regularly assessed for its impact on marine species protected under Part 13 of the EPBC Act for the purpose of maintaining export approval. In 2015, export approval was extended for 10 years, until 30 May 2025. A full list of previous assessments and outcomes can be found on the DAWE website at: https://www.awe.gov.au/environment/marine/fisheries/wa/pearl

The most recent ERA was undertaken in 2016 as a precursor to 2017 MSC certification. The 2016 ERA report (Travaille *et al.* 2016) is available at:

http://www.fish.wa.gov.au/Documents/wamsc_reports/wamsc_report_no_6.pdf

11.4 Risk Assessment Process

An important part of the risk assessment and risk management process is communication and consultation with stakeholders. DPIRD typically invites all relevant stakeholders to participate in collective risk scoring at the ERA workshop.

To prioritise management actions, the risk assessment process separates minor acceptable risks from major unacceptable risks. Once the relevant components and issues for the Resource are identified, they are prioritised using the ISO 31000-based qualitative risk assessment methodology. This methodology uses a consequence-likelihood analysis, which involves examining the magnitude of potential consequences from fishing activities and the likelihood that those consequences will occur given current management controls (Fletcher 2015).

Although consequence-likelihood analyses can range in complexity, this assessment utilised a 4x4 risk matrix (Appendix 1). The consequence levels range from 1 (minor impact) to 4 (major impact) and likelihood levels range from 1 (Remote) to 4 (Likely).

The various likelihood and consequence levels are defined in Appendix 1. Six consequence tables were used in this ERA to accommodate the variety of issues and potential outcomes:

- Target/retained species – measured at a stock level;
- Non-retained (bycatch) species – measured at a stock level;
- TEP species – measured at a population or regional level;
- Habitats – measured at a regional level.
- Ecosystem/Environment – measured at a regional level; and
- Genetic Integrity of wild stock– measured at population or regional level.

Scoring involves assessing the likelihood that a consequence level is occurring, or will occur within a 5-year period. For each issue, the consequence and likelihood levels are evaluated to determine the highest risk score using the risk matrix. Each issue is thus assigned a risk level within one of five categories: Negligible, Low, Medium, High or Severe.

If an issue is not considered to have any detectable impact, it could be considered to be a zero (0) consequence, but it is preferable to score such components as being a remote (1) likelihood of a minor (1) consequence.

12.0 Risk Analysis

Twenty-one broad ecological components were identified as potentially impacted by WA Silverlip Pearl Oyster harvesting and culturing activities (Figure 12.1). Where relevant, some of these were further separated into smaller categories, resulting in 26 individual ecological components that were assessed.

The risk ratings for each ecological component considered in the assessment are summarised in Table 12.1. The risk justifications given below include comments from stakeholders that attended the workshop. While these are a summary of individual views and may not be representative of every stakeholder at the workshop, the risk scores are reflective of the group consensus at the workshop.

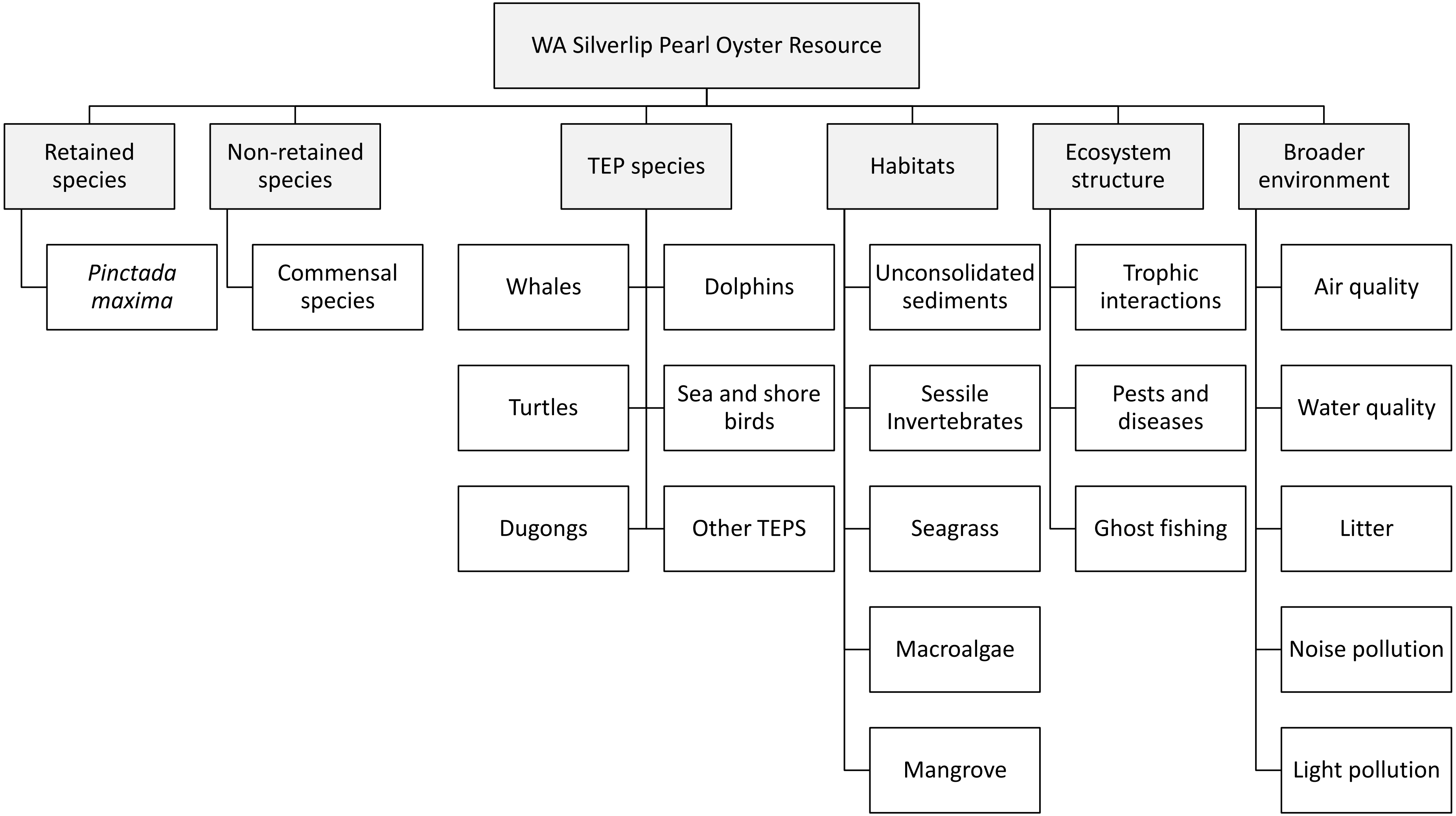


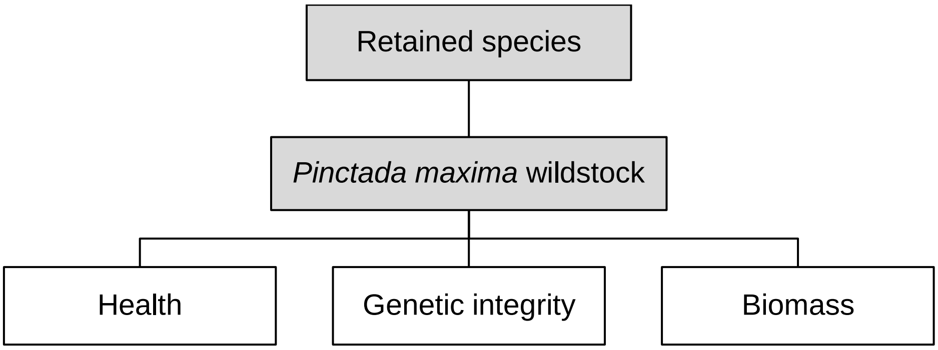
Figure 12.1. Component tree for assessing the ecological sustainability of the WA Silverlip Pearl Oyster (*P. maxima*) Resource.

Table 12.1. Overview of the objectives, components, and risk scores and ratings considered in the 2022 ecological risk assessment of the fishery for the WA Silverlip Pearl Oyster (*P. maxima*) Resource.

Aspect	Fishery Objective	Component	Issues	Risk Scoring	Risk rating
Retained species *Pinctada maxima*	To maintain biomass of each retained species at a level where the main factor affecting recruitment is the environment	Wild stock biomass	Fishing	C2, L3	MEDIUM
		Genetic integrity	Fishing & Farming Translocations	C2, L2	LOW
		Genetic integrity	Hatchery releases	C2, L2	LOW
		Health (pests & diseases)	All industry activities	C2, L1	NEGLIGIBLE
Bycatch Species	To ensure fishing and culturing impacts do not result in serious or irreversible harm to bycatch species populations.	Commensal/fouling species	Fishing & Farming	C2, L1	NEGLIGIBLE
TEPS (non-retained/incidental interactions)	To ensure fishing impacts do not result in serious or irreversible harm to TEP species' populations	Whale species	Fishing & Farming	C1, L2	NEGLIGIBLE
		Dolphin species	Fishing & Farming	C1, L2	NEGLIGIBLE
		Dugongs	Fishing & Farming	C1, L2	NEGLIGIBLE
		Marine turtle species	Fishing & Farming	C1, L2	NEGLIGIBLE
		Sea and shore bird species	Fishing & Farming	C1, L2	NEGLIGIBLE
		All other TEP species	Fishing & Farming	C1, L2	NEGLIGIBLE
Habitats	To ensure the effects of fishing and culturing do not result in serious or irreversible harm to habitat structure and function	Unconsolidated sediments	All industry activities	C2, L1	NEGLIGIBLE
		Sessile Invertebrates	All industry activities	C2, L1	NEGLIGIBLE
		Seagrass	All industry activities	C2, L1	NEGLIGIBLE
		Macroalgae	All industry activities	C1, L1	NEGLIGIBLE
		Mangrove	All industry activities	C1, L2	NEGLIGIBLE
Ecosystem structure	To ensure the effects of fishing and culturing do not result in serious or irreversible harm to ecological processes	Translocation (pests & diseases)	All industry activities	C2, L2	LOW
		Trophic interactions – removals	Fishing	C1, L1	NEGLIGIBLE
		Trophic interactions – discarded fouling	Fishing & Farming	C1, L4	LOW
		Trophic interactions – plankton depletion	Farming	C1, L1	NEGLIGIBLE

	Trophic interactions – eutrophication	Farming & Hatcheries	C1, L1	NEGLIGIBLE
	Ghost fishing (lost gear)	Fishing & Farming	-	NA
Broader environment To ensure the effects of fishing and culturing do not result in serious or irreversible harm to the broader environment	Litter	All industry activities	C2, L2	LOW
	Air quality	All industry activities	C1, L1	NEGLIGIBLE
	Water quality	All industry activities	C1, L2	NEGLIGIBLE
	Noise pollution	All industry activities	C1, L2	NEGLIGIBLE
	Light pollution	All industry activities	C1, L2	NEGLIGIBLE

12.1 Retained species



12.1.1 *Biomass of Pinctada maxima wild stock*

Risk Rating: Impact of all fishing on the WA wild stock of *Pinctada maxima* (C2×L3= MEDIUM).

- Risk rating based on annual assessment of stock status in Zone 2 (the main fishery area) undertaken by DPIRD, not re-assessed in this ERA workshop.

12.1.2 *Genetic integrity of Pinctada maxima wild stock*

Risk Rating: Impact of translocation of wild stock between fishing and farming locations on the WA wild stock of *Pinctada maxima* (C2×L2 = LOW).

- This discussion highlighted multiple knowledge gaps that would need to be addressed to fully understand the potential impact of this activity.
- Early studies suggest high gene flow throughout WA waters, except Exmouth Gulf – there seems to be barriers to flow to that area.
- Recent fine-scale sampling in Eighty Mile Beach area indicated extensive gene flow over that area, i.e., distances of ≤100 km (Thomas & Miller 2021). This suggests single homogenous population over that area.
- Ideally, to avoid risks, individuals should be transported no further than their larvae would naturally disperse. How far is this? Based on the Eighty Mile Beach study, ≤100 km could be regarded as a ‘safe’ (minimal genetic risk) distance to translocate stock. This assumes ‘regional structuring’ at similar spatial scales throughout WA. However, other parts of *P. maxima* distribution in WA have not been extensively sampled, so genetic structuring in WA is not clear. Spatial scales may differ because hydrodynamics vary between areas, which can affect distance of larval dispersal (& hence gene flow).
- Translocation distance is only one consideration in assessing risk. The abundance and genetic size of translocated and receiving populations are also relevant factors. These data currently not available.
- Currently, wild stock is harvested only from Eighty Mile Beach area. Approximately 500,000-800,000 oysters are collected from here each year and placed on farms. Oysters on farms are a mixture of males and females and are presumed to breed with

each other. Thus larvae of Eighty Mile Beach genetic stock are being produced on farms and released into surrounding waters.

- Note - Oysters on farms are not likely to breed directly with any local wild stock because unfertilised gametes do not survive for long in the water column.
- Successful recruitment is not guaranteed. Successful larval settlement requires suitable substrate. There is limited availability of suitable substrate in the Kimberley region. Some farms are near suitable habitat, some aren't. Also, dispersal to settlement sites requires favourable local hydrodynamics.
- Comment by Dr Luke Thomas - It is important to note the levels of genetic difference between populations (e.g., between Eighty Mile Beach and Exmouth Gulf) are really low, so the risk of admixture from farms is probably low. The risk of introducing harmful alleles into the population is even lower.
- Several workshop participants noted there have already been decades of translocation in WA, including prior to adoption of any translocation protocols. So presumably there is low risk of further impact because any impact has already occurred.

Risk Rating: Impact of release of hatchery-reared animals on the WA wild stock of *Pinctada maxima* (C2×L2 = LOW).

- This discussion highlighted multiple knowledge gaps that would need to be addressed to fully understand the potential impact of this activity.
- Under current management arrangements it is estimated that up to ~2 million hatchery-reared oysters could potentially be present on WA leases in a given year, assuming maximum uptake of quotas plus some reseeding. However, the quantity of hatchery-reared stock on currently farms is estimated to be lower than this.
- This maximum potential level (i.e., 2 million) is higher than the maximum potential number of wild-caught oysters on farms, which is less than 1 million.
- Comment by Dr A Hart - Farms are not located near Eighty Mile Beach which hosts the largest wild population, so risk of genetic impacts to this 'main stock' is probably fairly low.
- Comments from industry members:
    - historical breeding programs did not focus on genetics, but that has changed. Maintenance of genetic diversity is now a priority.
    - The production cycle of pearl oysters is relatively slow, compared to, for example, Atlantic salmon which has multiple cycles per year, and so rate of genetic changes would be relatively slow.
    - The process of selective breeding for Australian *P. maxima* is much slower than that of intensive breeding programs in other aquaculture industries (e.g., Atlantic salmon which has multiple production cycles per year) due to the extended nature of pearl production. Thus, the rate of genetic selection in a hatchery population is relatively slow.

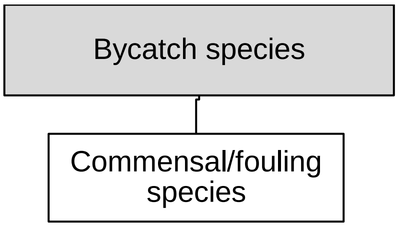
- Comments by Dr L. Thomas:
  - in general pearl oyster populations are large and have high levels of genetic diversity so the risk of inbreeding depression is lower than other aquacultured species.
  - Selecting for certain traits doesn't necessarily result in a strong bottleneck in the population. If hatchery-reared are much more fit (e.g., selected for fast growth) then maybe there is potential for impact, but it depends on the degree of difference between hatchery and wild.
  - If large numbers were repeatedly stocked over time there may be an effect, but the lines being bred in the hatcheries are still very diverse and not different enough from the wild gene pool to pose a risk.

12.1.3 *Health of Pinctada maxima wild stock*

Risk Rating: Impact of translocation of pests and diseases on the WA wild stock of *Pinctada maxima* (C2×L1 = NEGLIGIBLE).

- Comments by Dr K. Webb:
  - There have been minor/local disease outbreaks in the past, but these have been picked up and contained (e.g., *Haplosporidium*), with no ongoing problems.
  - There is an issue going back a decade or so with Oyster Oedema Disease (OOD), particularly in Exmouth Gulf. There is still ongoing research to understand the mechanisms of OOD. However, there is currently little industry activity in Exmouth Gulf.
  - Many mitigation measures are in place to prevent translocation of diseases between zones (or from interstate). This issue is "well managed".
  - Similarly, many measures in place to prevent disease transmission from hatcheries to wild stock. Batches of spat are tested before release.
  - Risk of disease transmission to wild stock is very low.
- Comment by Dr A. Hart – DPIRD researchers have surveyed wild stock at Exmouth Gulf and found no evidence of a problem due to OOD.
- Comment by B. Herbert - Oyster spat are inspected histologically before being taken out, e.g., a bacterial problem was detected recently. Risk of disease transmission from hatchery is low, diseases are quite well managed.
- Comment by Dr S Bridgwood – pearl oyster health testing processes focus on detecting diseases, not pests. They do often detect pests, but not always.

12.2 Bycatch species (discards)

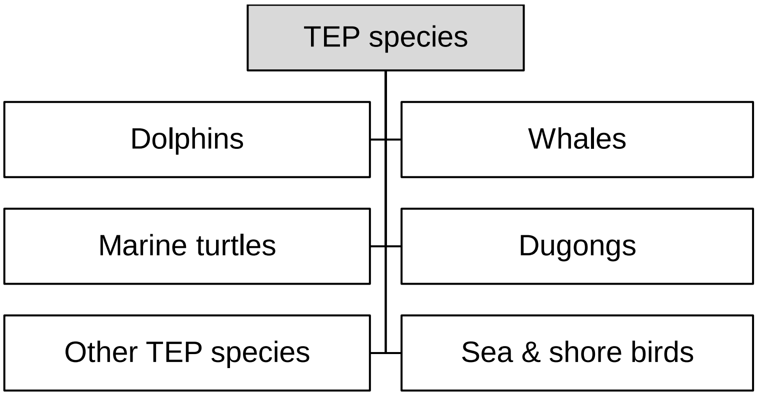


12.2.1 *Fouling and other commensal species*

Risk Rating: Impact of fishing and farming on wild populations of commensal species (C2×L1 = NEGLIGIBLE)

- Numerous commensal species living on/in pearl oysters and are incidentally collected and discarded.
- Pontinine shrimp likely to be the commensal species most vulnerable to fishing removals, due to *P. maxima* being its only known host. However, this shrimp mainly occurs in deeper water, outside the fishing area.
- Other commensal species are unlikely to be strongly dependent on *P. maxima*. Pea crab has many other hosts apart from *P. maxima*, and fouling species likely to have multiple other available substrates.
- Due to TAC, a limited proportion of *P. maxima* (the host) is removed from each area.
- Fouling species are removed from infrastructure at leases and discarded. Infrastructure likely to increase habitat availability for some fouling species.

12.3 TEP species



12.3.1 *Whales*

Risk Rating: Impact of all WA pearling industry activities on humpback and other whale species (C1×L2 = NEGLIGIBLE).

- Humpbacks regarded as most likely whale species to interact with industry due to their overlap with fishing and farming areas. They are also very abundant in the area.
- Despite the overlap, and high whale abundance, there have only been 4 entanglements with pearl oyster infrastructure since 1990, and none since 2008, which suggests a low likelihood of industry interactions.

12.3.2 *Dolphins*

Risk Rating: Impact of all WA pearling industry activities on whale species (C1×L2 = NEGLIGIBLE).

- Multiple dolphin species occur in the region, but Australian snubfin and Indo-Pacific humpback are regarded as most vulnerable to industry activities due to their greater overlap with fishing and farming areas, and their higher conservation status.
- Pearling vessels travel slowly, posing low risk of boat strike.
- No negative interaction by the industry with dolphins is known to have occurred.

12.3.3 *Dugongs*

Risk Rating: Impact of all WA pearling industry activities on dugongs (C1×L2 = NEGLIGIBLE).

- Comment by S. McDowell - dugongs in Roebuck Bay are threatened, but given depth of water in which industry operates, an interaction is unlikely.
- Pearling vessels travel slowly, posing low risk of boat strike.
- No negative interaction by the industry with dugongs is known to have occurred.

12.3.4 *Marine turtles*

Risk Rating: Impact of all WA pearling industry activities on marine turtle species (C1×L2 = NEGLIGIBLE).

- Six marine turtle species occur in the region, all overlap to some extent with fishing and farming areas. Green turtles are particularly common.
- Pearling vessels travel slowly, posing low risk of boat strike.
- No negative interaction by the industry with marine turtles is known to have occurred.

12.3.5 *Birds*

Risk Rating: Impact of all WA pearling industry activities on sea and shore birds (C1×L2 = NEGLIGIBLE).

- Multiple migratory shorebird species occur in the region, including Critically Endangered and Endangered species.
- Vessels generally do not travel close to shore and farms are located offshore so the industry is unlikely to disturb birds on the shore.
- Comment by S. McDowell - unlike to be an impact on shorebirds in Roebuck Bay. There are some shore landings at Eighty Mile Beach where crew changes, etc occur, but these impacts would be “very minimal”.
- No negative interaction by the industry with sea or shore birds is known to have occurred.

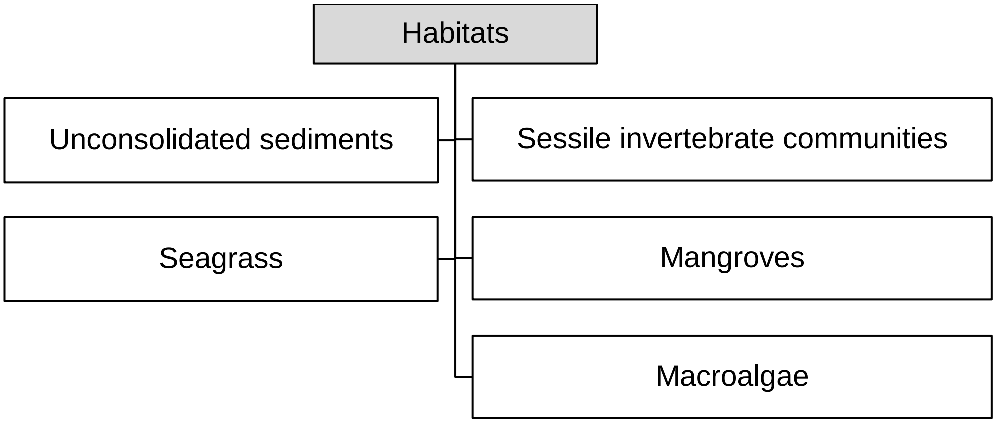
12.3.6 *All other TEP species*

Risk Rating: Impact of all WA pearling industry activities on all other TEP species (C1×L2 = NEGLIGIBLE).

- Other TEP species in the region include crocodiles, sea snakes, syngnathids (seahorses, pipefish), and elasmobranchs (sharks, rays, sawfish).

- There are no reported interactions or known issues relating to the industry for any other TEP species.

12.4 Habitats



12.4.1 *Unconsolidated sediments*

Risk Rating: Impact of all WA pearling industry activities on unconsolidated sediment habitat (C2×L1 = NEGLIGIBLE).

- Habitat type under leases is soft sediment, or gravel/coral rubble.
- Multiple past studies have indicated pearling leases have a minimal impact on sediments under them.
- Points of contact with bottom are few – only a couple of permanent anchoring points. Boats moor, they do not anchor.

12.4.2 *Sessile invertebrate communities*

Risk Rating: Impact of all WA pearling industry activities on communities of habitat-forming sessile invertebrates (C1×L2 = NEGLIGIBLE).

- This habitat type occurs in fishing areas. Pearl divers typically do not make contact with the bottom.
- This habitat type includes hard corals.

12.4.3 *Seagrass*

Risk Rating: Impact of all WA pearling industry activities on seagrass habitat (C1×L2 = NEGLIGIBLE).

- Limited fishing activity in this habitat type.
- No anchoring or bottom structures are permitted in seagrass beds.

12.4.4 *Mangroves*

Risk Rating: Impact of all WA pearling industry activities on mangrove habitat (C1×L2 = NEGLIGIBLE).

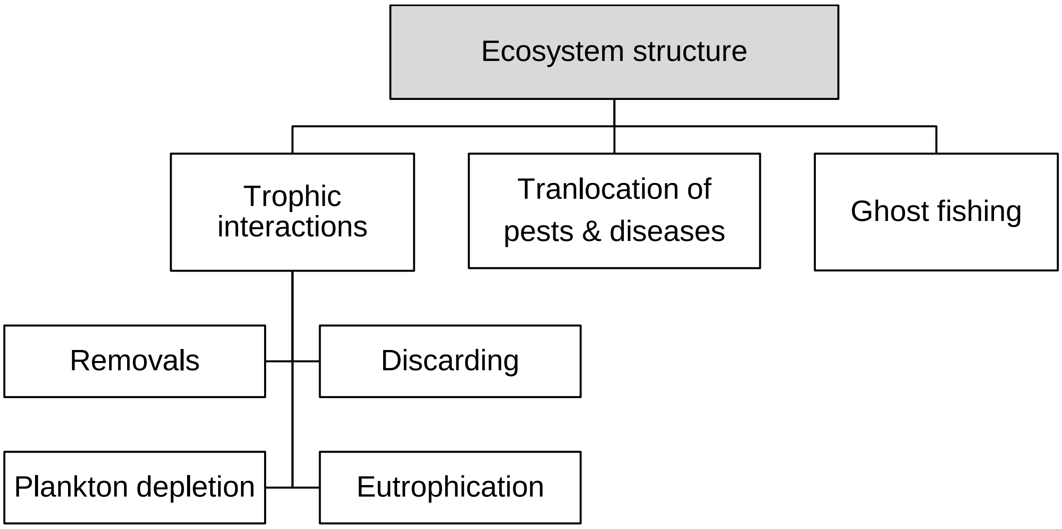
- Historical impacts by industry occurred when mangroves were cleared to build sheds, etc. However, mangroves are now legally protected so future impacts are not expected to occur.

12.4.5 *Macroalgae-dominated habitat*

Risk Rating: Impact of all WA pearling industry activities on macroalgae-dominated habitat (C1×L1 = NEGLIGIBLE).

- Limited amount of this habitat type in fishing or farming areas.

12.5 Ecosystem structure



12.5.1 *Trophic interactions – removals of biomass*

Risk Rating: Impact of WA pearl oyster fishing on ecosystem via removals of *P. maxima* (C1×L1 = NEGLIGIBLE).

- A limited proportion of the total *P. maxima* stock in a given area can be removed, due to TAC. Therefore, role of *P. maxima* in local food webs is unlikely to be compromised.
- *P. maxima* is just one of many local filter-feeding species so removals are unlikely to reduce this ecological function.
- *P. maxima* is not known to be a critical prey item for any predator.

12.5.2 *Trophic interactions – discards*

Risk Rating: Impact on ecosystem from discarding of fouling organisms during WA pearl oyster fishing and farming (C1×L4 = LOW).

- After being removed from oysters and gear, fouling organisms are discarded into the water. This attracts (and perhaps enhances) local populations of small fish.

12.5.3 *Trophic interactions – plankton depletion*

Risk Rating: Impact of on ecosystem via plankton depletion by farmed WA pearl oysters (C1×L1 = NEGLIGIBLE).

- High densities of filter-feeding bivalves, such as oysters, could potentially result in localised plankton depletion.
- Stocking densities of WA pearl oysters are much lower than densities used in other bivalve aquaculture activities where such impacts occur. High tidal flow and water exchange around leases reduces risk of plankton depletion.
- Workshop agreed that plankton depletion (if any) from WA pearl oyster farms would be sufficiently small as to be difficult to measure.

12.5.4 *Trophic interactions – eutrophication (nutrient pollution)*

Risk Rating: Impact on ecosystem by nutrient pollution from WA pearl oyster farms and hatcheries (C1×L1 = NEGLIGIBLE).

- Two potential sources of localised eutrophication considered here – 1) oyster waste products could accumulate under leases. 2) hatchery discharges may contain nutrients.
- Several past studies have indicated minimal/no impact under leases.
- High water flow around leases likely to disperse waste products away from leases.
- WA lease conditions stipulate that operators must monitor the status of the benthos under leases. Industry members stated that this monitoring does not occur because they have funded several past studies that indicated minimal/no impact under leases and, since industry practises have not changed since those studies were undertaken, there is no need to keep monitoring.
- Over next 5 years there could be up to 3 hatcheries operating in WA waters. (currently only 2).
- Low amounts of N and P in hatchery discharges. Discharges are into sand, not directly into water. No evidence of algal blooms around hatcheries.

12.5.5 *Translocation of pests and diseases*

Risk Rating: Impact on the ecosystem of translocation of pests and diseases by the pearling industry (C2×L2 = LOW).

- Workshop agreed this risk mainly related to potential spread of pests, with diseases being less of a concern due to current rigorous health testing.
- Comment by B. Herbert - There is a possibility of pests being translocated between zones. This demonstrated by the case of *Didemnum perlucidum* (pest ascidian), introduced to NT a few years ago by illegal fishing boat and has spread widely including into WA. The industry could potentially contribute to spread of such a pest by moving shells around.
- There are effective government monitoring programs in place in NT and WA ports to detect introduced pests before they have a chance to spread.
- Fishery zoning arrangements helps to reduce translocation risks, due to translocation protocol requirements.

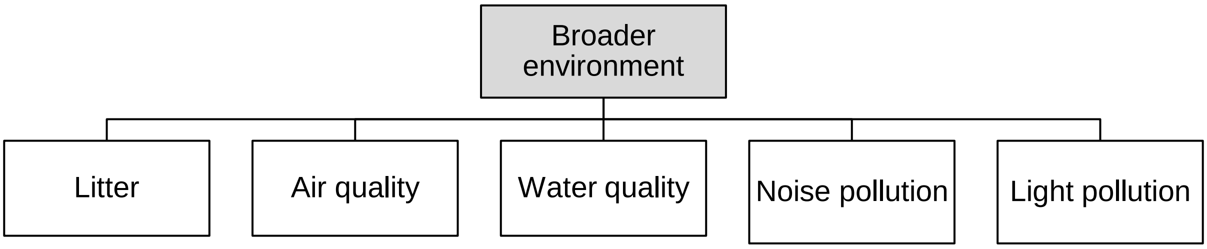
- Smaller industry boats used locally do not spend time in Broome port (which limits opportunities to pick up pests from other vessels in the port).
- A few larger industry boats travel between WA-NT, generally only once a year. These could pose a translocation risk if appropriate biofouling mitigation measures were not occurring.
- Workshop recommended that industry work with DPIRD Biosecurity group to develop and adopt a Biofouling Plan. Noting that the industry is likely to already be doing many of the things that would be contained in such a Plan, it would be a simple action, and it would help the industry to articulate what it is doing to mitigate this risk.

12.5.6 *Ghost fishing (lost gear)*

Risk Rating: Impact on WA pearl oyster wild stock by ghost fishing of lost gear.

- Not applicable to pearl oysters.
- The potential impact of lost gear is considered under ‘Litter’.

12.6 Broader environment



12.6.1 *Litter*

Risk Rating: Impact of WA pearl oyster industry on ecosystem via litter (C2×L2 = LOW).

- The workshop recognised three categories of litter: 1) accidental, 2) losses during cyclones/storms, 3) historical.
- Comments from S. McDowell
  - Litter from pearling industry is a significant issue around Broome. DPIRD Broome office receives many complaints from local residents and Traditional Owners (TOs) “deeply upset” about this issue.
  - Floats from pearl farms often wash up on the beaches around Broome.
  - North of Broome, TOs report historical litter issues with old, abandoned pearling equipment (sunken boats, fuel drums, machinery, ropes, panels).
  - Some historical litter could be removed (and some has been), but some is considered too large to move. Historical litter has created substantial local ecological damage and is a major social issue in the region. DBCA are reportedly mapping the extent of historical litter in the region and are expected to liaise with DPIRD and industry to develop a plan to remediate areas.

- Breakoffs during cyclones are unavoidable and floats are always washing up on beaches. Floats can be taken into Broome and a reward given (buy-back scheme) and this is "self-policing" quite well.
- The main problematic litter currently being generated by industry is plastic pearling tags issued by DPIRD. Tags are not robust and so readily become detached from panels. Tags are small enough to be ingested by marine fauna.
- Other plastic debris on beaches is probably coming from overseas.

- Comments by Industry:
  - Companies are aware of this issue. Paspaley have regular patrols around leases to clean up accidental and cyclone litter on beaches. There is a buy-back scheme for anyone finding pearling equipment.
  - There is misunderstanding about source of historical litter, some is not from pearling industry, e.g., there are drums from WW2.

NOTE: Although historical litter is a major issue that has existed for a long time and needs to be addressed, the risk score in this ERA refers only to the ecological impact of the types of litter currently (and over the next 5 years) being generated by industry, i.e., mainly tags and floats.

The ecological impact of historical litter is clearly greater than that of current litter and, accordingly, a risk score for historical litter would be expected to be higher.

12.6.2 *Air quality*

Risk Rating: Impact of WA pearl oyster industry on air quality (C1×L1 = NEGLIGIBLE).

- Over next 5 years the size of pearling fleet is not expected to change significantly.
- Small aircraft (sea planes) are used by the industry to transport staff to/from leases.
- Some industry members have signed up to a 'Carbon Zero' scheme and are in the process of calculating their carbon footprint.
- Exhaust emissions from vessels are relatively minor (compared to many other industries), highly localised, unlikely to be detectable beyond immediate area.

12.6.3 *Water quality*

Risk Rating: Impact of WA pearl oyster industry on water quality (C1×L2 = NEGLIGIBLE).

- Accidental spills of fuel or chemicals could occur in any industry.
- Vessels are prohibited from releasing sewage at sea, must only be released on land (plan/protocol in place).
- A few live-aboard boats used by the industry, from which there may be domestic spills.
- Water quality is regularly monitored at pearl oyster farms.

12.6.4 *Noise pollution*

Risk Rating: Impact of WA pearl oyster industry on environment via noise pollution (C1×L2 = NEGLIGIBLE).

- Industry vessels and water and land-based activities generally emit small amounts of noise.
- Marine Parks have guidelines in place for vessels to reduce noise pollution, especially around whale migration paths.

12.6.5 *Light pollution*

Risk Rating: Impact of WA pearl oyster industry on environment via light pollution (C1×L2 = NEGLIGIBLE).

- Light can disorientate marine turtles, but industry activities generally do not coincide with turtle nesting locations and times. Turtle nesting near Cable Beach usually happens around November/December each year.
- Hatcheries are energy conscious and do not emit high amounts of light.
- Farm lighting (flashing yellow lights) requirements are determined by the WA Department of Transport.

13.0 References

Adame M., Zakaria R., Fry B., Chong V., Then Y., Brown C., and Lee S.Y. 2018. Loss and recovery of carbon and nitrogen after mangrove clearing, Ocean and Coastal Management 161:117-126. https://doi.org/10.1016/j.ocecoaman.2018.04.019

Ahyong S.T. and Brown D.E. 2003. Description of *Durckheimia lochi* n. sp., with an annotated checklist of Australian Pinnotheridae (Crustacea: Decapoda: Brachyura). Zootaxa 254:1-20.

Ahyong S.T. and Ng P.K. 2007. The pinnotherid type material of Semper (1880), Nauck (1880) and Bürger (1895) (Crustacea: Decapoda: Brachyura). Raffles Bulletin of Zoology, Supplement 16:191-226.

Akerman K. and Stanton J. 1994. Riji and Jakoli: Kimberley Pearl shell in Aboriginal Australia. Northern Territory Museum of Arts and Sciences, Darwin

Benzie JAH and Smith-Keune C. 2006. Microsatellite variation in Australian and Indonesian pearl oyster *Pinctada maxima* populations. Marine Ecology Progress Series 314:197-211. Doi:10.3354/meps314197

Bouchet P.J., Thiele D., Marley S.A., Waples K., Weisenberger F., Rangers B., Rangers B.J., Rangers D., Rangers N.B.Y., Rangers N.N. and Rangers U. 2021. Regional Assessment of the Conservation Status of Snubfin Dolphins (*Orcaella heinsohni*) in the Kimberley Region, Western Australia. Frontiers in Marine Science 7:614852. https://doi.org/10.3389/fmars.2020.614852

Bridgwood S. and McDonald J. 2014. A likelihood analysis of the introduction of marine pests to Western Australian ports via commercial vessels. Fisheries Research Report No. 259. Department of Fisheries, Western Australia. 212 pp. https://www.fish.wa.gov.au/Documents/research_reports/frr259.pdf

Brown A.M., Bejder L., Pollock K.H. and Allen S.J. 2016. Site-specific assessments of the abundance of three inshore dolphin species to inform conservation and management. Frontiers in Marine Science 3:4. https://doi.org/10.3389/fmars.2016.00004

Bruce A.J. 1989. Notes on some Indo-Pacific Pontoniinae, XLV. *Conchodytes maculatus* sp. Nov., a new bivalve associate from the Australian northwest shelf. Crustaceana, 56:182-192.

Cabrera-Cruz S.A., Smolinsky J.A. and Buler J.J. 2018. Light pollution is greatest within migration passage areas for nocturnally-migrating birds around the world. Nature Scientific Reports 8:e3261. https://doi.org/10.1038/s41598-018-21577-6

Commonwealth of Australia (CoA). 2007. A Characterisation of the Marine Environment of the North-west Marine Region. A summary of an expert workshop convened in Perth, WA, 5-6 September 2007. Canberra: DEWHA.

Commonwealth of Australia (CoA). 2015a. Sawfish and River Sharks Multispecies Issues Paper, Commonwealth of Australia. https://www.awe.gov.au/environment/biodiversity/threatened/publications/recovery/sawfish-river-sharks-multispecies-recovery-plan

Commonwealth of Australia (CoA). 2015b. Wildlife Conservation Plan for Migratory Shorebirds, Commonwealth of Australia. https://www.awe.gov.au/sites/default/files/documents/widlife-conservation-plan-migratory-shorebirds.pdf

Commonwealth of Australia (CoA). 2017. EPBC Act Policy Statement 3.21—Industry guidelines for avoiding, assessing and mitigating impacts on EPBC Act listed migratory shorebird species, Commonwealth of Australia. https://www.awe.gov.au/sites/default/files/documents/bio4190517-shorebirds-guidelines.pdf

Commonwealth of Australia (CoA). 2020. National Light Pollution Guidelines for Wildlife Including Marine Turtles, Seabirds and Migratory Shorebirds, Commonwealth of Australia. https://www.agriculture.gov.au/sites/default/files/documents/national-light-pollution-guidelines-wildlife.pdf

Condie S.A., Mansbridge J.V., Hart A.M. and Andrewartha J.R. 2006. Transport and recruitment of silver-lip pearl oyster larvae on Australia's North West Shelf. Journal of Shellfish Research 25:179-185. https://doi.org/10.2983/0730-8000(2006)25[179:TAROSP]2.0.CO;2

Connolly R.M., Connolly F.N. and Hayes M.A. 2020. Oil spill from the Era: Mangroves taking eons to recover. Marine Pollution Bulletin 153:110965 https://doi.org/10.1016/j.marpolbul.2020.110965

D'anastasi B.R., Van Herwerden L., Hobbs J.A., Simpfendorfer C.A. and Lukoschek V. 2016. New range and habitat records for threatened Australian sea snakes raise challenges for conservation. Biological Conservation 194:66-70. https://doi.org/10.1016/j.biocon.2015.11.032

Daume S; Fromont J; Hart A. 2009. Management of bioeroding sponges in wild stocks of *Pinctada maxima* in Western Australia. Final FRDC Report – Project 2005/074. Fisheries Research Report No. 196; Department of Fisheries WA. 48 pp. http://www.fish.wa.gov.au/Documents/research_reports/frr196.pdf

Dawson C. 1985. *Indo-Pacific pipefishes (Red Sea to the Americas)*. Ocean Springs, Mississippi: Gulf Coast Research Laboratory.

Department of Agriculture, Water and the Environment (DAWE). 2022. Listing Advice *Megaptera novaeangliae* Humpback Whale. Canberra: Department of Agriculture, Water and the Environment. http://www.environment.gov.au/biodiversity/threatened/species/pubs/38-listing-advice-26022022.pdf

Department of Primary Industries and Regional Development (DPIRD). 2022. Silver-Lip Pearl Oyster (*Pinctada maxima*) Harvest Strategy 2022–2026. Version 2.0. Fisheries Management Paper 276. Department of Primary Industries and Regional Development, Perth. 35 pp. https://library.dpird.wa.gov.au/fr_fmp/269/

Di Franco E., Pierson P., Di Iorio L., Calò A., Cottalorda J.M., Derijard B., Di Franco, A., Galvé A., Guibbolini M., Lebrun J. and Micheli F. 2020. Effects of marine noise pollution on Mediterranean fishes and invertebrates: A review. Marine Pollution Bulletin 159:111450. https://doi.org/10.1016/j.marpolbul.2020.111450

Dix T.G. 1973. Mantle changes in the pearl oyster *Pinctada maxima* induced by the pea crab *Pinnotheres villosulus*. Veliger 15:330-331.

DSEWPaC. 2012a. Species group report card – Cetaceans. Canberra: Commonwealth of Australia. https://www.agriculture.gov.au/sites/default/files/env/pages/1e59b6ec-8b7e-42a8-9619-b5d728f878b2/files/temperate-east-report-card-cetaceans.pdf

DSEWPaC. 2012b. Species group report card – Dugongs. Canberra: Commonwealth of Australia. https://www.agriculture.gov.au/sites/default/files/env/pages/1670366b-988b-4201-94a1-1f29175a4d65/files/north-west-report-card-dugongs.pdf

Duarte C.M., Chapuis L., Collin S.P., Costa D.P., Devassy R.P., Eguiluz V.M., Erbe C., Gordon T.A., Halpern B.S., Harding H.R. and Havlik M.N. 2021. The soundscape of the Anthropocene ocean. Science 371(6529):eaba4658. https://doi.org/10.1126/science.aba4658

Erbe C., Dunlop R. and Dolman S. 2018. Effects of noise on marine mammals. In: Effects of anthropogenic noise on animals. Pp. 277-309. Springer, New York, NY. https://doi.org/10.1007/978-1-4939-8574-6_10

Fisher R., O'Leary R.A., Low-Choy S., Mengersen K., Knowlton N., Brainard R.E. and Caley M.J. 2015. Species richness on coral reefs and the pursuit of convergent global estimates. Current Biology, 25:500-505. https://doi.org/10.1016/j.cub.2014.12.022

Fletcher W.J. 2002. *Policy for the Implementation of Ecologically Sustainable Development for Fisheries and Aquaculture within Western Australia*. Fisheries Management Paper No. 157. WA Department of Fisheries, Perth. https://library.dpird.wa.gov.au/fr_fmp/148/

Fletcher W.J. 2005. Application of qualitative risk assessment methodology to prioritise issues for fisheries management. ICES Journal of Marine Research 62:1576-1587. https://doi.org/10.1016/j.icesjms.2005.06.005

Fletcher W.J. 2015. Review and refinement of an existing qualitative risk assessment method for application within an ecosystem-based fisheries management framework. ICES Journal of Marine Science 72:1043-1056. https://doi.org/10.1093/icesjms/fsu142

Fletcher W.J. Chesson J., Fisher M., Sainsbury K.J., Hundloe T., Smith A.D.M. and B. Whitworth. 2002. National ESD Reporting Framework for Australian Fisheries: The 'How To' Guide for Wild Capture Fisheries. FRDC Project 2000/145, Canberra, Australia. Perth, WA Department of Fisheries. 120 pp.

Fletcher WJ, Friedman K, Weir V, McCrea J and Clark R. 2006. ESD Report Series No 5: Pearl Oyster Fishery. Perth, Department of Fisheries WA. https://library.dpird.wa.gov.au/fr_esd/4/

Fletcher W.J, Gaughan D.J., Metcalf S.J., and Shaw J. 2012. Using a regional level, risk based framework to cost effectively implement Ecosystem Based Fisheries Management (EBFM). In: Global progress on Ecosystem-Based Fisheries Management (G.H. Kruse, H.I. Browman, K.L. Cochrane, D. Evans, G.S. Jamieson, P.A. Livingston, D. Woodby, C. Ik Zhang eds.). Fairbanks: Alaska Sea Grant College Programme pp. 129-146. https://doi.org/10.4027/gpebfm.2012.07

Fletcher W.J, Shaw J., Metcalf S.J. and Gaughan D. 2010. An ecosystem-based fisheries management framework: the efficient, regional-level planning tool for management agencies. Marine Policy 34:1226-1238. https://doi.org/10.1016/j.marpol.2010.04.007

Fletcher W.J, Wise B., Joll L., Hall N., Fisher E., Harry A., Fairclough D., Gaughan D., Travaille K., Molony B. and Kangas M. 2016. Refinements to harvest strategies to enable effective implementation of Ecosystem Based Fisheries Management for the multi-sector, multi-species fisheries of Western Australia. Fisheries Research 183:594-608. https://doi.org/10.1016/j.fishres.2016.04.014

Forrest B.M., Keeley N.B., Hopkins G.A., Webb S.C. and Clement D.M. 2009. Bivalve aquaculture in estuaries: review and synthesis of oyster cultivation effects. Aquaculture 298:1-15. https://doi.org/10.1016/j.aquaculture.2009.09.032

Fulton C.J., Berkström C., Wilson S.K., Abesamis R.A., Bradley M., Åkerlund C., Barrett L.T., Bucol A.A., Chacin D.H., Chong-Seng K.M. and Coker D.J. 2020. Macroalgal meadow habitats support fish and fisheries in diverse tropical seascapes. Fish and Fisheries 21:700-717. https://doi.org/10.1111/faf.12455

Gilmour J.P., Cook K.L., Ryan N.M., Puotinen M.L., Green R.H., Shedrawi G., Hobbs J.P.A., Thomson D.P., Babcock R.C., Buckee J. and Foster T. 2019. The state of Western Australia's coral reefs. Coral Reefs 38:651-667. https://doi.org/10.1007/s00338-019-01795-8

Global Coral Reef Monitoring Network (GCRMN). 2020. Status of Coral Reefs of the World: 2020. Chapter 8. Status and trends of coral reefs of the Australia region. https://gcrmn.net/2020-report/

Goldberg L., Lagomasino D., Thomas N. and Fatoyinbo T. 2020. Global declines in human-driven mangrove loss. Global Change Biology 26:5844-5855. https://doi.org/10.1111/gcb.15275

Grant J., Hatcher A., Scott D.B., Pocklington P., Schafer C.T. and Winters G.V. 1995. A multidisciplinary approach to evaluating impacts of shellfish aquaculture on benthic communities. Estuaries 18:124-144. https://doi.org/10.2307/1352288

Grant W.S., Jasper J., Bekkevold D. and Adkison M. 2017. Responsible genetic approach to stock restoration, sea ranching and stock enhancement of marine fishes and invertebrates. Reviews in Fish Biology and Fisheries 27:615-649. https://doi.org/10.1007/s11160-017-9489-7

Hart A.M. and Friedman K. 2004. Mother-of Pearl Shell (*Pinctada maxima*): Stock Evaluation for Management and Future Harvesting in Western Australia. FRDC Project 1998/153, Fisheries Research Contract Report No. 10. Department of Fisheries, Western Australia.

Hart A.M. and Joll L.M. 2006. Growth, mortality, recruitment and sex-ratio in wild stocks of silver-lipped pearl oyster *Pinctada maxima* (Jameson) (Mollusca: Pteriidae), in western Australia. Journal of Shellfish Research 25:201-210. https://doi.org/10.2983/0730-8000(2006)25[201:GMRASI]2.0.CO;2

Hart A.M., Murphy D. and Brown S. in prep. Pearl Oyster Managed Fishery Resource Status Report 2022. In: Status Reports of the Fisheries and Aquatic Resources of Western Australia 2021/22: The State of the Fisheries (eds. Newman, S.J., Wise, B.S., Santoro, K.G. and Gaughan, D.J.). Department of Primary Industries and Regional Development, Western Australia.

Hart A.M., Thomson A.W. and Murphy D. 2011. Environmental influences on stock abundance and fishing power in the silver-lipped pearl oyster fishery. ICES Journal of Marine Science 68:444-453. https://doi.org/10.1093/icesjms/fsq166

Hart A., Travaille K.L., Jones R., Brand-Gardner S., Webster F., Irving A. and Harry A.V. 2016. Western Australian Marine Stewardship Council Report Series No. 5: Western Australian Silver-lipped Pearl Oyster (*Pinctada maxima*) Industry. Department of Fisheries, Western Australia. 316 pp.

Hawkins A.D. and Popper A.N. 2017. A sound approach to assessing the impact of underwater noise on marine fishes and invertebrates. ICES Journal of Marine Science, 74:635-651. https://doi.org/10.1093/icesjms/fsw205

Hazel J., Lawler I.R., Marsh H. and Robson S. 2007. Vessel speed increases collision risk for the green turtle *Chelonia mydas*. Endangered Species Research 3:105-113. https://www.int-res.com/abstracts/esr/v3/n2/p105-113/

Holley D.K., Lawler I.R. and Gales N.J. 2006. Summer survey of dugong distribution and abundance in Shark Bay reveals additional key habitat area. Wildlife Research 33:243-250. https://doi.org/10.1071/WR05031

Hughes T.P., Anderson K.D., Connolly S.R., Heron S.F., Kerry J.T., Lough J.M., Baird, A.H., Baum J.K., Berumen M.L., Bridge T.C. and Claar D.C. 2018a. Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. Science 35980-83. https://doi.org/10.1126/science.aan8048

Hughes T.P., Barnes M.L., Bellwood D.R., Cinner J.E., Cumming G.S., Jackson J.B., Kleypas J., Van De Leemput I.A., Lough J.M., Morrison T.H. and Palumbi S.R. 2017. Coral reefs in the Anthropocene. Nature 546:82-90. https://doi.org/10.1038/nature22901

Hughes T.P., Kerry J.T., Baird A.H., Connolly S.R., Dietzel A., Eakin C.M., Heron S.F., Hoey A.S., Hoogenboom M.O., Liu G., McWilliam M.J., Pears R.J., Pratchett M.S., Skirving W.J., Stella J.S., Torda G. 2018b. Global warming transforms coral reef assemblages. Nature 556:492-496. https://doi.org/10.1038/s41586-018-0041-2

Humphrey J.D., Norton J.H., Jones J.B., Barton M.A., Connell, M.T., Shelley C.C. and Creeper J.H. 1998. Pearl Oyster (*Pinctada maxima*) Aquaculture: Health Survey of Northern Territory, Western Australia and Queensland Pearl Oyster Beds and Farms. FRDC Project No. Final Report 94/079.

Hunt T.N., Allen S.J., Bejder L. and Parra G.J. 2020. Identifying priority habitat for conservation and management of Australian humpback dolphins within a marine protected area. Scientific Reports 10:1-14. https://doi.org/10.1038/s41598-020-69863-6

Irvine L.G., Thums M., Hanson C.E., McMahon C.R. and Hindell M.A. 2018. Evidence for a widely expanded humpback whale calving range along the Western Australian coast. Marine Mammal Science 34:294-310. https://doi.org/10.1111/mms.12456

Jelbart J.E., Schreider M. and MacFarlane G.R. 2011. An investigation of benthic sediments and macrofauna within pearl farms of Western Australia. Aquaculture 319:466-478. https://doi.org/10.1016/j.aquaculture.2011.07.011

Jernakoff P. 2002. Environmental risk and impact assessment of the pearling industry. Project Report No. 2001/099 to the FRDC by IRC Environmental, Perth, WA.

Johnson M.S. and Joll L.M. 1993. Genetic subdivision of the pearl oyster *Pinctata maxima* (Jameson, 1901) (Mollusca: Pteriidae) in northern Australia. Marine and Freshwater Research 44:519-526. https://doi.org/10.1071/MF9930519

Joll L.M. 1996. Stock evaluation and recruitment measurements in the WA pearl oyster fishery. FRDC Project 92/147, Department of Fisheries WA. 63 pp.

Krause-Jensen D. and Duarte C.M. 2016. Substantial role of macroalgae in marine carbon sequestration. Nature Geoscience 9:737-742. https://doi.org/10.1038/ngeo2790

Kristensen E., Bouillon S., Dittmar T. and Marchand C. 2008. Organic carbon dynamics in mangrove ecosystems: a review. Aquatic Botany 89:201-219. https://doi.org/10.1016/j.aquabot.2007.12.005

Lind C.E., Evans B.S., Knauer J., Taylor J.J. and Jerry D.R. 2009. Decreased genetic diversity and a reduced effective population size in cultured silver-lipped pearl oysters (*Pinctada maxima*). Aquaculture 286:12-19. https://doi.org/10.1016/j.aquaculture.2008.09.009

Liu D., Peng Y., Keesing J.K., Wang Y. and Richard P. 2016. Paleo-ecological analyses to assess long-term environmental effects of pearl farming in Western Australia. Marine Ecology Progress Series 552:145-158. https://doi.org/10.3354/meps11740

Lourie S., Foster S., Cooper E. and Vincent A. 2004. A guide to the identification of seahorses. Projects Seahorse; TRAFFIC North America; University of British Columbia; World Wildlife Fund.

Lourie S., Vincent A. and Hall H. 1999. Seahorses: an identification guide to the world's species and their conservation. London: Project Seahorse.

Lynn K.D., Flynn P.T., Manríquez K., Manríquez P.H., Pulgar J., Duarte C. and Quijón P.A. 2021. Artificial light at night alters the settlement of acorn barnacles on a man-made habitat in Atlantic Canada. Marine Pollution Bulletin 163:111928. https://doi.org/10.1016/j.marpolbul.2020.111928

McCallum B and Prince J. 2009. Development of the scientific requirements of an Environmental Management System (EMS) for the pearling (*Pinctada maxima*) industry. Report on FRDC Project No. 2005/044; Pearl Producers Association, WA.

Nagelkerken I.S.J.M., Blaber S.J.M., Bouillon S., Green P., Haywood M., Kirton L.G., Meynecke J.O., Pawlik J., Penrose H.M., Sasekumar A. and Somerfield P.J. 2008. The habitat function of mangroves for terrestrial and marine fauna: a review. Aquatic Botany 89:155-185. https://doi.org/10.1016/j.aquabot.2007.12.007

Nayfa M.G. and Zenger K.R. 2016. Unravelling the effects of gene flow and selection in highly connected populations of the silver-lip pearl oyster (*Pinctada maxima*). Marine Genomics 28:99-106. https://doi.org/10.1016/j.margen.2016.02.005

Niquil N., Pouvreau S., Sakka A., Legendre L., Addessi L., Le Borgne R., Charpy L., Delesalle B. 2001. Trophic web and carrying capacity in a pearl oyster farming lagoon (Takapoto, French Polynesia). Aquatic Living Resources 14:165-175. https://doi.org/10.1016/S0990-7440(01)01114-7

O'Connor W.A., O'Connor S.J. and Ottoway N.M. 2003. An examination of the potential for biodeposition from pearl cultivation in Port Stephens. In: W.A. O'Connor, N.F. Lawler, and M.P. Heasman (eds.). Trial farming the akoya pearl oyster, *Pinctada imbricata*, in Port Stephens, NSW. NSW Fisheries, Nelson Bay, Australia.

Pearl Producers Association (PPA). 2004. Workshop report: 2004 Environmental Risk Assessment of the Pearling Industry. Seafood Services Australia. http://www.environment.gov.au/system/files/pages/489e726d-1763-4007-8139-32d824d5b55d/files/application-2013-appendix2.pdf

Pearl Producers Association (PPA). 2007. Environmental Code of Conduct. Pearl Producers Association, WA. 9 pp.

Pearl Producers Association (PPA). 2008a. Pearling in Perspective: an overview of the Australian pearling industry and its environmental credentials. http://www.environment.gov.au/system/files/pages/489e726d-1763-4007-8139-32d824d5b55d/files/application-2013-appendix2.pdf

Pearl Producers Association (PPA). 2008b. *Pearling Industry Whale Management Policy and Protocol*. Pearl Producers Association, WA. 10 pp. http://www.environment.gov.au/system/files/pages/489e726d-1763-4007-8139-32d824d5b55d/files/application-2013-appendix4.pdf

Price J.T., Drye B., Domangue R.J. and Paladino F.V. 2018. Exploring the role of artificial light in Loggerhead turtle (*Caretta caretta*) nest-site selection and hatchling disorientation. Herpetological Conservation and Biology 13:415-422. http://www.herpconbio.org/Volume_13/Issue_2/Price_etal_2018.pdf

Prince J. 1999. The effects of farming of the pearl oyster, *Pinctada maxima*, on the benthic infauna in sediments at the Montebellos Islands, Western Australia. No. 773. A Report for Bowman Bishaw and Gorham Environmental Management Consultants.

Prince R. 1994. Status of Western Australian marine turtle populations: The Western Australian marine turtle project 1986-1990. In: James R. (compiler) *Proceedings of the Australian marine turtle conservation workshop*. Queensland Department of Heritage and Australian Nature Conservation Agency. pp. 1–14.

Prince R.I.T. 2001. Aerial survey of the distribution and abundance of dugongs and associated macrovertebrate fauna – Pilbara coastal and offshore region, WA. Completion Report to Environment Australia. Department of Conservation and Land Management, Perth.

Rogers D.I., Hassell C.J., Boyle A., Gosbell K., Minton C., Rogers K.G. and Clarke R.H. 2011. Shorebirds of the Kimberley Coast-Populations, key sites, trends and threats. Journal of the Royal Society of Western Australia 94:377. https://www.rswa.org.au/publications/Journal/94(2)/Rogersetal.pp.377-391.pdf

Rose R.A. and Baker S.B. 1994. Larval and Spat Culture of the Western Australian Silver- or Gold Lip Pearl Oyster, *Pinctada maxima* (Jameson) (Mollusca: Pteriidae). Aquaculture 126:35-50. https://doi.org/10.1016/0044-8486(94)90246-1

Rose R.A., Dybdahl R.E. and Harders S. 1990. Reproductive cycle of the Western Australian silver-lip pearl oyster, *Pinctada maxima* (Jameson) (Mollusca: Pteriidae). Journal of Shellfish Research 9:261-272.

Saucedo P. and Southgate P.C. 2008. Reproduction, development and growth. In: P.C. Southgate and J.S. Lucas (eds). The Pearl Oyster. London: Elsevier. pp. 131-186.

Schligler J., Cortese D., Beldade R., Swearer S.E. and Mills S.C. 2021. Long-term exposure to artificial light at night in the wild decreases survival and growth of a coral reef fish. Proceedings of the Royal Society B 288(1952):20210454. https://doi.org/10.1098/rspb.2021.0454

Scoones R.J.S. 1991. Research on practices in the Western Australian cultured pearl industry. Final report to FRDC project BP12. MG Kailis Group of Companies.

Sippo J.Z., Lovelock C.E., Santos I.R., Sanders C.J. and Maher D.T. 2018. Mangrove mortality in a changing climate: An overview. Estuarine, Coastal and Shelf Science 215:241-249. https://doi.org/10.1016/j.ecss.2018.10.011

Souchou P., Vaquer A., Collos Y., Landrein S., Deslous-Paoli J., and Bibent B. 2001. Influence of shellfish farming activities on the biogeochemical composition of the water column in Thau lagoon. Marine Ecology Progress Series 218:141-152. doi:10.3354/meps218141

Southgate PC and Lucas JS (eds) 2008. The Pearl Oyster. London: Elsevier.

Thiel, D 2010. Collision course: snubfin dolphin injuries in Roebuck Bay. A report prepared for WWF Australia. 16 pp. https://wwf-staging.wwf.org.au/ArticleDocuments/353/pub-collision-course-snubfin-injuries-roebuck-bay-1jul10.pdf.aspx

Thomas L. and Miller K.J. 2022. High gene flow in the silverlip pearl oyster *Pinctada maxima* between inshore and offshore sites near Eighty Mile Beach in Western Australia. PeerJ 10 p.e13323. https://doi.org/10.7717/peerj.13323

Thums M., Whiting S.D., Reisser J.W., Pendoley K.L., Pattiaratchi C.B., Proietti M., Hetzel Y., Fisher R. and Meekan M. 2016. Artificial light on water attracts turtle hatchlings during their near shore transit. Royal Society Open Science 3:e160142. https://doi.org/10.1098/rsos.160142

Travaille K.L., Jones R. and Wise B.S. 2016. Western Australian Marine Stewardship Council Report Series No. 6: Ecosystem-Based Fisheries Management (EBFM) Risk Assessment of the Western Australian Silver-Lipped Pearl Oyster (*Pinctada maxima*) Industry. Department of Fisheries, Western Australia. 100pp. https://www.fish.wa.gov.au/Documents/wamsc_reports/wamsc_report_no_6.pdf

Vincent A. 1996. The International Trade in Seahorses. Cambridge: Traffic International.

Western Australian Museum. 1997. Restricted marine biological survey of the “garden bottom” of Beagle Bay, Kimberley, Western Australia. Western Australian Museum, Perth.

Wada K.T. and Tëmkin I. 2008. Taxonomy and phylogeny. In: P.C. Southgate and J.S. Lucas (eds.) The Pearl Oyster. pp.37-75. London: Elsevier.

Watson-Capp J.J. and Mann J. 2005. The effects of aquaculture on bottlenose dolphin (*Tursiops* sp.) ranging in Shark Bay, Western Australia. Biological Conservation 124:519-526. https://doi.org/10.1016/j.biocon.2005.03.001

Webb G. and Manolis S. 1989. Crocodiles of Australia. Sydney: Reed Books.

Webb G., Whitehead P. and Manolis S. 1987. Crocodile management in the Northern Territory of Australia. In: G. Webb, S. Manolis, and P. Whitehead (eds.) Wildlife Management: Crocodiles and Alligators. NSW: Surrey Beatty and Sons. pp. 107-124.

Wells F.E. and Jernakoff P. 2006. An assessment of the environmental impact of wild harvest pearl aquaculture (*Pinctada maxima*) in Western Australia. Journal of Shellfish Research 25:141-150. https://doi.org/10.2983/0730-8000(2006)25[141:AAOTEI]2.0.CO;2

Whalan S., Puotinen M., Wakeford M., Parnum I. and Miller K. 2021. Distribution of the Pearl Oyster *Pinctada maxima* off Eighty Mile Beach, Western Australia. Frontiers in Marine Science 8:1-13. https://doi.org/10.3389/fmars.2021.679749

Woodhead A.J., Hicks C.C., Norström A.V., Williams G.J. and Graham N.A. 2019. Coral reef ecosystem services in the Anthropocene. Functional Ecology 33:1023-1034. https://doi.org/10.1111/1365-2435.13331

Yokoyama H. 2002. Impact of fish and pearl farming on the benthic environments in Gokasho Bay: evaluation from seasonal fluctuations of the macrobenthos. Fisheries Science 68:258-268. https://doi.org/10.1046/j.1444-2906.2002.00420.x

Yu S. and Brisbout J. with Tigan A. 2011. In Mayala country with Aubrey Tigan. Report to Department of Sustainability Energy Water Populations and Communities.

Appendix 1: Consequence – Likelihood Risk Matrix and Description of Risk Levels

Table A1. Consequence – Likelihood Risk Matrix (based on AS 4360 / ISO 31000; adapted from Department of Fisheries 2015).

		Likelihood			
		Remote (1)	**Unlikely (2)**	**Possible (3)**	**Likely (4)**
Consequence	**Minor (1)**	Negligible	Negligible	Low	Low
	Moderate (2)	Negligible	Low	Medium	Medium
	High (3)	Low	Medium	High	High
	Major (4)	Low	Medium	Severe	Severe

Table A2. Description of risk levels applied to evaluate individual risk issues (modified from Fletcher 2005).

Risk Levels	Description	Likely Reporting and Monitoring Requirements	Likely Management Action
Negligible	Acceptable; Not an issue	Brief Notes – no monitoring	Nil
Low	Acceptable; No specific control measures needed	Full Notes needed – periodic monitoring	None specific
Medium	Acceptable; With current risk control measures in place (no new management required)	Full Performance Report – regular monitoring	Specific management and/or monitoring required
High	Not desirable; Continue strong management actions OR new / further risk control measures to be introduced in the near future	Full Performance Report – regular monitoring	Increased management activities needed
Severe	Unacceptable; Major changes required to management in immediate future	Recovery strategy and detailed monitoring	Increased management activities needed urgently

LIKELIHOOD LEVELS

Table A3: Likelihood Levels

1	Remote	The consequence has never been heard of in these circumstances, but it is not impossible within the timeframe (Probability <5%).
2	Unlikely	The consequence is not expected to occur in the timeframe but it has been known to occur elsewhere under special circumstances (Probability 5 - <20%).
3	Possible	Evidence to suggest this consequence level is possible and may occur in some circumstances within the timeframe (Probability 20 - <50%).
4	Likely	A particular consequence level is expected to occur in the timeframe (Probability ≥50%).

CONSEQUENCE LEVELS

Table A4. Consequence Levels - Target/Primary (Retained and Discarded) Species

1. Ecological: Target/Primary (Retained and Discarded) Species		
1	Minor	Fishing impacts either not detectable against background variability for this population; or if detectable, minimal impact on population size and none on dynamics. Spawning biomass > Target level
2	Moderate	Fishery operating at maximum acceptable level of depletion. Spawning biomass < Target level but > Threshold level (B_{MSY})
3	High	Level of depletion unacceptable but still not affecting recruitment levels of stock. Spawning biomass < Threshold level (B_{MSY}) but > Limit level (B_{REC})
4	Major	Level of depletion is already affecting (or will definitely affect) future recruitment potential of the stock. Spawning biomass < Limit level (B_{REC})

Table A5. Consequence Levels - Non-Target/Secondary (Retained and Discarded) Species

2. Ecological: Non-Target/Secondary (Retained and Discarded) Species		
1	Minor	Measurable but minor levels of depletion of fish stock.
2	Moderate	Maximum acceptable level of depletion of stock.
3	High	Level of depletion of stock unacceptable but still not affecting recruitment level of the stock.
4	Major	Level of depletion of stock are already affecting (or will definitely affect) future recruitment potential of the stock.

Table A6. Consequence Levels - Threatened, Endangered and Protected Species (TEPs)

3. Ecological: Threatened, Endangered and Protected Species (TEPs)		
1	Minor	Few individuals directly impacted in most years.
2	Moderate	Level of capture is the maximum that will not impact on recovery.
3	High	Recovery may be affected.
4	Major	Recovery times are clearly being impacted.

Table A7. Consequence Levels - Habitat

4. Ecological: Habitat		
1	Minor	Measurable impacts but very localized. Area directly affected well below maximum accepted.
2	Moderate	Maximum acceptable level of impact to habitat with no long-term impacts on region-wide habitat dynamics.
3	High	Above acceptable level of loss/impact with region-wide dynamics or related systems may begin to be impacted.
4	Major	Level of habitat loss clearly generating region-wide effects on dynamics and related systems.

Table A8. Consequence Levels - Ecosystem/Environment

5. Ecological: Ecosystem/Environment		
1	Minor	Measurable but minor changes to the environment or ecosystem structure but no measurable change to function.
2	Moderate	Maximum acceptable level of change to the environment or ecosystem structure with no material change in function.
3	High	Ecosystem function altered to an unacceptable level with some function or major components now missing and/or new species are prevalent.
4	Major	Long-term, significant impact with an extreme change to both ecosystem structure and function; different dynamics now occur with different species/groups now the major targets of capture or surveys.

Table A9: Consequence Levels - Genetic integrity of wild population

6. Ecological: Genetic integrity of wild population		
1	Minor	Measurable but minor changes to the genetic integrity of wild stock at local subpopulation level but no impact at broader population level. The impact (if any) is acceptable and meets the conservation/restoration objective.
2	Moderate	Maximum acceptable level of change to the genetic integrity of wild stock at local subpopulation level but minimal impact at broader population level. Impact is acceptable and meets the conservation/restoration objective.
3	High	Unacceptable level of change to the genetic integrity of wild stock at local subpopulation level and measurable changes to the genetic integrity of broader population. Restoration after this impact is possible in short/medium term. Negative effect on meeting objective.
4	Major	Widespread, long-term or irreversible change to genetic integrity of wild stock at local subpopulation level. Loss/substantial reduction of genetic integrity of broader population. Restoration after this impact will take a long time or not be possible.

Appendix 2: Standard Operating Procedure used by Pearling Inspectors when conducting Hatchery Inspections

Objectives:

Record keeping:

- Ensure a general operations logbook for the hatchery is being filled out containing particulars. (See sub regulation 3 of 44D(1)(a) for particulars)
- Ensure a batch logbook is being filled out for each batch of pearl oysters produced in that hatchery. (See sub regulation 3 of 44D(1)(b) for particulars)
- Ensure that all spat supplied or sold has a certificate of health in respect of that spat.

Spawning:

- Ensure that a Notice of settlement of spat has been completed and filled out within 24 hours of the completion of each spat settlement.
- Ensure that the Notice of settlement of spat has been lodged with an inspector within 3 days of the completion of the settlement of that batch of spat.
- Ensure samples from each batch of spat that is settled in the hatchery are collected and kept in accordance with Regulation 144C of the Fish Resources Management Regulations 1995.

NB: It is also a requirement of sub regulation 3 of 44D(a)(b) that these details be recorded in the batch logbook.

Separation of batches / preventing cross-infection:

- Ensure that each batch of spat is kept separate from other batches of spat.
- Ensure that the hatchery has processes in place (as are necessary, or as directed by an inspector) to prevent cross-infection between batches of spat held in the hatchery.

N.B: The risk of disease transfer between batches of spat and species must be minimised. Processes should be in place for stock and animal movement; staff movement; equipment movement and water and waste management. Examples of appropriate risk management measures are described in the National biosecurity plan guidelines for Australian oyster hatcheries.

Cleaning:

- Ensure that when a batch of spat is removed from a tank that the tank and all associated equipment is disinfected and cleaned before any other pearl oysters are placed in that tank.
- Ensure that when a hatchery and all associated equipment is to be cleaned and disinfected through direction from an inspector or stock inspector that it is done so in the correct manner.
- Ensure that if a hatchery or any specific equipment is required under regulation 44A(3) to be cleaned or disinfected that it is done so in accordance with the procedure set out in Division 1 of Schedule 2 or as directed in writing by an inspector or stock inspector.
- Ensure all equipment used in the production of algal food for spat is cleaned and disinfected (as per Division 1 of Schedule 2) or autoclaved before each time it is used.

Treatment of air:

- Ensure that air used to produce algal food for spat is filtered through a 20-micron sterile filter.

Treatment of water:

- Ensure that seawater pumped to hatcheries is treated before it is used.
- Water used to rear spat is to be filtered through a 20 micro meter filter or finer (0.02mm)
- Water used in the production of algal food for spat is to be autoclaved or filtered through a 20 micro meter filter.
- Water which is to be used for any other purpose is to be filtered to at least 20 microns using duplicate filters.
- Ensure water that is discharged from the hatchery is filtered through sand or treated with a solution of 60mg of free chlorine per litre of discharged water.
- If the hatchery discharges water into the sea (after filtration or treatment), ensure the pipe/s used for intake of seawater into the hatchery is located away from the seaward opening of the outlet pipe to avoid cross contamination.

Source of brood stock:

- Ensure pearl oysters used in the hatchery as brood stock were produced in that hatchery OR were taken from the wild within the waters defined as Zones 1,2, or 3 of the Western Australian pearl oyster fishery.

<u>Procedures:</u>

- Conduct an unannounced random inspection where possible.
- Ask to speak with the hatchery manager or person in charge and inform them you are there to conduct a hatchery inspection.
- Ask about the hatchery entry conditions for visitors. Inspectors must comply with all entry conditions and processes for visitors. In general as a minimum, an inspector should have had a head-to-toe shower since any previous contact with the aquatic environment and wear laundered clean clothes and disinfected footwear.
- The inspection should be planned to ensure it flows unidirectionally (from low- to high-risk zones) and ensure it complies with hatchery procedures. In some instances spat may be kept in one part of the hatchery and brood stock in another. This is to prevent cross contamination and may be the hatchery standard operating procedure not to allow personnel who have been in one part of the hatchery into another part of the facility to stop spread of any disease.
- It may be necessary when entering sterile areas to change or decontaminate footwear or wear scrub booties over footwear, and to sanitise hands between zones. Hatchery staff should advise the inspector of these requirements
- Ask to see the hatchery licence. Read any conditions on the licence.
- Ask if they are currently holding any brood stock or batches of spat in the hatchery, if so ask to see the general operations log book and or the batch logbook to ensure it reflects the information required in sub regulation 44D(2)(a)(b) and or sub regulation 44D(3).
- If the facility is holding brood stock count them and make sure numbers are correct in the logbook.
- If the facility is holding spat ensure a pearl oyster settlement log sheet has been filled out in relation to that batch. Ensure each batch of spat is kept separate from another.

- Ensure Transport log sheets have been filled out and approved by an inspector for any pearl oysters entering or leaving the facility. Spat leaving the facility must have attached to the Transport log sheet a certificate of health in relation to that batch of spat.
- Check size of filters being used in the facility. The hatchery should be able to demonstrate that their filtration is compliant via records or equipment information. It usually has it written on the side of the filter ask hatchery employee to show you. Filters should be 20 microns or finer (as required by Division 1 and 2 of Schedule 2)
- Ask how water discharged from the facility is treated either by filtering it through sand or treating it in 60mg free chlorine per litre of discharged water.
- Make sure cleaning is carried out as per the requirements set out in Division 1 of Schedule 2.

Strategies:

- If the facility is producing algal food it is likely there are pearl oysters somewhere in the facility so ask questions and look around. (Algal food when it is being produced looks like bright green water normally produced in what looks like large glass jars or bottles in some sort of lab)

Resources:

- Required personnel – 1 or 2 inspectors
- Copy of hatchery licence

Legislation:

Pearling (General) Regulations 1991:

- Part 7A – Hatcheries
- Part 13A – Control of disease in pearl oysters
- Regulation 144C – Spat samples to be taken, preserved etc

Useful documents:

- National biosecurity plan guidelines for Australian oyster hatcheries

Appendix 3: Risk ratings from previous ERAs for the Resource

Table A10. Summary of ecological risks assessed in 2001 and 2004 for cultivation aspects of the Western Australian pearling industry (Jernakoff 2002; PPA 2004).

Year	Issue	Risk Rating
2001	Introduction of disease from translocation	LOW
	Introduction of disease from hatchery	MED
	Introduction of disease from seeding	MED
	Spread of disease	MED
	Attraction of other fauna (pearl leases)	MED
	Impact of entanglement of protected/endangered species	LOW
	Impact of farm lighting on protected/endangered species	LOW
	Impact on habitat	LOW
	Potential for litter	LOW
	Perceived change in water quality	LOW
	Nutrient impacts in sediment	LOW
	Reduction in primary productivity	LOW
	Introduction of exotic organisms	MED
2004	Introduction of disease from hatchery	LOW
	Introduction of disease via technicians	MED
	Spread of disease from translocation of shell	LOW
	Spread of endemic disease across bivalve populations	LOW
	Impact on wildlife, endangered species and pearl oysters	LOW
	Entanglement in longlines	LOW
	Panel impact on habitats	LOW
	Damage to benthic biota	LOW
	Litter (e.g. plastic tags, bags) in the water	LOW
	Reduction in water quality (filtering by oysters)	LOW
	Nutrient addition	LOW
	Alienation of water areas from other users	LOW
	Water quality loss (hydrocarbon spill approx. 80 L)	LOW
	Groundwater quality loss (diesel 50 000 on land)	MED
	Water quality loss (aviation fuel 35 000 L)	MED
	Water quality loss (chemical treatment of sewage)	MED

Table A11. Summary of ecological risks assessed in 2002, 2008 and 2013 for wild collection and hatchery aspects of the WA pearling industry. N/A indicated 'Not Assessed'.

Issue	Risk Rating		
	2002	**2008**	**2013**
Impact on spawning stock of *P. maxima* oysters	LOW	LOW	LOW
Impact of movement on genetic disruption to *P. maxima* oyster populations	NEG	N/A	N/A
Impact of removing pearl oysters – Loss of habitat for fouling or commensal species	NEG	NEG	NEG
Impact of recreational take of specimen shells on species populations	N/A	N/A	LOW
Impact of removing pearl oysters – Trophic interactions	NEG	NEG	NEG
Impact on *P. maxima* stock – Discarding shells	NEG	N/A	N/A
Impact on benthic habitats – Diver activities	NEG	NEG	NEG
Impact on benthic habitats – Anchoring	NEG	NEG	NEG
Impact on benthic habitats – Fish holding sites	NEG	NEG	NEG

Table A12. Identified Components, Objectives, Sub-Components, Issues and Risk Ratings related to the Ecological Sustainability of the pearling industry, assessed in 2016 ERA workshop.

Component	Industry Objective	Sub-Component	Issue	2016 Risk Rating
Retained Species	To maintain spawning stock biomass of *P. maxima* at a level where the main factor affecting recruitment is the environment	Silverlip Pearl Oyster, *P. maxima*	Collection of pearl oysters from the wild (WA specific)	**LOW**
			Collection of pearl oyster from the wild (NT specific)	**NEGLIGIBLE**
			Translocation: impact on genetic structure of pearl oyster populations	**NEGLIGIBLE**
			Translocation: transfer of diseases between pearl oyster populations (all Zones)	**LOW**
			Hatchery propagation: impact on genetic structure of pearl oyster populations	**NEGLIGIBLE**
			Hatchery propagation: transfer of diseases between wild pearl oyster populations	**NEGLIGIBLE**
			Hatchery propagation: transfer of diseases between hatchery populations	**LOW**
Non-retained Species	To ensure fishing impacts do not result in serious or irreversible harm to bycatch (non-retained) species' populations	Commensal / Fouling ('Piggyback') Species	Loss of habitat for fouling / commensal species populations from pearl oyster collection	**NEGLIGIBLE**
TEP Species	To ensure fishing impacts do not result in serious or irreversible harm to TEP species' populations	Whales and Dolphins	Boat strike	**NEGLIGIBLE**
			Entanglement in culture lines	**NEGLIGIBLE**
		Crocodiles	Boat strike	**NEGLIGIBLE**
			Entanglement in culture lines	**NEGLIGIBLE**
		Marine Turtles	Boat strike	**NEGLIGIBLE**
			Entanglement in culture lines	**NEGLIGIBLE**
		Sharks and Rays	Entanglement in culture lines	**NEGLIGIBLE**
		Sea snakes	Entanglement in culture lines	**NEGLIGIBLE**

		Sea birds	Disturbance from industry activities	**NEGLIGIBLE**
		Shore birds ('waders')	Disturbance from industry activities	**NEGLIGIBLE**
		Seahorses and Pipefish	Entanglement in culture lines	**NEGLIGIBLE**
Habitats	To ensure the effects of fishing do not result in serious or irreversible harm to habitat structure and function	Benthic Habitats	Diver activities	**NEGLIGIBLE**
			Anchoring	**NEGLIGIBLE**
			Holding and resting sites	**NEGLIGIBLE**
			Pearl leases	**NEGLIGIBLE**
Ecosystem Structure	To ensure the effects of fishing do not result in serious or irreversible harm to ecological processes	Trophic Interactions	Removal / addition of materials to the ecosystem	**NEGLIGIBLE**
		Community Structure	Depletion of phytoplankton at pearl leases	**NEGLIGIBLE**
			Introduction of diseases, pests or invasive species	**NEGLIGIBLE**
Broader Environment	To ensure the effects of fishing do not result in serious or irreversible harm to the broader environment	Air Quality	Fuel usage / exhaust fumes	**NEGLIGIBLE**
			Greenhouse gas emissions	**NEGLIGIBLE**
		Water Quality	Debris / litter	**NEGLIGIBLE**
			Oil discharge	**NEGLIGIBLE**

Appendix 4: ERA workshop stakeholders

Table A13. List of invited ERA workshop stakeholders.

Name	Organisation
Doug Hall	Aquaculture Council of Western Australia
Dr Luke Thomas	Australian Institute of Marine Science
James Brown	Commercial representative
Steve Gill	Commercial representative
Kym Coffey	Commercial representative
Nicole Anderson	Commercial representative
Bryn Warnock	DPIRD (Aquaculture Management)
Dr Steve Nel	DPIRD (Aquaculture Management)
Amelia Bissell	DPIRD (Aquatic Resource Management)
Sarah Brown	DPIRD (Aquatic Resource Management)
Jo Kennedy	DPIRD (Aquatic Resource Management)
Dr Lachlan Strain	DPIRD (Aquatic Science and Assessment)
Dr Anthony Hart	DPIRD (Aquatic Science and Assessment)
Dr Kim Smith	DPIRD (Aquatic Science and Assessment)
Dr Steve Taylor	DPIRD (Aquatic Science and Assessment)
Dr Cam Desfosses	DPIRD (Aquatic Science and Assessment)
Dr Katie Webb	DPIRD (Biosecurity)
Dr Richmond Loh	DPIRD (Biosecurity)
Dr Jo Bannister	DPIRD (Biosecurity)
Dr Sam Bridgwood	DPIRD (Biosecurity)
Stuart McDowall	DPIRD (Compliance)
Brett Herbert	NT Department of Industry, Tourism and Trade
Dr Kevin Crook	WA Department of Biodiversity, Conservation and Attractions
Laura Orme	Western Australian Fishing Industry Council
Dr Jeremy Ringma	Birdlife Australia
James Paspaley	Commercial representative
Paul Birch	Commercial representative
Dr Scott Evans	DPIRD (Aquatic Science and Assessment)
Dr Cecile Dang	DPIRD (Biosecurity)
Prof Dean Jerry	James Cook University
Dr Jens Knauer	James Cook University
Matt Watson	Marine Stewardship Council
Mr Leyland Campbell	Recfishwest
Steve Arrow	Commercial representative
Michael Furlong	Commercial representative
Janice Bell	Commercial representative
Kim Schaap	Commercial representative
	Balanggarra Aboriginal Corporation RNTBC
	Bardi and Jawi Niimidiman Aboriginal Corporation RNTBC
	Buurabalayji Thalanyji Aboriginal Corporation RNTBC

Dambimangari Aboriginal Corporation

Gogolanyngor Aboriginal Corporation

Kariyarra Aboriginal Corporation

Karajarri Traditional Lands Association (Aboriginal Corporation) RNTBC

Mayala Inninalang Aboriginal Corporation

Miriuwung and Gajerrong #1 (Native Title Prescribed Body Corporate) Aboriginal Corporation RNTBC

Nganhurra Thanardi Garrbu Aboriginal Corporation, Yinggarda Aboriginal Corporation

Ngarluma Aboriginal Corporation RNTBC

Nimanburr Aboriginal Corporation

Nyangumarta Karajarri Aboriginal Corporation RNTBC

Nyangumarta Warrarn Aboriginal Corporation RNTBC

Nyul Nyul PBC Aboriginal Corporation

Walalakoo Aboriginal Corporation RNTBC

Wanjina-Wunggurr (Native Title) Aboriginal Corporation RNTBC

Wanparta Aboriginal Corporation RNTBC

Warrwa People Aboriginal Corporation

Wirrawandi Aboriginal Corporation RNTBC

Yawuru Native Title Holders Aboriginal Corporation RNTBC

Yindjibarndi Aboriginal Corporation RNTBC

Table A14. List of ERA workshop attendees.

Name	Organisation
Doug Hall	Aquaculture Council of Western Australia
Dr Luke Thomas	Australian Institute of Marine Science
James Brown	Commercial representative
Steve Gill	Commercial representative
Kym Coffey	Commercial representative
Nicole Anderson	Commercial representative
Bryn Warnock	DPIRD (Aquaculture Management)
Dr Steve Nel	DPIRD (Aquaculture Management)
Amelia Bissell	DPIRD (Aquatic Resource Management)
Sarah Brown	DPIRD (Aquatic Resource Management)
Jo Kennedy	DPIRD (Aquatic Resource Management)
Dr Lachlan Strain	DPIRD (Aquatic Science and Assessment)
Dr Anthony Hart	DPIRD (Aquatic Science and Assessment)
Dr Kim Smith	DPIRD (Aquatic Science and Assessment)
Dr Steve Taylor	DPIRD (Aquatic Science and Assessment)
Dr Cam Desfosses	DPIRD (Aquatic Science and Assessment)
Dr Katie Webb	DPIRD (Biosecurity)
Dr Richmond Loh	DPIRD (Biosecurity)
Dr Jo Bannister	DPIRD (Biosecurity)
Dr Sam Bridgwood	DPIRD (Biosecurity)
Stuart McDowall	DPIRD (Compliance)
Brett Herbert	NT Department of Industry, Tourism and Trade
Dr Kevin Crook	WA Department of Biodiversity, Conservation and Attractions
Laura Orme	Western Australian Fishing Industry Council

Table A15. List of ERA workshop apologies.

Name	Organisation
Dr Jeremy Ringma	Birdlife Australia
James Paspaley	Commercial representative
Paul Birch	Commercial representative
Dr Scott Evans	DPIRD (Aquatic Science and Assessment)
Dr Cecile Dang	DPIRD (Biosecurity)
Prof Dean Jerry	James Cook University
Dr Jens Knauer	James Cook University
Matt Watson	Marine Stewardship Council
Mr Leyland Campbell	Recfishwest