INTERNAL REPORT

Environmental Risk Assessment of Shellfish Farming in Tasmania

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SUMMARY

The Terms of Reference for this report were to undertake a qualitative analysis of the likelihood and significance of identified impacts associated with shellfish culture on the Tasmanian marine environment. This included a study of the available national and international scientific literature, and relating the environmental effects observed overseas with Tasmanian shellfish production, farming practices and marine environment. The main shellfish species cultured in Tasmania are the Pacific oyster *Crassostrea gigas*, which was introduced into Tasmania from Japan during the period 1948-1952, and the blue mussell, *Mytilus edulis*.

Important differences between shellfish culture in Tasmania and overseas were noted. These included much lower levels of total shellfish production from Tasmania, and also lower levels of production per area farmed. Densities of shellfish on Tasmanian farms are generally at least an order of magnitude lower than in major shellfish producing countries overseas, largely because of the relatively low nutrient levels, and hence phytoplankton production, in Tasmanian coastal waters.

There is also a lack of traditional shellfish culture in Tasmania compared with many overseas countries where practices of restocking shellfish beds and harvesting by dredging have changed little since the 1800's. By contrast, farm management protocols in Tasmania have developed since the 1970's with an emphasis on efficiency and a greater awareness of environmental management. Legislative-based Management Controls, which limit the production of shellfish per hectare in Tasmania, also serve to minimise environmental impacts. However, there appear to be few effective controls on shellfish stocking densities in other countries.

Beneficial effects of shellfish farming on the Tasmanian marine environment were identified, and included increased monitoring of estuarine and coastal waters and the potential for scallop aquaculture to enhance wild scallop stocks. Improved water clarity and reduced nutrients and phytoplankton concentrations may also occur in some shellfish growing areas due to the increased filtration by cultured shellfish.

Potential detrimental effects in Tasmania include the spread of introduced pests and diseases by movement of stock around the State. Alteration to the habitat may also occur but generally with minor ecological effect, and restricted to within the lease area.

A qualitative assessment of the risks of ecological impact occurring as a result of shellfish farming activities in Tasmania was conducted based on Australian/New Zealand Standards for Risk Management, 1999. This involved identifying the likelihood and consequence of each area of risk, and developing a qualitative risk analysis matrix from which the levels of risk were identified. These risk levels were based on information available from Tasmanian studies and by comparison with effects observed overseas, taking into account total production and density of shellfish. They were also based on shellfish farming only occurring at suitable locations and with industry standard management practices.

Outcomes of the qualitative risk assessment were:

- A high risk of spread of pests and pathogens due to movements of shellfish stock around the State, (however, it was also noted that a high risk exists from other anthropogenic activities such as commercial and recreational fishing and sea transport).

- A moderate risk within the lease area of changes to the environment resulting from habitat disturbance due to shellfish farming.
- Low risk of ecological impact due to organic enrichment.
- Low risk of reduced food resources for other filter feeders.

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1. Introduction

The Terms of Reference for this study were determined by the Marine Farming Branch, Department of Primary Industries, Water and Environment (DPIWE) and the Tasmanian Aquaculture Council. They were :

1. To undertake a study of the available national and international scientific literature with particular reference to the relevance of the studies to the Tasmanian marine environment.

2. To undertake a qualitative analysis of the likelihood and significance of identified impacts associated with shellfish culture on the Tasmanian marine environment. This should include a study of the available national and international scientific literature, and should identify beneficial and detrimental effects of shellfish aquaculture, with particular reference to the relevance of the studies to the Tasmanian environment.

It was further clarified by Darby Ross, Manager of the Marine Farming Branch, DPIWE, that this study involved only the ecological effects of shellfish farming on the marine environment. Social and economic aspects generally were not to be considered.

This review concentrates on shellfish species currently cultured on a commercial scale in Tasmania - the Pacific oyster *Crassostrea gigas* (Thunburg 1793) and the blue mussel *Mytilus edulis* (Linnaeus 1758). Other shellfish species which are farmed in small quantities, such as the commercial scallop *Pecten fumatus* (Reeve 1852), and the native or flat oyster *Ostrea angasi* (Sowerby 1871), are discussed in less detail. Species which are at the pilot commercial stage, e.g. abalone *Haliotus rubra* (Leach 1814) and *Haliotis laevigata* (Donovan 1808), and those which are being investigated for their suitability for farming in Tasmania, such as the clams *Katelysia scalarina* (Lamarck 1818) and *Venerupis largillierti* (Philippi 1849), are only briefly discussed.

Crassostrea gigas was introduced into Tasmania from Japan in 1948 - 1952 (Thomson, 1952; Thomson, 1959). All other shellfish cultured in Tasmania are assumed to be native species. However, the origin and taxonomic status of the Tasmanian blue mussel is currently in doubt as recent genetic research suggests it is a regional subspecies of *M. galloprovincialis* (Daguin & Borsa, in press).

2. Current Status of Shellfish Farming Worldwide and In Tasmania

2.1 Worldwide Shellfish Aquaculture Production

Marine aquaculture production in 1996, excluding aquatic plants, was 10.8 million metric tonnes (FAO, 1999). It was dominated by production from China. Over 90% of the mariculture production was either primary or secondary production (aquatic plants and filter feeding invertebrates) and only 7% was carnivorous finfish species. If plants are excluded, approximately 86% of mariculture production was from filter feeders such as oysters, mussels, scallops and cockles (Rana & Immink, n.d.).

Of the top 10 species in 1996 by volume of world cultured aquatic production (both marine and freshwater), the Pacific oyster (*Crassostrea gigas*) was second highest by volume, after silver carp, with 2.92 million tonnes. It was also second highest by value of world cultured aquatic production, worth US$3.23 billion (FAO, 1999). Yesso scallop (*Pecten yessoensis*) was seventh by volume with 1.27 million tonnes, and the Japanese carpet shell (*Ruditapes philippinarum*) was eighth with 1.20 million tonnes. Yesso scallop production was valued at US$1.62 billion, and the Japanese carpet shell production at 1.52 billion (FAO, 1999).

The production of shellfish in 1996 from some of the major shellfish producing areas of the world (FAO, 1997) is shown in Table 1. These production levels are much higher than for Tasmania (Table 2). Of relevance to this review is that most studies of environmental effects of shellfish farming have been conducted in Europe and the USA, regions with large bivalve production.

Mussel production in Spain has declined drastically in recent years from 247,000 metric tonnes (mt) in 1986 to 90,000 mt in 1993 due to the increasing occurrence of red tides, and to a lesser extent because of market saturation in Europe (FAO, 1997).

Exports of Greenshell mussels (*Perna canaliculus*) from New Zealand in 1998 were 33,000 tonnes (NZ Mussel Industry Statistics: available at http://www.greenshell.com/stats.htm).

Table 1. Shellfish production (metric tonnes) in 1996 from several major producing regions.

Region	Species	Total production (mt)
Europe	**Mussels**	**383,129**
	M. edulis	261,773
	- Spain (35.2%)	92,144
	- Netherlands (30.3%)	79,317
	- France (18.8%)	49,213
	M.galloprovincialis	121,356
	- Italy (78.3%)	95,022
	Oysters	**159,622**
	C. gigas	134,785
	- France (96.7%)	130,337
	Clams/cockles	**82,025**
	Clams/carpet shells	75,005
	- Italy (80.2%)	60,154
	Total molluscs	**626,213**
USA	**Oysters**	**117,000**
	Clams	**14,000**
	Mussels	**1,000**
China	**Marine molluscs**	**3,000,000**
Japan	**Pacific oyster**	**444,000**
	Yesso scallop	**228,000**
	Korean mussel	**75,000**
Canada	**Pacific oysters**	**41,000**
	Blue mussels	**11,000**

2.2 Current Status of Shellfish Farming in Tasmania

The production of Tasmanian shellfish in the two most recent years for which accurate figures are available from the DPIWE Marine Farming Branch records is shown in Table 2. Estimated gross values in 1997/98 were $10.46 million for Pacific oysters and $647,000 for mussels (DPIWE, 1999b).

Table 2. Production of shellfish in Tasmania in 1996/97 and 1997/98.

Species		1996/97	1997/98
Pacific Oysters	(tonne)	2,190	2,065
	(doz.)	2,807,549	2,647,964
Mussels	(tonne)	343	185

Quantities of other shellfish cultured in 1996-98 were low according to DPIWE statistical data, and it appears some production data may not have been included. Native oyster and clam production were recorded as 0 in 1996/97 and 36 and 48 dozen in 1997/98, respectively.

Shellfish farming is currently undergoing expansion in Tasmania, largely because of State Government support to provide additional water for farming. The Marine Farming Planning Act (1995) provides for a planning scheme which takes into account all users of estuaries and coastal waters, and allocates zones for marine farming to be implemented. This zoning system effectively eliminated protracted legal challenges to the establishment of marine farms that had previously stalled the development of the industry. In 1995 1,351 ha were available for shellfish farming, with approximately 1,051 ha in intertidal areas and 300 ha available for deep water culture. Approximately one third of the total area available was estimated to be developed at that time. Since the implementation of the Marine Farming Development Plans in 1995, the amount of water available for shellfish farming has increased by about 700 ha, mostly in subtidal waters (DPIWE, 1999b).

In 1997/98 Pacific oyster production was recorded from 55 marine farm licences, and mussels from 14 licences. Many more shellfish licences were issued but didn't produce shellfish, because some farms were used for growing animals below market size, some had only recently been allocated, and some had only been developed for finfish. Approximately 63% of the licences issued were for intertidal farms (unpublished data, DPIWE Marine Farming Branch).

An average size Pacific oyster farm in Tasmania has been estimated by (Ryan, 1997b) to occupy 14 hectares and produce approximately 65 000 dozen market size oysters annually (approx. 80 mm total length). For mussels, the average farm size was 5 - 10 ha. (Ryan, 1997b). Pacific oysters take an average of 18 months to reach market size, although longer than 36 months has been found in some areas where environmental conditions and food supply are not as conducive to farming. Mussels also take approximately 15 - 18 months to reach market size (Ryan, 1997b).

Most shellfish farms are owner-operated, although there is an increasing trend for syndicates and private companies to own farms, and most are Tasmanian owned (DPIWE, 1999b). In 1997 Pacific oyster farms employed approximately 200 workers and an additional 200-300 people were estimated to be indirectly employed in the industry providing materials and equipment. Mussel farms in 1996 employed 35 - 40 workers and indirectly employed about 100 more (Ryan 1997b). Employment on shellfish farms at Georges Bay was calculated as 0.5 full time equivalents per developed ha (Dyke & Dyke, 1997).

An ongoing study of the health status of shellfish in Tasmania has found that Pacific oysters and mussels are free of any prescribed or potential pathogens, whilst the native oyster is infected with a serious pathogen*, Bonamia* sp. Both oyster species have been found to be infected with several organisms which occur within either the shell or body tissue, whereas mussels have not (Wilson, Handlinger & Sumner, 1993). These infestations did not appear to be injurious to Pacific oysters at the levels observed, although the incidence of mudworms, *Polydora websteri* and *Boccardia knoxi* were higher in the south than the north of Tasmania. Infestations were also higher in wild Pacific oysters than in farmed oysters, but were not considered to be of any health significance (Judith Handlinger, pers. comm. 1999). Mussels may also contain commensal pea crabs within the shell cavity. These crabs do not affect the health of the mussels, but can affect the marketing of mussels in the shell.

Tasmanian shellfish are primarily marketed in the East Australian states, particularly in the cities of Sydney and Melbourne. Although there is some demand from overseas, especially in south east Asia and Japan, current production is not sufficient to meet overseas requirements. Shellfish are mainly sold live, in the shell, and only a small percentage is sold as chilled or frozen on the half shell (Ryan, 1997b).

A Tasmanian State Government report has predicted that Pacific oyster farming will significantly increase over the next few years, with an expected contribution to the Tasmanian economy in five years time of approximately $30-50 million per year, and emploing between 400 and 500 people full-time (DPIWE, 1999b).

3. Development of Shellfish Harvesting and Farming in Tasmania

3.1 Native Oyster (*Ostrea angasi*) Wild Harvesting and Farming

Shells found in numerous aboriginal middens around the Tasmania coast indicate that the native flat oyster *Ostrea angasi* has been harvested by humans for many thousands of years. During the 1800’s the early settlers extensively and indiscriminately fished the native oyster beds around the state, and at the height of the wild fishery fished bays and estuaries in the D’Entrecasteaux Channel, areas of Norfolk Bay, Tasman Peninsula, on the East and North East Coast, Tamar River, and the West Coast at Macquarie Harbour and Port Davey (Sumner, 1972). Besides a large local consumption of oysters, many were exported to the mainland and overseas. The number of oysters harvested from several of the principal native beds during one of the best harvest years was reported in the Parliamentary Report (1882) as: Southport 3.46 million, Cloudy Bay 2.33 million, Port Esperance 2.89 million, Spring Bay 8.44 million, Swanport 5.24 million oysters.

This quantity of oysters, around 22.5 million, was dredged annually from South and South Eastern Tasmanian waters during 1860-1870. In the 1870’s the fishery began to decline, and by the early 1880’s it had collapsed. This deterioration of native beds was blamed on several factors including overfishing, mussel encroachment, disease and inclement weather (Report, 1882) The colonisation and clearing of the land for settlement and agriculture which led to increased silt loads in the rivers and bays was also thought to have killed many beds (Report, 1885).

Government and private reserves were established in the mid 1880’s for broodstock and reseeding of natural beds (Report, 1887). Initial success led to the establishment by 1887 of 33 native oyster farms, including many private ventures. However, by 1889 the government beds at Oyster Cove had silted up and the project was abandoned (Parliamentary Report, 1889).

Limited dredging continued for several years. By 1907 New Zealand oysters were being imported cheaply and no dredging of commercial importance occurred in Tasmania. A more detailed account of the oyster industry in Tasmania in the 19th century is provided by Sumner (1972).

Various attempts to farm native oysters have been made since the 1970's, to capitalise on the declining stocks of *Ostrea edulis* in Europe. A significant effort was made in the early 1990's when oysters were harvested from the wild in Georges Bay and grown out on marine farms around the state under the Flat Oyster Culture Program. However, this program was terminated when the protozoan parasite *Bonamia* spp. was discovered in the wild harvested oysters in 1992. In 1997 two farms were producing small quantities of native oysters, and by 1999 this had reduced to one. On this farm spat collected from the wild are ongrown and then shipped to specialised mainland markets.

3.2 Development of Pacific Oyster (*Crassostrea gigas*) Farming

The Pacific oyster was introduced into Tasmania from Japan in 1947 - 1948 and in 1951 – 1952 by the CSIRO (Thomson, 1952) First attempts at Pittwater met with limited success but later introductions at Port Sorell were successful, followed by colonisation in the Tamar River (Thomson, 1959). Pacific oysters flourished in the Tamar and from 1959 to 1964 the population underwent massive expansion and increased distribution to over 15 nautical miles of the river (Sumner, 1974). It was this expansion of *C. gigas* that lead to the realisation that aquaculture of this species was a possibility. Details of the development of the Pacific oyster industry from its introduction to the early 1970's are provided by Sumner (1974).

Commercial culture of Pacific oysters commenced in 1967 when 3 licences to farm oysters were granted by the Department of Sea Fisheries (Dix, 1987). Farming at this stage was based on collecting naturally spawned oyster spat on sticks and transporting them to intertidal farms around the State for ongrowing. The Tamar River was the major source of wild spat, but supply was unpredictable between years because of fluctuating environmental conditions. During 1977-78 a pilot commercial hatchery at the Marine Research Laboratories at Taroona successfully cultured Pacific oysters, and as a consequence an industry co-operative commercial hatchery was commissioned in 1979/80. Reliance on wild caught spat quickly declined and in the 1980's the industry changed to relying totally on hatchery produced stock. This provided far greater control over the production of spat, and the industry expanded rapidly in the 1980's with major penetration of mainland markets.

With the advent of cultchless spat from the hatchery (i.e. spat which settled on very small pieces of shell and thus were not attached to a large, hard substrate such as sticks), farming methods changed to primarily holding spat in plastic mesh envelopes or baskets and this method, described in detail by (Ryan, 1997a), is still commonly used today on intertidal farms. Baskets are suspended across wooden racks in the intertidal zone, and the height of the racking above the bottom varies between farmers and between areas. Generally the oysters are exposed for 30-40% of the time. Intertidal rack culture has several advantages: easy access from the shore, and hence farms can be maintained using tractors, exposure at low tide reduces the amount of fouling on oysters because most fouling organisms can't tolerate exposure to air, and regular air exposure hardens the shell and strengthens the adductor muscle, enabling longer shelf life.

Deep water culture developed in the late 1980's as suitable intertidal areas rapidly became scarce. Oysters grown subtidally generally have a faster growth rate because they are continually submersed and can feed for longer periods. Another advantage of deepwater farming is that longlines can be serviced by boat at any state of the tide. However, the oysters are commonly relocated to intertidal culture for several months to harden the shell and strengthen the adductor muscle. In deep water the oysters are generally grown in plastic trays which are stacked one above the other, and the unit of trays is suspended below a long line of buoys and ropes floating at the surface (Ryan, 1997a).

A new farming method developed in South Australia for relatively exposed sites, called the 'BST' method, has been trialed on intertidal farms in Tasmania over the last 3-4 years. This method consists of plastic mesh cylinders which are hung off wire strung between posts in the intertidal zone. Advantages of this method are that the oysters can't be washed out of the cylinder and the wire can be easily raised or lowered to control growth rates.

As the industry has developed, each farmer has developed his/her culture techniques to suit individual farm management protocols and environmental conditions. The industry has also become more specialised, and there are several hatcheries and land-based nurseries producing spat of 4-6 mm. Some farmers only grow small seed oysters to about 6-10 mm shell length in fine meshed trays or baskets, whilst others produce intermediate sized ($\approx$ 10-60 mm) oysters. Some farmers specialise in growing the larger oysters to market size and condition at about 80-100 mm total length.

Mechanisation of shellfish farming has also been occurring, with mechanical sorting and grading equipment, and specialised equipment for the movement of oysters on and off the farms, especially in large deep water operations.

3.3 Mussel (*Mytilus edulis*) Culture

Mussel farming has slowly developed in Tasmania over the last two decades. Government research and marketing assistance was provided in the early 1980's to help establish the industry but production was minimal until the mid 1990's. This slow development is largely attributed to the concentration of effort in the more lucrative Pacific oyster industry. An unreliable supply of spat collected from the wild has also hindered progress, but recent research to improve wild spat collection and the development of hatchery culture methods has resulted in a more reliable source of spat (Cameron, 1997). Currently, most of the mussel seed is sourced from the wild and research has assisted with the identification of prime seeding areas, and methods to determine the best times to deploy spat collectors. Mussel seed have also been successfully produced in the hatchery, and initial problems of predation during the nursery phase in the sea have largely been eliminated because other relatively predator-free areas have been identified (Graham Schroeter, pers. comm, 1999).

Mussels are grown in subtidal waters suspended below longlines, but instead of being in trays like oysters, mussel seed is dispersed along ropes and held in place with fine meshing (socking) until the mussels attach to the rope with their byssal threads. Ongrowing to market size occurs whilst the mussels are attached to the ropes. Details of mussel culture methods are provided in Ryan (1997a).

The Tasmanian Government in its audits of Tasmanian industries has identified the potential for major expansion of the mussel culture industry to some 1500 tons per annum in the next few years. This expansion would be primarily for the domestic market as demand currently exceeds supply (DPIWE, 1999a).

3.4 Scallop (*Pecten fumatus*) Farming

Scallop culture using Japanese methods of wild spat collection and reseeding juveniles on marine farm leases was seriously attempted in the 1980's when the Scallop Enhancement Research Project was established in conjunction with the Overseas Fishery Cooperative Foundation of Japan. However, a number of difficulties were encountered, in particular high predation of reseeded juvenile scallops (Thomson, 1995). Most scallops are now reared in lantern-type cages or by ear hanging (see Ryan (1997b) for details), and currently only two aquaculture enterprises on the east coast of Tasmania are farming commercial quantities of scallops. These scallops are mainly sold shucked, fresh and frozen, to local and mainland Australia markets, although the fresh whole shell market for the restaurant trade is expanding.

According to the Tasmanian Industry Audits, scallop culture has the potential to expand and to supply markets when the wild scallop fishery is closed. However, this industry is considered to be limited at present by a reliance on wild collected spat, and hatchery production will be necessary for industry expansion (DPIWE, 1999a).

4. The Tasmanian Marine Environment

Primary production in Australian waters is generally low compared with temperate waters overseas, largely because of limited availability of essential nutrients (Rochford, 1993). Although nutrient concentrations around Tasmania are generally higher that those recorded in mainland Australia, they are amongst the lowest for temperate latitudes worldwide (inorganic nitrate 1-2 µM). Highest nutrient levels generally occur around the Tasmanian south coast where periodic intrusions of nitrate rich subantarctic waters occur, whilst Central Bass Strait waters are nutrient poor with nitrate concentrations generally <1 µM (Rochford, 1993).

Off eastern Tasmania, and as far south as Storm Bay, seasonal and interannual variability in water properties, including nutrient levels, have been attributed to variability in climate, in particular to the changing strength of the East Australian Current (Clementson *et al*., 1989; Harris *et al*., 1991). This current generally varies in accordance with El Niño/Southern Oscillation (ENSO) events. During El Niño years stronger westerly winds occur, resulting in colder, nitrogen rich waters compared with La Niña years when the East Australian Current penetrates further south with warmer, nutrient depleted waters. Even so, phytoplankton biomass is generally within the range of 0.3 – 4.0 µg L^{-1} in Storm Bay (Clementson *et al*., 1989). Additionally, long term hydrological records at Maria Island on the east coast indicate a slow increase in temperature and salinity, and a decrease in nitrate concentrations over the last 50 years, presumably due to an increase in strength and extension further south of the East Australian Current (Crawford, Edgar & Cresswell, 2000; Harris *et al*., 1987).

Data on primary production in Tasmanian estuaries are limited, although it is generally recognised to be low in estuaries in southern and western Tasmania where dark tannin-stained waters limit the penetration of light essential for photosynthesis (Coughanowr, 1997; Edgar, Barrett & Graddon, 1999). Thus densities of phytoplankton available for consumption by shellfish are likely to be low in Tasmanian waters compared with many of the shellfish growing areas overseas.

Phytoplankton densities, measured by chlorophyll a levels, in several oyster growing areas in eastern and southeastern Tasmania, at Pittwater, Pipeclay Lagoon, Georges Bay, Little Swanport and Simpsons Bay, and primary production from Pittwater and Pipeclay Lagoon, were recorded over several years by (Crawford, Mitchell & Brown, 1996; Crawford & Mitchell, 1999). Chlorophyll a levels were generally within the range of 0.5 - 4 µg L^{-1}, with peaks approaching bloom conditions occurring periodically, but most commonly in late summer. Chlorophyll a concentrations tended to be higher at the estuarine sites than the marine sites at the mouths of estuaries and marine inlets, although oceanic influences were periodically observed. Nitrate+nitrite measurements were mostly around 10 µg/l at all sites with some irregular large peaks. Chlorophyll a peak concentrations generally occurred in the same month or just after peaks in nitrate concentrations, and at the estuarine sites of Little Swanport and Georges Bay these high values often occurred after heavy rains resulting in low salinities. Phosphate-phosphorus concentrations were routinely within the range of 4 -15 µg/l, with slightly lower values at Pipeclay Lagoon and Little Swanport. There were no apparent trends between seasons or between stations at each site. Of the few measurements of silicate - silicon, results were varied, generally between 20 - 250 µg/l, and they were often lowest at the Marine station at the three sites investigated.

Shellfish culture in Tasmania is concentrated in estuaries and coastal embayments where the waters are sheltered and readily accessible. Only recently have farms ventured into more exposed areas because suitable estuarine locations have become limited. Pacific oyster farming initially was completely intertidal, and later expanded to subtidal areas as the industry developed and became more specialised. All mussel farms are in subtidal waters.

Tasmanian estuaries and sheltered coastal waters have wide ranging environmental conditions, ranging from the relatively pristine estuaries and coastal lagoons on the West Coast and Bass Strait Islands to estuaries that have at some stage been amongst the most polluted in the world e.g. the Derwent, and Macquarie Harbour (Crawford *et al*., 2000; Sustainable Development Advisory Council, 1996). One hundred and eleven Tasmanian estuaries were recently classified according to their conservation significance by (Edgar *et al*., 1999) based on physico-chemical parameters, biological attributes and human population densities of the estuaries and their catchments. Of the 90 mainland catchments they examined, 24 were considered to be pristine, and these were nearly all distributed in the south and west of the state. Urban development and land clearance levels were highest in catchments along the south-east, east and north coasts, areas where shellfish farming predominantly occurs in Tasmania. Siltation was considered by (Edgar *et al*., 1999) to be a major threat to the health of Tasmanian estuaries because all estuaries with moderate to high levels of human population densities in catchments consistently possessed higher levels of silts and clays. They also listed marine farming as one of nine major threats to Tasmanian estuaries, although they do not specify the types of farming.

The biota and habitats within 11 estuaries and associated catchments (North East Inlet, Black, Bryans Lagoon, New River Lagoon, Thirsty Lagoon, Tamar, Southport Lagoon, Louisa River, Bathurst Harbour, Payne Bay and Wanderer) were recommended by (Edgar *et al*., 1999) to be protected from further development. None of these areas currently contain marine farms, although several, e.g. North East Inlet and the Black River, have been suggested by potential farmers as suitable areas for marine farming.

Other than the (Edgar *et al*., 1999) report, there are few other comprehensive studies of estuarine and shallow coastal waters. Environmental status reports for the Derwent and Tamar estuaries have been prepared by (Coughanowr, 1997) and (Pirzl & Coughanowr, 1997), respectively. As part of preparing the Marine Farming Development Plans for each growing area around Tasmania, baseline environmental data have been collected and an environmental impact assessment conducted in each proposed marine farming zone to assess their suitability for farming. Environmental data for inshore coastal waters have also been collected as part of the bioregionalisation process for Tasmanian inshore waters and the development of a system of marine protected areas in Tasmania (Edgar, 1984; Edgar, 1986; Edgar *et al*., 1997).

The first State of the Environment Tasmania report by the Sustainable Development Advisory Council (1996) highlighted the lack of baseline monitoring and environmental information as a key issue in coastal, estuarine and marine systems. They recommended that more detailed environmental information was required on: water quality and hydrodynamics, native species inventories and population distributions, spread of introduced species, landscape condition and human pressures. Because of this paucity of data, it is difficult to assess the state of the marine environment and changes that have occurred, or from which to measure future changes. In accordance with this, limited baseline information is available from shellfish farming areas in Tasmania. Thus environmental changes resulting from shellfish farming activities are difficult to detect from natural variability. Similarly, effects of the environment on aquaculture, primarily due to anthropogenic activities, are not clear because of a paucity of background environmental data. Aquaculture is listed as one of a number of threats to Tasmanian coastal and marine ecosystems by the (Sustainable Development Advisory Council, 1996) because of organic enrichment and nutrient release from salmon farms, and also from physical habitat disturbance, including from oyster farming in many estuaries and sheltered bays.

Thus, much of the environmental information which would be of specific relevance to shellfish farming, including hydrodynamics and water flow rates, primary production, nutrient levels, and water quality of growing areas, is not available. This information is required to predict carrying capacities of shellfish growing areas, i.e., the potential maximum production of shellfish that can be maintained in relation to available food resources in an area (Rosenthal *et al*., 1988). However, more information is slowly becoming available. Data on water movements and nutrients in several important oyster growing areas have been collected as part of developing predictive models of carrying capacity for each area (Crawford *et al*., 1996; Crawford & Mitchell, 1999). Hydrodynamic models and nutrient budgets are currently being prepared for the Huon estuary by the CSIRO in Hobart. Nevertheless, environmental information needed to predict shellfish carrying capacity is required for each growing area because the specific environmental characteristics of each region preclude generalisations across areas. .

Various anthropogenic impacts on estuaries and coastal waters, which also affect shellfish farming, have been described in the first State of the Environment Tasmania report by the(Sustainable Development Advisory Council, 1996) and by (Crawford *et al*., 2000). These include industrial and residential development, and agriculture and forestry activities in coastal areas and catchments. Major threats include increased siltation and the introduction and spread of exotic. Introduced vegetation such as rice grass *Spartina anglica* and marrom grass (*Ammophila arenaria*) have altered the coastal geomorphology, whereas introduced fauna such as the Pacific seastar *Asterias amurensis*, and the European shore crab *Carcinus maenas* are impacting directly on native flora and fauna. The latter two species also predate on Pacific oysters and mussels under culture in Tasmania. The introduced toxic dinoflagellate *Gymnodinium catenatum* has severely affected shellfish culture in the D'Entrecasteaux Channel region because shellfish which consume this dinoflagellate concentrate toxins and become unsafe for human consumption for a period of time while the bloom is present.

The Tasmanian Shellfish Quality Assurance Program (TSQAP) which was established in 1984 to ensure that shellfish harvested in Tasmania were safe for human consumption has provided environmental data on many Tasmanian estuaries. TSQAP is based on a strategy that shellfish can only be harvested and marketed from waters that have been shown to be free of harmful contaminants or pathogenic microbes, i.e. a clean waters policy. All commercial shellfish growing areas in Tasmania are routinely monitored for bacterial levels and a toxic dinoflagellate monitoring program is in place, primarily for southern Tasmania. Heavy metals and other contaminants that accumulate in shellfish flesh are also periodically monitored, and potential sources and risks of contaminants are surveyed. Each growing area is assigned a classification based on the level of public health risk. A substantial data set has accumulated on environmental conditions in many Tasmanian estuaries and coastal waters since the inception of this program, which has been funded jointly by industry and State government.

5. Literature Review of Environmental Impacts

Natural ecosystems normally tend towards stability, due to feedback mechanisms of checks and balances. Such systems can potentially be disturbed by shellfish farming because of the concentration of large numbers of a single species in a confined area. However, shellfish farming is generally considered to have less environmental impact than finfish farming because there are no exogenous sources of food or prophylactic treatments (Kaiser *et al*., 1998). Nevertheless, because shellfish farms now occupy large areas of coastline, the scale of potential disturbance to natural ecosystems is correspondingly large (de Grave et al, 1998).

The following section reviews much of the literature on ecological effects of shellfish farming. Most information has come from European countries and North America, where government and community concerns about detrimental environmental effects of shellfish culture have been increasing in recent years. However, very little information was found in the primary literature from the major shellfish producing countries such as China and Japan. Also, much of the relevant information is in the grey literature and not always readily accessible.

5.1 Impacts on the seabed

5.1.1 Organic enrichment of the seabed

Shellfish produce solid wastes - faeces and pseudofaeces - which consist of particulate organic and inorganic matter bound together by mucus into larger particles. These particles have a faster settling rate than the original small, suspended particles consumed by the shellfish, and are generally deposited in higher concentrations near the shellfish farm than would occur naturally. Many factors affect the rate of production of organically-enriched faeces and pseudofaeces by shellfish, including the density and distribution of the shellfish, environmental conditions such as temperature, salinity, phytoplankton concentrations and turbidity, and the feeding rate of the shellfish (Dame, 1996; Jaramillo, Bertran & Bravo, 1992). Rates of accumulation or dispersion of biodeposits also depends on the velocity and direction of water currents around the farm, especially water movements close to the seabed (Widdows *et al*., 1998).

In a normal, unstressed ecosystem, these biodeposits are generally broken down at a rate that precludes accumulation of wastes. However, in an organically enriched environment the sediment porewater and near bottom water become depleted in oxygen because of the increased activity by the benthic fauna and microorganisms decomposing the organic matter. When the oxygen supply is depleted, anaerobic benthic metabolism occurs whereby organisms adapted to sulphide metabolism increasingly participate in carbon mineralisation (increase in sulphides and decrease in sulphates) (Gowen, 1991; Gowen & Bradbury, 1987; Wu, 1995). Thus a highly enriched environment can be detected from a changed benthic flora and fauna, and changed sediment nutrient fluxes, especially levels of carbon, nitrogen (nitrates and ammonium), oxygen and sulphur (sulphates and sulphides).

Most studies on organic enrichment of the seabed from shellfish farming have concluded that the effect is small, and much less than that caused by finfish farming, e.g. mussel farming in France (Baudinet *et al*., 1990) and in Canada (Grant *et al*., 1995), and shellfish farming in Chile (Buschmann, Lopez & Medina, 1996). Only a few, e.g Dahlbäck and Gunnarsson (1981) and Mattson and Linden (1983) working on mussel culture in Scandinavia, have described similar impacts to finfish culture. Interestingly, the vast majority of the literature pertaining to organic enrichment by shellfish farms is for mussel farming, even though total mussel production worldwide is considerably less than that of Pacific oysters.

Increased sedimentation under shellfish farms due to of the accumulation of faeces and pseuofaeces has been recorded in several studies of shellfish culture, especially for mussels (Table 1). For example, the biodeposition rate at a mussel farm in Nova Scotia Canada was approximately 2.4 times that at an reference site 30 m away (Grant *et al*., 1995). Similarly, Dahlbäck and Gunnarsson (1981) observed that sedimentation rates under mussel culture in Sweden were 2-3 times higher than at a reference site 100m away. Mussels in Spain cultured at high densities were estimated to ingest 180 tonnes of organic matter and deposit 100 tons of detritus from each raft every year (Figueras, 1989).

Table 3. Rates of deposition and sediment accumulation by shellfish.

Species and System	Production or Density	Location	Depth	Current Velocity	Biodeposition	Sediment Accumulation	Reference
M. edulis longlines	23.6 $kg.m^{-2}.yr^{-1}$	Sweden	8-13 m	~3 $cm.s^{-1}$	3 g C $m^{-2}d^{-1}$ ref. site 1.7 g C $m^{-2}d^{-1}$	10-15 cm H2S rich mud, *Beggiatoa*	Dahlback & Gunnarsson (1981)
M. edulis longlines	30 $kg.m^{-2}.yr^{-1}$	Sweden	8-15 m	~3 $cm.s^{-1}$		several cm per year high mussel densities	Mattson and Linden (1983)
M. edulis rafts	165 $kg.m^{-2}.yr^{-1}$	Spain	av.19 m		0.2-2.4 g C $m^{-2}d^{-1}$ 0.01-0.15 g N $m^{-2}d^{-1}$	bottom scouring	Tenore *et al*. (1982)
M. edulis longlines	density 12 $kg.m^{-2}$	Canada	7 m	4-7 $cm.s^{-1}$	88.7 g $DW.m^{-2}d^{-1}$ ref. 36.4 g $DW.m^{-2}d^{-1}$	1.6 $cm.y^{-1}$ before farming 2.3 $cm.yr^{-1}$ after farming	Grant *et al*. (1995)
M. chilensis reseeded bed	density 250-300 m^{-2} (~10-15 $kg.m^{-2}$)	Chile	~4m	< 45 $cm.s^{-1}$	234 $gDW.m^{-2}d^{-1}$	201.9 $kgDWm^{-2}yr^{-1}$ (553 $gDW.m^{-2}d^{-1)}$	Jaramillo *et al*. (1992)
M. edulis rafts	250 $kg.m^{-2}$	Ireland	> 15 m	10 $cm.s^{-1}$	26 g $C.m^{-2}d^{-1}$ 3 g $N.m^{-2}d^{-1}$	no significant biodeposits mussel shells & starfish	Rodhouse *et al*. (1985)
M. edulis longlines	30 $kg.m^{-2}$	Sweden	< 10 m	2-3 $cm.s^{-1}$	2.4 g $C.m^{-2}d^{-1}$		Rosenburg and Loo (1983)
M. galloprovincialis rafts	~250 $kg.m^{-2}$	Spain			100t/raft/yr ~846 $g.m^{-2}d^{-1}$		Figueras (1989)
M. edulis natural bed	biomass 620 $kg.m^{-2}$	Baltic Sea	5 m		0.5-10 $g.m^{-2}d^{-1}$	1-37 gDW $m^{-2}d^{-1}$	Kautsky & Evans (1987)
C. gigas racks	~15 kg/m2	France			8-99 g $C.m^{-2}d^{-1}$ 480-6000 $g.m^{-2}d^{-1}$		Sornin *et al.* (1983)
C. gigas intertidal racks		France			19 $g.m^{-2}d^{-1}$		Martin *et al*, 1991)

Biodeposition and sediment accumulation rates listed in Table 1 vary considerably between sites with different environmental conditions. Not surprising, biodeposition rates were generally highest in areas of low current flow or shallow water depths. For example, Dahlbäck and Gunnarsson (1981) observed a significant impact of mussel culture in an area of poor current flow in Sweden, whereas Tenore *et al*. (1982) didn't under areas of high mussel production in Spain, largely because periodic strong bottom currents dispersed the organic wastes from the culture area. Biodeposition rates reported for *C. gigas* were variable. Additionally, Nunes and Parsons (1998), using data from the literature, estimated that an oyster rack holding 420,000 oysters would generate 16 t of faeces and pseudofaeces during a 9 month grow-out period.

Increased organic content under areas of high density shellfish culture compared to reference sites or low production areas has been recorded in many areas, e.g. in Spain by Tenore *et al*. (1982), in New Zealand by Kaspar *et al*. (1985), in France by Castel *et al*. (1989), in Sweden by Dahlbäck and Gunnarsson (1981), Mattson and Linden (1983), and in Canada by Hatcher *et al*. (1994). Negative redox values or other signs of a highly reduced sediment such as black colour and H_2S smell have also been observed under shellfish farms (e.g.Baudinet *et al*., 1990; Dahlbäck and Gunnarsson, 1981; Gilbert *et al*., 1997; Mattson and Linden, 1983). However, highly reduced sediments with extensive *Beggiatoa* bacterial mats have been recorded in very few studies. The one example that is widely quoted in the literature of significant impacts of shellfish farming is the work by Dahlbäck and Gunnarsson (1981) in Sweden. Grant *et al*. (1995) observed bacterial films under mussel culture and black reduced sediment to within 2 cm of the sediment surface in summer, but other environmental parameters were variable and not different from the reference site.

Sediments under shellfish farms have been observed to be generally finer and more flocculent, i.e. a greater percentage of silts and clays, than at reference sites (Baudinet *et al*., 1990; Castel *et al*., 1989; Kaspar *et al*., 1985; Mattson & Linden, 1983; Tenore *et al*., 1982). Increased concentrations of chlorophyll *a* (Barranguet, Alliot & Plante-Cuny, 1994) or phaeophytin pigments (Kaspar *et al*., 1985), or both (Castel *et al*., 1989; Dahlbäck & Gunnarsson, 1981) in the top layers of sediment under shellfish farms have also been recorded.

Changes in benthic community composition under shellfish farms compared to reference sites have been found in several studies (e.g. Dahlbäck and Gunnarsson, 1981; Kaspar *et al*, 1985; Rodhouse *et al,* 1985). In some cases, mussels fallen from culture ropes accumulated on the bottom, providing substrates for the attachment of other organisms and attracting predators such as starfish and fish. This resulted in higher species diversity of epibenthic fauna under mussel farms, and these mussels on the seabed were considered by Grant *et al*. (1995) to have greater environmental effect on the benthos than organic sedimentation.

By contrast, lower diversity of the benthic infauna under mussel farms compared to reference sites has been observed, for example, in France (Baudinet *et al*., 1990), in New Zealand (Kaspar *et al*., 1985), in Sweden (Mattson & Linden, 1983), and in Spain (Tenore *et al*., 1982). Farm sites with significant organic enrichment were dominated by polychaetes, whereas the reference sites typically contained a variety of infauna including brittle stars, bivalves, crustaceans and polychaetes. For example, under mussel (*Mytilus galloprovincialis*) culture, the original diverse and species rich fauna was replaced by a few species at very high densities, e.g. *Capitella capitata* at 10 000 per m^2 and *Ophryotrocha sp*. at 60 000 per m^2 (Baudinet *et al* 1990). In intensive raft culture of the blue mussel *Mytilus edulis* in the Spanish rias, mussel faeces and pseudofaeces accumulated within the interstices of the rope and on the bottom, attracting epifauna and associated predators, and resulted in an estimated ancillary production of biota and detritus on the mussel lines of 67%, and seaweed production of 33%, of the mussel production (Tenore *et al*., 1982). In Sweden pportunistic polychaetes, *Capitella capitata, Scolelepis fuliginosa* and *Microphthalmus sczelkowii* became dominant under and near mussel longlines after six months of culture, and only limited recovery of the site was observed 18 months after harvesting the mussels (Mattson & Linden, 1983).

At a densely stocked oyster park in Arcachon Bay, France, where Pacific oysters were cultured either directly on the bottom or in net bags on trestles above the bottom, macrofaunal abundance was almost half, but meiofaunal (infauna < 0.5 mm size) abundance increased by 3-4 times at the farm sites compared with adjacent sand banks (Castel *et al*., 1989). This was partly attributed to meiofauna having greater tolerance to increased organic matter content from biodeposits and anoxic conditions than the macrofauna. Thirty percent of oyster and mussel farms in France have been estimated to be periodically abandoned or relocated because of the accumulation of biodeposits, i.e. production has exceeded the capacity of the site to assimilate the amount of waste generated (Sornin,1979; cited in GESAMP,1991).

Effects of shellfish biodeposits on seagrass beds have been shown in most studies to be localised and short term. For example, under oyster culture in Mexico the benthic community structure was typical of organically enriched areas, and beds of *Zostera marina* generally disappeared within two months of the commencement of farming. *Z. marina* recolonised again about four months after the removal of oysters, but the invertebrates took approximately six months to reestablish (Villarreal, 1995). Similarly, Everett *et al*. (1995) observed that the abundance of *Z. marina* declined in areas of Pacific oyster stake and rack culture to less than 25% after one year of culture compared to reference areas, and seagrass was absent from rack culture after 17 months. In South Australia no significant differences in sea grass (*Posidonia* sp) cover were detected between oyster growing sites (gaps between racks) and adjacent sites, but there was some localised loss under seed trays due to shading (Hone, 1996).

These studies point to the importance of site selection in reducing impacts on the seabed under shellfish farms. Farms located in areas of poor current flow, less than or equal to ~5 cm s^{-1}, are much more likely to result in accumulations of organic wastes and develop anoxic sediments. Farm management practises are also important, although this is not commonly discussed in the literature. Selecting shellfish stocking densities and farming techniques appropriate to the environmental conditions of the farm site is essential to minimise impacts on the benthic environment.

5.1.2 Effects on the physical environment

Structures, such as intertidal racks, trestles or longlines, used for shellfish culture alter the hydrodynamics of an area to some degree (Kaiser *et al*., 1998). Racks on the bottom can redirect the water flow and produce either scouring or accretion of sediment around the farm structures, depending on the local hydrography (Hecht & Britz, 1992).

Benthic macrofauna under an intertidal Pacific oyster farm in Dungarvan Bay, Ireland was not obviously affected by organic enrichment, largely due to the tides and strong currents around the farm site dissipating biodeposits (de Grave et al, 1998). However, physical disturbance as a result of compaction and dispersal of the sediment by heavy vehicle traffic appeared to be responsible for differences in species composition and abundance of epibenthos and infauna between access lanes, underneath oyster trestles and at a control site (de Grave et al, 1998). Nevertheless, no details were provided of the type or frequency of vehicle use. Castel *et al*. (1989) reported that Pacific oyster culture on suspended racks in Arcachon Bay, France, increased sedimentation and enhanced the accumulation of debris. An investigation of the effects of two types of oyster mariculture on sediment surface topography by Everett *et al*. (1995) found that stake culture resulted in a significant increase in sediment deposition, whilst rack culture resulted in greater erosion compared with reference sites. However, Hone (1996) found no detectable changes in sedimentation rates within Pacific oyster leases compared to controls in South Australia, largely because of the coarse sediments and naturally low levels of sediment in the water.

Reseeding large areas of the seabed with cultured or wild collected seed stock for ongrowing, and then harvesting market-size fish by dredging is common practice in many parts of the world, for example, USA, France, Netherlands, and Japan. However, dredging has been widely reported in the literature to cause major habitat and community changes (see review by Jennings and Kaiser (1998). Disadvantages of intrusive harvesting devices such as dredges are listed by Kaiser *et al*. (1998) and include direct mortality of non-target species, habitat destruction, and depletion of food resources for other species such as birds, crabs and starfish. For example, Thrush *et al*. (1998) found species richness and diversity of benthic communities decreased with increasing trawl and dredge fishing. Similarly, a study of the effects of commercial scallop dredging on the environment of Port Phillip Bay, Victoria, showed a 20-30% decrease in infaunal invertebrate abundance which lasted for up to 14 months (Currie & Parry, 1996). According to Dankers and Zuidema (1995), the most obvious impact of mussel culture on the Dutch Wadden Sea environment was dredging of seed mussels which reduced the food supply for several bird species. As a consequence, high mortalites occurred in eider ducks, and oystercatchers had low breeding success.

In some countries, the culture area is also mechanically worked before seeding to remove predators or prepare the substrate. For example, some intertidal oyster culture areas in Washington, USA, are commonly cultivated with tractor-towed harrows to level the seabed (Simenstad & Fresh, 1995). In Japan scallop reseeding beds are scraped with a ‘mop’ to remove predators, particularly starfish. Relatively large areas (km^2) can be affected, and the mopping activity can substantially alter the benthic epifaunal community structure.

5.2 Impacts on the water column

Shellfish consume detritus and phytoplankton that have been produced over a much wider area of water than that of the farm, and generally select food particles by size and composition. They thus can alter the abundance and composition of phytoplankton and detritus in the water body in which they are growing, and hence affect marine food webs (e.g. Tenore *et al*. (1982). As a consequence of the large quantities of phytoplankton they consume, shellfish can also have a significant impact on the transfer of nutrients through the system. Nitrogen is most affected because this nutrient essential for primary production may be limited in the marine environment.

However, the role of dense aggregations of shellfish in nutrient cycling and phytoplankton dynamics in an estuary or coastal waters is complex, and dependent on site-specific environmental conditions. Also, large differences in nutrient fluxes have been reported both between and within sites; thus the effects of shellfish farming can be difficult to quantify (Hatcher *et al*., 1994). For example, nitrogen cycling can occur across several chemical pathways and different routes of nitrogen cycling have been reported for shellfish species under different environmental conditions.

Most research on the effects of shellfish on benthic nutrient fluxes and phytoplankton dynamics has been conducted with mussels, either in expansive natural beds such as in the Dutch Wadden Sea, or on intensive raft or longline culture. Oyster culture has been found to have a lesser, but similar, effect on nutrient cycling than mussel culture (Barranguet *et al*., 1994). Similarly, the uptake and release of particulate organic matter is generally higher for mussel beds than oyster reefs because of higher mussel densities and the different environmental conditions (Dame & Dankers, 1988).

Overall, estimates of nutrient and phytoplankton concentrations in relation to shellfish culture have shown that shellfish farms are a sink for nitrogen. Shellfish accumulate nitrogen from the ecosystem during growth which is permanently removed at harvest (Folke & Kautsky, 1989; Kaspar *et al*., 1985; Tenore *et al*., 1982). They also facilitate loss of nitrogen to the atmosphere by denitrification (Kaspar *et al*., 1985). Some researchers interpret this as a detrimental effect of shellfish farming because the nitrogen is not available to support the normal functioning of the system, whilst others view this as a positive impact because shellfish are useful in removing excessive nutrients from the system.

In New Zealand the loss of nitrogen through mussel (*Perna canaliculus*) harvest and denitrification was calculated by Kaspar *et al*. (1985) to be 65 % higher at the mussel farm than at a nearby reference site. There was also a substantially higher concentration of organic nitrogen in the mussel farm sediment than at the reference site, which may have further reduced the amount of nitrogen available for primary production because of burial of the organic nitrogen. Kaspar *et al*. (1985) concluded that concentrating shellfish on farms may lead to a decreased availability of nitrogen which is crucial to the functioning of coastal ecosystems, and also may limit the long-term sustainability of high density mussel farming. Similarly, Rodhouse and Roden (1987), from a study of the carbon budget in relation to mussel farming in a coastal inlet in Ireland, anticipated severe modifications to the ecosystem and decreasing mussel yields if more than half the primary production was consumed by mussels.

On the other hand, a number of reports in recent years, for example by Folke and Kautsky (1992 and Wu (1995), have suggested that shellfish farming has an important role in controlling phytoplankton growth and eutrophication. Folke and Kautsky (1989) advocate growing shellfish around finfish farms as a means of reducing nutrient input into the environment from the fish farms and hence reduced the risk of algal blooms. However, Stirling and Okumus (1995) and Wu (1995) caution about bacterial and chemical contamination of shellfish from fish farms. Results of polyculture studies have varied. Improved growth of mussels cultured near salmon farms was observed by Wallace (1980) and Jones and Iwama (1991), but not by Taylor *et al*. (1992) or Stirling and Okumus (1995).

A report on the environmental effects of aquaculture in the USA by the Environmental Defence Fund, a nonprofit research and advocacy organisation, concluded that mollusc farming can be beneficial to the environment because mussels filter out food particles from the water and thus reduce nutrient pollution. Some 35-40% of the total organic matter ingested by molluscs were reported to be used for growth and permanently removed at harvest (Goldberg and Triplett, 1997).

Recommendations have been made to introduce shellfish into degraded estuaries around the world to help clean them up by filtering out the phytoplankton and hence removing excessive nutrients, particularly nitrogen. For example, re-establishment of oyster beds in Chesapeake Bay has been proposed to reduce phytoplankton densities and regulate nutrient cycling (Gottleib & Schweighofer, 1996; Mann, Burreson & Baker, 1991). This bay supported a large dredge fishery for the Eastern Oyster (*Crassostra viginica*) in the late 1800's and early 1900's but a massive population decline occurred due to overfishing, pollution, siltation and disease. During its peak, oysters in the bay were estimated to filter the entire volume of the bay in 3.3 days, but by 1988 the filtering time had increased to 325 days (Newell, 1988). The trophic structure of the bay ecosystem changed from predominantly filter feeding to bacterial production, and eutrophication is now common. The Pacific oyster has been recommended, rather than the endemic oyster, because it is less prone to diseases common in the area (Mann *et al*., 1991). Gottlieb and Schweighofer (1996), however, express caution about the introduction of an exotic species for ecosystem restoration because the outcomes are not completely predictable. To date, Pacific oysters have not been introduced into Chesapeake Bay.

The North Carolina Blue Ribbon Advisory Council on Oysters (1995) listed the benefits of oyster culture as removing suspended matter and excess algal production, and as a nursery habitat for economically important invertebrates and fishes. Their oyster industry has been based on a dredge fishery of naturally occurring populations of the eastern oyster, *C. virginia*, which have steadily declined to about 2 % of previous maximum landings. However, no scientific justification for their conclusions on the benefits of oyster culture are provided, and they do not mention the environmental impacts of dredging for reseeded oysters - their main harvest method.

Other studies have shown that the role of shellfish populations in regulating nutrient and phytoplankton concentrations in estuaries is more complex than the simple removal of nutrients or suspended matter from the water column (e.g. Asmus and Asmus, 1991; Kaspar *et al*., 1985). Mussel farming has been observed to facilitate more rapid cycling of ammonium, which is the most readily available form of nitrogen to the ecosystem. Rates of ammonium excretion by mussels are high; for example, Kaspar *et al*. (1985) found that the areal rate of ammonium excretion by mussels was 10 times the rate of net nitrogen mineralisation in the reference site sediment. The ammonium pool and the rate of mineralisation in the sediments was also considerably higher in the mussel farm than reference sediments. Gilbert et al (1997) also found that the more reduced conditions under a mussel farm favoured ammonium production, and 98% of nitrate was reduced to ammonium which remained available for the ecosystem. Thus, because mussels (and other shellfish) make ammonium more readily available, they can enhance primary production in areas where nitrogen is limiting. Higher ammonium levels under mussel farms than at reference sites have also been observed by Baudinet *et al*. (1990), Asmus and Asmus (1991), Barranguet *et al*. (1994), Baudinet *et al*. (1990), Grant *et al*. (1995) and Hatcher *et al*. (1994).

Thus, whilst shellfish reduce phytoplankton biomass, they also have the potential to locally increase primary production because of the nutrients released. Thus, Asmus and Asmus (1991) concluded, in contrast to reports mentioned above, that eutrophication caused by anthropogenic activities may not be reduced by introducing beds of mussels because mussels remineralise more organic matter than just phytoplankton. Also, phytoplankton consumed by mussels may be recycled back into the water column faster than natural sedimentation.

Fluxes of phosphates have been found to be higher under mussel culture than at reference sites at some farms (Baudinet *et al*., 1990), and at similar levels at others (Hatcher et al, 1994). However, phosphate levels generally have less effect on the ecosystem than nitrogen concentrations because phosphorus is rarely limiting in the marine environment. Baudinet *et al*. (1990) also found that silicate levels were higher under mussel culture than outside the culture site, which could alter the phytoplankton community structure. The N:P ratio in the water column of a mussel farm may also be affected, resulting in altered primary production and most likely species composition of the phytoplankton (Hatcher *et al*., 1994).

In addition, effects on the environment may be greatest at a regional scale (e.g. a whole bay where a number of farms are concentrated in one area), than at a local on-farm scale. The impact of each farm may be additive and affect the ecology of the whole growing area and beyond, for example the removal of phytoplankton from the water column by all the farms (Midlen & Redding, 1998). In the Marennes-Oléron Bay in France, dense concentrations of oyster farms have resulted in an increase of the grow-out time of oysters from 18 months to up to four years, because of insufficient food for all the oysters in the Bay (Raillard & Menesguen, 1994). A number of studies have been conducted to predict the maximum sustainable production of shellfish in a given body of water. Models of carrying capacity of oyster growing areas, based on hydrodynamics, rate of production of phytoplankton food, and food requirements of the shellfish have been developed (e.g Carver and Mallet, 1990; Ferreira *et al*., 1998; Raillard and Menesguen, 1994). However, most of these models are site-specific, and can only be applied in general principle to other growing areas. They also require detailed information on water movements and primary production, which can be time-consuming and costly to collect.

Overall, the main impacts of shellfish farming on the water column environment are a reduction in phytoplankton concentrations, a net loss of nitrogen from the system, and a decrease in suspended matter. In degraded estuaries this is widely viewed as a positive benefit of shellfish farming. However, in areas relatively unaffected by human activities it may be judged as detrimental because nutrients essential to the functioning of the ecosystem are reduced.

5.3 Effects on Wildlife

High densities of cultured shellfish may impact on other filter feeders growing in the same area because they can deplete the food resources available for all planktonic herbivores present. The effects of these limited food supplies may also be felt by the wider water body ecosystem because, for example, competition between filter feeders for depleted food resources can alter the trophic structure of the culture area. GESAMP (1991) concluded that large scale intensive cultivation of bivalves, such as occurs in western Europe, can affect the marine food web by the removal of phytoplankton and organic detritus, and by competing with other planktonic herbivores. Other research has also found that intensive shellfish culture can reduce the food available to all suspension feeders in the area, e.g. increased mussel culture in the Oosterschelde estuary (van Stralen & Dijkema, 1994). Similarly in Japan where dense pearl oyster culture has resulted in a reduced quality of pearls (Rosenthal 1994), the growth and survival of other organisms is also likely to be affected. However, few studies have been conducted in this area because of the difficulties in verifying that high density shellfish farming is depleting food supplies for other filter feeders

Folke and Kautsky (1989) also suggested that large-scale mussel culture could cause structural changes in the marine ecosystem, and may indirectly affect the recruitment of other commercially important species. Likewise, Kaiser *et al*. (1998) suggest that the settlement of benthic species may be reduced in areas of high bivalve densities because the larvae are filtered out and digested by adult bivalves. Shellfish farming has been reported to affect shore birds through loss of habitat, reduction in intertidal feeding area, and disturbance of breeding populations, although limited scientific data are available to support these reports (Gowen, 1991; Kaiser *et al*., 1998).

Positive effects of shellfish aquaculture on wildlife have been listed by Rosenthal (1994), including enhancement of wild shellfish fisheries in the vicinity of shellfish farms due to high densities of spawning bivalves significantly increasing local recruitment. For example, cultured scallops which spawn during the grow-out period can contribute to recruitment of wild stocks. Other positive aspects include the provision of stock for enhancement of marine and fresh waters, and the protection and conservation of endangered species (Rosenthal, 1994). Aquaculture of tropical giant clams of the genus *Tridacna* has prevented the possible extinction of larger species in several regions of the IndoPacific. Stock enhancement has also occurred throughout much of the natural range to increase stocks severely depleted by poaching and overfishing, and to establish new breeding populations (Lucas, 1994). Another positive aspect of shellfish culture reported by Kaiser *et al* (1998) is the provision of hard substrata, including culture infrastructure and shells on the bottom, for attachment and shelter of other marine organisms.

5.4 Introduction and translocation of new species

Intentional introductions of shellfish around the world, such as the Pacific oyster *Crassostrea gigas*, have occurred to establish new commercial fisheries or to replace existing native fisheries in serious decline, and have been the basis of multimillion dollar industries in many countries, e.g. Australia, New Zealand, USA, France, Ireland, (Chew, 1990; Reise, 1998).

The economic advantages have been enormous; however, there have also been environmental impacts, many of which have been detrimental.

Several reviews have been conducted on introductions of shellfish species for aquacultural purposes, (e.g. Andrews, 1980; Chew, 1990), particularly in relation to the introduction of Pacific oysters into new regions (e.g. Coleman, 1996; Shatkin *et al*., 1997). These reviews document detrimental effects of shellfish introductions including changes to biodiversity and habitat type within the receiving system as a result of the establishment and spread of the exotic species, introductions of pests and diseases associated with the shellfish, and alteration of genetic stocks. Most information is available on the Pacific oyster which has been introduced to, and established on, all major coasts of the Northern Hemisphere (except the North American Atlantic Coast), the west coast of South America, South Africa, New Zealand and south-eastern Australia.

Although the introduction of Pacific oysters has resulted in economically successful aquaculture industries in a number of countries, it has also contributed to the decline of wild oyster fisheries and culture of endemic flora and fauna. In New South Wales, Australia, the Pacific oyster has been declared a noxious species (except in Port Stephens) because it can settle on Sydney rock oysters (*Saccostrea commercialis*) and affect the farming of this native oyster (Davis, 1996). The importation of Pacific oysters into France from Japan is thought to be responsible for the demise of the Portuguese and flat oysters due to the associated introduction of viruses which affected these species, but not the Pacific oyster (Andrews, 1980; Shatkin *et al*., 1997). Similarly, the Japanese oyster drill (*Ceratostoma inornatum*), a predatory flat worm (*Pseudostylochus ostreophagus*) and the copepod parasite (*Mytilicola orientalis*) were introduced with the Pacific oyster on the USA west coast and have contributed to the decline in native oyster populations (Goldberg & Triplett, 1997).

However, not all introductions have had negative consequences. The Manila clam, *Venerupis japonica*, inadvertently introduced with Pacific oyster seed to the western seaboard of North America has resulted in a major fishery, with significant economic advantages (Andrews, 1980; Chew, 1990). Also, no environmental effects of Pacific oysters have been reported in Chile ten years after the first production record for this species (Buschmann *et al*., 1996).

Introductions of shellfish species have also altered the physical environment, and consequently community composition. In British Columbia, Canada, Pacific oysters introduced for commercial culture spawned and established dense oyster reefs which, because of their biodepositional activities, ‘profoundly modified regions that previously did not support large filter-feeding populations’ (Bernard, 1974).

In recent years tighter protocols for the movements of species around the world have been instigated. A ‘Code of Practice’ for the introduction of nonendemic species, developed by the International Council for the Exploration of the Seas (ICES), has been adopted by many countries around the world (Sinderman, Steinmetz & Hershberger, 1992). This Code of Practice requires that the species being considered for introduction is studied in its native habitat for known pests, diseases, predators, and its biological characteristics such as genetic makeup is also considered. Only broodstock is introduced into quarantine facilities in the recipient country, and only the F1 offspring released into open waters after comprehensive testing of the F1 seedstock to ensure no diseases or pests. This new code of practice should reduce the risks associated with introductions and translocations. For example, Pacific oysters were introduced to the United Kingdom using the ICES Code of Practice, and no new pathogens or pests have been detected in conjunction with the oysters (Shatkin *et al*., 1997).

Genetic impacts of transferring bivalve stock from one region to another have generally not been addressed. *C. gigas* has hybridised with *C. virginica* in the laboratory; however, the only potential impact of interaction between the two species is reduced reproductive success because their gametes can combine to produce nonviable progeny ((Shatkin *et al*., 1997). Because much of the seed stock for shellfish farming around the world is still collected from the wild, aquaculture is having minimal impact on genetic diversity of wild shellfish stocks. However, as hatchery production of seed increases, the potential to alter the genetic characteristics of wild stocks will increase.

5.5 Chemical usage

Although the use of chemicals is generally much lower for shellfish than finfish culture, chemicals have been used in overseas shellfish farming for a variety of purposes. Antibiotics are used in some shellfish hatcheries to improve the survival rate of larvae, although the extent of antibiotic usage is difficult to gauge because this information is not readily available from commercial hatcheries (Kaiser *et al*., 1998). Pesticides have been used to control predators of shellfish or organisms that disturb shellfish farming habitat. For example a carbamate insecticide is widely dispersed by aerial spraying over the intertidal area used for Pacific oyster bottom culture in Washington state, USA, to destroy burrowing shrimps which disturb the seabed and smother the oysters (Simenstad and Fresh 1995). According to Goldberg and Triplett (1997), this application of insecticide is controversial. Proponents claim that spraying of insecticide which only occurs every 6 years helps stabilise the seabed and promotes increased biodiversity (Bill Dewey, pers. comm. 1999). However, opponents claim that that the insecticide indiscriminately kills other marine life, including the Dungeness crab which is commercially fished in the area (Simestad and Fresh 1995).

Nutrients, such as superphosphate and ammonium nitrate, are periodically added to earthen ponds and enclosed intertidal areas to stimulate phytoplankton production for oyster nurseries. Some aquaculture construction materials may also release chemicals into the environment, such as plastic additives and heavy metals (GESAMP 1991). The effects of many of these materials are unknown and few standards exist to regulate construction materials used in aquaculture.

6. Environmental Impacts in the Tasmanian Context

Several important differences exist between shellfish culture in Tasmania and other parts of the world.

6.1 Production Levels in Tasmania Compared with Other Countries

As shown in Tables 1 and 2, the production of shellfish in Tasmania is very small by world standards. The annual yield of Pacific oysters in Tasmania is 0.07% of the world production. It is less than 2% of Pacific oyster production in each of France and the USA, and less than 0.5% of the Japanese production. Mussel yields in Tasmania are considerably lower, at 0.05% of the total production from Europe.

There are two main reasons for the comparatively low shellfish production in Tasmania. Firstly, as discussed earlier, the nutrient concentrations, and hence food supplies, are much lower in Tasmanian waters than many other shellfish growing areas. Thus shellfish in Tasmania are generally cultured at much lower densities. Secondly, large expanses of protected intertidal areas suitable for shellfish culture, such as the Wadden Sea in Western Europe and the Marennes-Oleron Bay in France, do not exist in Tasmania. Intertidal oyster growing areas In Tasmania are scattered around the coastline, and most bays or estuaries contain less than 100 ha of productive shellfish farms.

6.2 Densities of cultured shellfish

Comparisons of stocking densities or production per area between major shellfish growing areas around the world are difficult because densities are expressed in different ways, such as numbers (or weight) per culture area, which can be numbers per raft or area of racking, and may, or may not, include the area between culture structures. The total number of shellfish farms in a bay or growing area is also often not supplied, even though this can have a major effect on shellfish production.

Nevertheless, some comparisons were possible for mussel culture and examples of average annual production in kg m^{-2} y^{-1}, calculated from the information provided in the literature, are given in Table 4. Mussel farming in Spain occurs at a much higher density than in other countries, largely because of high concentrations of phytoplankton in the nutrient-rich upwelling waters of the western coast. Figueras (1989) described mussel culture rafts of average size 18 m x 18 m and 600-700 ropes per raft, with an average density of mussels of 250-270kg m^{-2}. At these concentrations in 1989 the mussels reached market size in 12-18 months.

Table 4. Average annual production (kg m^{-2} y^{-1}) from mussel farms in different regions of the world.

Country	Farm area m2	Time to harvest (mo)	Density / Production kg m^{-2}	Production kg m-2 y-1	Reference
Sweden	1500	14-17	53-80	51.3	Folke and Kautsky (1989)
Sweden	4500	19	36	22.7	Rosenberg and Loo (1983)
Canada	4000	<24	12	~6	Grant (1995)
Spain	324	12-18	250-270	208	Figueras (1989)
Tasmania	10,000	18	1.5-2.4	1.4	Schroeter (pers. comm.)

Mussel farms in Tasmania generally consist of 3 double backbones per hectare, and produce on average 15 -18 metric tons. A few have 4 backbones producing 20-24 tons per hectare. Thus the density of mussels at harvest is around 1.5 - 2.4 kg m^{-2}, and time to harvest from small spat is about 18 months (Graham Schroeter, pers. comm.). As shown in Table 4, density of mussels in Tasmania is much lower than that recorded elsewhere.

Similarly, the production of Pacific oysters is also relatively low. Generally, production from intertidal farms is around 5.5 - 10 oysters m^{-2} and time to harvest from spat is 18-24 months (Colin Dyke, pers. comm.). An economic assessment of the Tasmanian Pacific oyster industry by Morrow (1993), based on a survey of oyster farmers in south eastern Tasmania, assumed a standard production unit of 3 km of rack per 5 ha which produced 18 000 dozen oysters per km annually, i.e. 13 oysters m^{-2} y^{-1}. An unpublished report on the economic potential of farming Pacific oysters in Victoria used data from Tasmanian oyster growers and provided production rates of from 7.1 - 17.2 oysters m^{-2} for intertidal culture, and 17.2 - 21 oysters m^{-2} for subtidal culture (Davis, 1996). However, these subtidal production figures are considered to be too high by some Tasmanian farmers, and about 12 oysters per m^{-2} per annum is more common (Michael Cameron, pers. comm. 1999). The average combined subtidal production of oysters and mussels in Tasmania has been estimated at approximately 7 tonnes per developed hectare, reaching a maximum in some areas of 24.5 tonnes per developed hectare

(DPIWE unpublished report, 1999). These production levels are low compared with many areas overseas.

Many studies of the effects of shellfish farming on the environment have been conducted in areas of much higher production than in Tasmania, both in terms of the area under production and the density of cultured shellfish, e.g. Tenore *et al*. (1982) in Spain, and (Dahlbäck and Gunnarsson (1981) in Sweden. Thus, the cumulative impact on the environment would be expected to be significantly greater than in Tasmania.

6.3 Lack of Traditional Culture

Most shellfish producing countries have a strong tradition of shellfish culture with farming methods established at least a century ago. By contrast, shellfish farming is a relatively new enterprise in Tasmania, having first become established on a small scale in the 1970's. As a consequence, innovative farming methods have been developed in Tasmania which are based on efficiency and a better understanding of environmental management practices than occurred in the 1800's or early 1900's. All commercial shellfish culture in Tasmania is from artificial structures, either some form of racking in the intertidal zone or long lines in deeper water. Thus there is limited physical disturbance to the seabed compared with reseeding the bottom and harvesting by dredging.

An example of traditional farming methods which cause major change to the environment is from the state of Washington, USA where the intertidal zone is cultivated by tractor, sprayed with an insecticide to kill the burrowing shrimp, and the oysters are harvested by dredging (Simenstad & Fresh, 1995).

Harvesting oysters by dredging, either for recreational or commercial purposes currently does not occur in Tasmania. Extensive harvesting of wild stocks of flat oysters ceased over a century ago and most Tasmanians are now not aware that massive beds of native oysters once existed in Tasmania. By contrast, there is still a strong tradition for recreational harvesting of the Eastern oyster along the eastern seaboard of the USA. For example, in North Carolina the state government funds maintenance and enhancement of public oyster beds for recreational harvesting (Gottlieb and Schweighofer 1996). Although harvesting by dredging has assisted in the massive decline in population numbers, there is still a strong call for this traditional practice to continue. Likewise, in Europe traditional practices of collecting seedstock and harvesting by dredging occur in many regions (Kaiser *et al*., 1998) .In Tasmania, the wild scallop fishery that occurred in the D'Entrecasteaux Channel and collapsed in the 1950-60's has many similarities with the Eastern oyster fishery in that it was both a commercial and a recreational dredge fishery with strong cultural traditions, and the environmentally detrimental dredging practices had a major influence on the demise of the fishery.

This combination of new technology developed in an era of greater environmental awareness and off bottom culture is likely to have reduced the detrimental effects of shellfish culture on the Tasmanian environment compared with many Northern Hemisphere shellfish farms.

6.4 Management of marine farms

Management Controls, which are enforceable under the Tasmanian Marine Farming Planning Act (1995) and effectively regulate the stocking densities of cultured shellfish, are described in the Marine Farming Development Plans for Tasmania (available at http://www.dpif.tas.gov.au/domino/DPIF/Fishing.nsf).

A general Control for all Shellfish Marine Farming Zones is:

'*There must be no unacceptable environmental impact outside the boundary of the marine farming lease area. Relevant environmental parameters must be monitored in accordance with the requirements specified in the relevant marine farming license.*'

Environmental Controls relating to carrying capacity of shellfish include:

(i) *'In all new lease areas used for the intertidal farming of oysters there must not be more than 1 km of stocked racking per hectare of lease area. When racking is next replaced in all existing lease areas used for the intertidal farming of oysters there must not be more than 1 km of stocked racking per hectare of lease area.*

(ii) *Containers of oysters in intertidal lease areas must be clear of the seabed and there shall be no layering of containers on the racking.*

(iii) *In all new lease areas used for deepwater farming of shellfish there must not be more than 1.1 km of effective backbone longline per hectare of lease area. When longlines are next replaced in all existing lease areas used for deepwater farming of shellfish there must not be more than 1.1 km of effective backbone longline per hectare of lease area.*

(iv) *All longlines and associated equipment for filter feeding shellfish must be maintained clear of the seabed.'*

These management controls were developed from voluntary practices adopted by oyster farmers in Pipe Clay Lagoon. They were instigated to minimise environmental impacts of shellfish farms and to assist in maintaining production levels within the carrying capacity of coastal waters. A major advantage of these management controls is that it is easier to monitor the length of racking or longlines on each lease compared with controlling numbers or densities of oysters.

Little information was found in the literature on stocking density controls implemented in other countries, and from personal discussions with government regulators, in many places they don't exist. An aquaculture project in Europe, MARAQUA, has been reviewing current and proposed licensing, regulatory and monitoring guidelines and procedures for marine aquaculture in Europe, and this information should be available in 2001 (MARAQUA NEWS, available at http://www.biol.napier.ac.uk/maraqua). In South Australia the permissible density of Pacific oysters is 100,000 production size oysters (70-80mm) or its weight equivalent per hectare (Hone, 1996). This is similar to the densities provided by intertidal and subtidal oyster farmers in Tasmania of 10-12 oysters m^{-2} (Colin Dyle and Michael Cameron, pers. comm).

6.5 Impacts on the seabed

6.5.1. Organic enrichment

Effects of shellfish farming on the environment have been examined at four intertidal Pacific oysters farms in Tasmania, at Pittwater, Pipeclay Lagoon, Little Swanport and St Helens, by Thorne (1998). Overall, environmental conditions and benthic community structure showed greater variation between farm sites than between culture and reference areas at each site, (although reference sites were located close to farms and weren't replicated). Thorne (1998) concluded that shellfish farming appeared to be having little effect on the environment. Current velocity, flushing times, average high tide levels and organic carbon content were the main environmental variables that differed between the farm sites. Nevertheless, subtle differences in environmental conditions between culture areas and reference sites at each farm location were apparent. Organic carbon content of the sediment was consistently higher within each farm (mean 2.32%) than at nearby reference sites (mean 1.62%), but these values were generally low compared with shellfish farms overseas. The diversity and abundance of species was generally higher in the oyster culture areas than at reference sites, which suggests low levels of organic enrichment at the culture areas (Pearson & Rosenberg, 1978).

Biodeposition rates of Pacific oysters were investigated on a 10.3 ha farm at Pipeclay Lagoon by Mitchell (2001) by collecting biodeposits in sediment traps under baskets of oysters in summer 1995 and winter 1996. Oyster densities in the baskets were approximately 23 kg m^{-2}, and over the whole lease area were approximately 1.0 -1.7 kg m^{-2}. The mean daily rate of deposition of faeces and pseudofaeces varied from 39.6 g dry weight (DW) $m^{-2}\,d^{-1}$ in winter to 180.5 g (DW) $m^{-2}\,d^{-1}$ in summer, and natural sedimentation was measured at 7.3 - 8 g (DW) $m^{-2}\,d^{-1}$. Average daily deposition rates from the entire lease area were calculated to be approximately 494 kg DW d^{-1} in summer and 185 kg (DW) d^{-1} in winter (Mitchell, 1999). The organic matter content of the sediments was low (1.9 - 2.5%) and Mitchell (2001) concluded that the biodeposits were most likely being transported from the lease area and deposited or utilised elsewhere.

The effects of shellfish culture on the Tasmanian marine environment is currently being investigated by a joint project between the Tasmanian Aquaculture and Fisheries Institute and the Tasmanian Oyster Research Council. The benthic environment around three new longline shellfish farms and associated reference sites has been comprehensively surveyed before farming commences to provide detailed baseline data from which changes due to shellfish farming activities can be later assessed. Similarly, the benthic environment was investigated at three existing longline farms which have been in production for many years. Conditions under the farm were compared with those at sites outside the lease area to determine if there was a gradient of effect from outside to within the farm. The sediment chemistry and benthic biota were examined, and bottom conditions were recorded on video tape. Preliminary results indicate overall limited impact, with significant differences between farms but not between sites inside and outside the lease area.

6.5.2. Physical Impacts

Although effects of racking on the hydrodynamics of shellfish growing areas have been observed in some culture areas in Tasmania, such as accumulation of sediment under racking at some farms in the D'Entrecasteaux Channel and in Port Sorell, these environmental changes have rarely been documented. Thorne (1998) observed a build up of sediment around oyster racking at Pipeclay Lagoon, and proposed that the sediment accretion may be due to the culture infrastructure modifying the current velocity and direction of water movement. Alternatively, it may result from tractors building up sediment when they are driven between the racks during maintenance and harvesting. However, the effect of sediment movements due to shellfish culture has generally not been problematic in Tasmania. Regular maintenance of shellfish farms has also been observed to minimise physical impacts.

Currently no shellfish are cultured in Tasmania by reseeding the bottom and harvesting by dredging. Scallop reseeding was conducted in Great Oyster Bay in the 1980's and 1990's, but problems were encountered, in particular heavy predation on reseeded scallops. Farmed scallops are currently being ongrown on longlines, however, a large lease area for scallop reseeding is still available, and this could occur again (Scott Crawford, pers. comm., 1999). Effects on the environment of harvesting by dredging have not been investigated in Tasmania. However, a study conducted in Port Phillip Bay, Victoria, using similar dredging gear to that used in Tasmania showed detrimental effects on the benthic and infaunal invertebrate community (Currie & Parry, 1996).

Culture of clams by seeding areas in the intertidal zone and harvesting manually by hand or rake is being investigated on a small scale in Tasmania and is not presently having a major impact on the environment. This experimental fishery is under close scrutiny by Government regulators, and current indications are that clam farming is not likely to expand because of poor spat supply due to sporadic recruitment and little success in hatchery production of spat. However, if commercial scale farming of clams by this method does develop, some impact on the intertidal area of several popular recreational areas in Tasmania, such as Ansons Bay and Cockle Creek, could be expected. Mechanical harvesting would likely have a greater effect on the ecology of the area than harvesting by hand. Populations of wading birds also may be affected.

Concerns about the effects of shellfish culture on seagrass beds in Tasmania have been expressed by the general public during the preparation of Marine Farming Development Plans (Tony Thomas, pers. comm. 2000). Shading by the shellfish and farm infrastructure, and farm activities such as boats and vehicle traffic may damage or destroy seagrass on the farms. However, effects of shellfish farming on seagrass beds have not been specifically investigated in Tasmania. The potential for permanent loss of seagrass is much higher in northern Tasmania and around the Furneaux group of islands because the main seagrass found there, genera *Posidonia*, have taken decades to recolonise, if at all, after die off in other parts of Australia. By contrast, the main species in southern Tasmania, *Heterozostera tasmanica*, naturally cycles in abundance and can rapidly regenerate (Hamdorf & Kirkman, 1995).

Thorne (1998) observed a reduction in sea grass (presumably *Heterozostera tasmanicus*) cover under oyster racks at St. Helens and Little Swanport compared with the cover at reference areas 150m away with no racking. He suggested this might be due to erosion and shading effects of the racks. He also noticed that the seagrass cover beneath unstocked racks was similar to the cover between racks. Because racks are rarely left unstocked for any length of time, Thorne (1998) surmised that sea grass can recover quickly from any damage caused by oyster culture.

As part of the environmental assessment of proposed marine farming zones, several growing areas with existing shellfish farms and sea grass beds have been examined. Generally sea grass beds in Blackman Bay and Little Swanport have shown little evidence of disturbance from shellfish farm activities, except for areas directly underneath racks. The seagrass beneath baskets of oysters were thought to be affected by shading (Mitchell, Crawford & Brown, 1999).

6.2. IMPACTS ON THE WATER COLUMN

The effects of shellfish farming on nutrient cycling and phytoplankton dynamics in Tasmanian estuaries has not been thoroughly investigated, largely because of the costs involved in this type of research. However, data have been collected on the nutrient and phytoplankton concentrations in several shellfish growing areas as part of a study to develop models of carrying capacity (Crawford *et al*., 1996). Generally, nutrient and chlorophyll *a* concentrations were low, and chlorophyll a levels were mostly in the range of 1-2 mg/l. In some estuaries, e.g. Pittwater, the carrying capacity was believed to have been reached, or even exceeded in certain years, because the shellfish were taking almost twice as long to reach market. Phytoplankton and nutrient cycling of the Huon estuary in relation to finfish farming has been investigated by CSIRO, but shellfish farming was not generally included.

A Ph.D. study by Brian Cheshuk in North West Bay investigated the effects of salmon farming on the growth of cultured mussels. He found little difference in the growth of mussels on longlines 70-100 m from the salmon cages to those at a reference site further away (1200 m). There was also no detectable difference in particulate matter or chlorophyll *a* levels between the farm and reference site. This similar growth rate of mussels at the salmon farm and the reference site was attributed to the particulate matter from the salmon farm being dispersed and rapidly diluted to undetectable levels. Also, natural food levels were considered to be above the satiation level of the mussels so animals were not food limited (Cheshuk, 2000).

6.3. Effects on Wildlife

Pacific oysters are described in the Sustainable Development Advisory Council (1996) State of the Environment Tasmania report as the basis of a successful aquaculture industry, but have become established in many estuaries, and 'are probably out-competing native species, although they may provide protective habitats for other invertebrates'. The impact of Pacific oysters, however, is difficult to determine because of an absence of baseline data before they were introduced.

A project recently completed at the Tasmanian Aquaculture and Fisheries Institute with supporting funding from the National Heritage Trust has attempted to redress this lack of information. The ecological effects of feral Pacific oysters were investigated from field surveys and manipulative studies of wild oysters at several sites around Tasmania over a two year period. Preliminary results from two areas with dense feral populations, at Port Sorell and the Tamar River, have shown a reduction in species diversity and abundance within oyster beds compared to reference sites without oysters. This is thought to be due to increased deposition of fine sediments within the oyster bed smothering other fauna or making the habitat unsuitable. (Craig Munday, pers. comm., 1999). However, the presence or absence of oysters did not affect invertebrate communities on cobbles. Onn rock platforms the diversity of mobile invertebrates was positively correlated with the density of oysters, but not for sessile invertebrates. A new suite of species that wouldn't normally occur on open rock platforms was using the oysters as habitat (Craig Munday, pers. comm., 2001).

The time taken for Pacific oysters to reach market size and condition has significantly increased in one growing area in Tasmania, implying that food resources were limited. No obvious adverse effects on other phytoplankton feeders was observed, although no specific investigations were conducted. The stocking density of cultured oysters in the area was subsequently reduced.

Parks and Wildlife Service in DPIWE have highlighted the potential for tractors driving across intertidal oyster leases, such as at Pipeclay Lagoon, to affect intertidal invertebrate communities through physical crushing and/or compaction of air spaces. However, they have not studied this in detail (Stewart Blackhall, pers. comm. 1999).

6.4. Introductions and Translocations

Past introductions of oysters into Tasmania have impacted on the environment by the establishment and spread of new species inadvertently introduced with the oysters. Oysters from New Zealand, mainly *Ostrea lutaria*, were marketed live in Tasmania in the early 1900's and are thought to have been the host for the introduction of several species, including seastars *Patiriella regularis* and *Astrostole scabra* (Sumner 1974)**.** *P. regularis* is now dominant in the Port of Hobart and has probably outcompeted native seastars. The Rosy Screw shell, *Maoricolpus roseus*, from New Zealand also was first recorded in the Derwent estuary at this time and has subsequently become extremely abundant around the Tasmanian coastline (Turner, unpublished report). Other species which are native to New Zealand but have been recorded in Tasmanian waters for most of this century include *Amaurochiton glaucus, Petrolisthes elongatus, Cancer novaezelandie,*and *Venerupis largillierti* (Furlani, 1996). They were also possibly introduced with imports of New Zealand oysters. However, there are no reports of other species being introduced with the Pacific oyster when it was introduced into Tasmania approximately 50 years.

The distribution and abundance of feral Pacific oysters around Tasmania and associated environmental conditions have recently been investigated by the Tasmanian Aquaculture and Fisheries Institute with financial support from the National Heritage Trust (Mitchell, Jones & Crawford, 2000). This research found that Pacific oysters were widely distributed around the

Tasmanian mainland, occupying a wide range of habitats and attached to a broad range of substrate types. The main factors restricting settlement, regardless of substrate type, were high exposure and fetch. High wave action appears to either prevent settlement or result in dislodgement. Because Pacific oysters were deliberately translocated to many areas around Tasmania in the 1950's, it was not possible to determine whether feral populations have stemmed from these intentional introductions or from Pacific oyster farms. No correlation was found between densities of feral Pacific oysters and location of shellfish farms (Mitchell *et al*., 2000).

Both shellfish farmers and environmental groups have expressed concern about potential transfers of introduced pests around the State with the movement of shellfish between farms. The toxic dinoflagellate, *Gymnodinium catenatum* has had a major impact on shellfish aquaculture in some areas because shellfish which consume this dinoflagellate accumulate toxins in their flesh and become unfit for human consumption (Hallegraeff & Bolch, 1991). Farms are closed for sale of shellfish during blooms under the Tasmanian Shellfish Quality Assurance Program. *G. catenatum* has been largely confined to the D'Entrecasteaux Channel and Derwent River, although its range has spread to eastern side of Bruny Island and Norfolk Bay. It can be relatively easily dispersed through viable dinoflagellate cells or resting cysts in the guts and faeces of oysters Oyster farmers in southern Tasmania have voluntarily agreed to restrict the movement of shellfish between growing areas when toxic dinoflagellates are abundant.

Undaria pinnatifida, a seaweed introduced from Japan, has recently increased its distribution from the Tasmanian east coast to the D'Entrecasteaux Channel, and movements with shellfish translocations are one possible mechanism for range expansion (others include transport on the hull of boats or amongst fishing gear). Other introduced species which have the potential to be dispersed around the state during shellfish translocations, and can affect survival of cultured shellfish as well as many endemic species, include the Japanese sea star *Asterias amurensis* and the European shore crab *Carcinus maenas*.

The potential for the transfer of exotic species along with shellfish movements may decline, however, with the implementation of the new National Policy for the Translocation of Live Aquatic Organisms (available at http://www.brs.gov.au/translocation.html).

6.5. Chemical Usage

Chemical usage on shellfish farms in Tasmania is minimal. Chromium, copper and arsenic treated pine is generally used for intertidal racking but elevated levels of heavy metals have not been recorded in farmed shellfish due to the high pressure marine standard treatment for this pine (TAFI, unpublished data).

7. SUMMARY OF BENEFICIAL AND DETRIMENTAL EFFECTS OF SHELLFISH AQUACULTURE ON THE ENVIRONMENT

7.1. Effects of shellfish farming in other countries

The positive and negative impacts of shellfish farming on the environment based on the overseas literature are summarised below. However, it is important to emphasis that many effects on the environment are site specific. Detrimental effects in many instances are due to the aquaculture operation being located at an unsuitable site, such as low current flow. They are also dependent on the scale of the activity, so low production in a bay may have minimal impact, whereas high production can have major effects. Similarly, the husbandry practices employed can significantly affect the level of impact on the environment.

Beneficial effects of shellfish aquaculture :

- reducing the sediment loads and turbidity of estuarine and coastal waters
- removal of excess nutrients from the water column
- enhancement of depleted wild stocks of shellfish
- conservation of endangered species
- increased monitoring of the environmental conditions of estuaries and coastal waters

Detrimental effects of shellfish aquaculture :

- organic enrichment of the sediment around shellfish farms
- reduction in food supplies for other filter feeding organisms
- habitat alteration and degradation
- introduction and spread of pests and pathogens

7.2. BENEFICIAL AND DETRIMENTAL EFFECTS OF SHELLFISH AQUACULTURE IN TASMANIA

An important benefit of shellfish aquaculture to the Tasmanian environment is the regular monitoring of shellfish growing areas for bacterial levels and biotoxin concentrations, as part of the requirements for ensuring high quality shellfish safe for human consumption. Surveys are also conducted for point and diffuse sources of pollution into estuaries and coastal waters, and the shellfish are periodically tested for heavy metal concentrations. This monitoring program, the Tasmanian Shellfish Quality Assurance Program (TasQAP), provides the only long-term ongoing monitoring of the health status of many estuaries around Tasmania. It has been in operation since 1984 and is largely funded by industry. The TasQAP has been instrumental in detecting and raising awareness of high levels of faecal coliform bacteria, of both human and animal origin, in estuarine and coastal waters. This has resulted in improved treatment of sewage and disposal of farm animal wastes by several municipal councils.

Other benefits include the potential for scallop aquaculture to enhance wild scallop stocks. Spawning of cultured animals could result in the establishment of new beds of wild scallops when the right environmental conditions are present.

Shellfish farming may also improve water clarity and reduce nutrient and phytoplankton concentrations in some areas. Increased turbidity and sedimentation since European settlement is common in many Tasmanian estuaries used for shellfish farming, and the cultured shellfish would assist in the deposition of fine sediment particles and the reduction of phytoplankton and detritus concentrations in the water column. Additionally, native flat oyster densities in Tasmanian estuaries and coastal lagoons are now much lower that those that naturally occurred in the early 1800's. Cultured Pacific oysters would replace some of the filtering capacity of flat oysters, thus supporting the return of local waters towards their natural pristine state. However, Tasmanian waters generally do not reach the eutrophic levels of many estuaries overseas, such as Chesapeake Bay, so the beneficial effects of shellfish culture are not likely to be as substantial in Tasmania compared with overseas.

The reported (but not verified) increased abundance and number of species of fish and macroinvertebrates around some shellfish farms in Tasmania is considered by some to be a positive benefit of aquaculture. In particular, the higher abundances of fish and large invertebrates provide increased recreational fishing opportunities. These species are generally attracted to a shellfish farm because the farm infrastructure provides shelter and protection, and the shellfish biodeposits provide an additional food source. Shellfish consume phytoplankton which has been produced over a proportionately much larger area of water than on the farm, and then concentrate the waste organic matter in a much smaller area than would normally occur. This can result in a change to the ecology of the area because normally widely dispersed fauna congregate in one small farming location. However, it is difficult to assess the ecological significance of increased faunal abundance and diversity around marine farms, and generally there is no consensus of opinion as to whether such ecological change is positive or negative (Gowen, 1991).

Significant degradation of the benthic environment around shellfish farms in Tasmania due to organic enrichment of the seabed has not been obvious, although it has not been comprehensively investigated until recently. Environmental conditions around intertidal oyster farms have been found to vary more between farms due to the specific environmental characteristics of each site than levels of organic enrichment. Current research also indicates minimal organic enrichment of the seabed under longline shellfish farms

In shellfish growing areas where the carrying capacity of the system has been reached, as indicated by reduced growth and condition of the shellfish, there is likely to be some competition between filter feeders for the available food. Thus endemic filter feeding populations may be affected by reduced food supplies. However, farmers have generally reduced shellfish stocking densities when food has become limited to increase the growth rate of the cultured shellfish.

Alteration to the habitat does occur, particularly from intertidal racking which can redirect the flow of water. However, this is generally minimal, and oyster farming is not likely to continue in areas of unstable sediments because sediment accretion will eventually affect the oysters and erosion will make the racks unstable.

Inadvertent translocation of pests and diseases could occur with the movement of shellfish around the State, and if it occurred, could have a significant impact on the receiving environment. Effects could include reduced biodiversity and altered habitat. However, shellfish farming is only one of many vectors responsible for the movement of pests and diseases in the marine environment. Other means by which they could be spread include recreational and commercial fishing and sea transport, or by natural movements in inshore currents.

8. Qualitative Risk Assessment of the Effects of Shellfish Aquaculture in Tasmania

8.1 Ecological Risk Assessment Methodology

Ecological risk assessment methods were reviewed by Hayes (1997) who defined risk as:

‘the likelihood of an undesired event occurring as a result of some behaviour or action (including no action)’,

and risk assessment as: ‘the means by which the frequency and consequences of such events are determined’.

Hayes (1997) stressed that the assessment of risk is dependent on the assessment endpoints, which are ‘an expression of the values that one is trying to protect by undertaking the risk assessment procedure’. Because of the subjectivity associated with risk assessment, decisions regarding the acceptability of risk are part of the broader risk management process where political and socio-economic aspects are also considered.

According to Hayes (1997) there is no universal standard procedure for conducting ecological risk assessments, partly because of the complexity of issues involved. The USA Environmental Protection Agency established a framework in 1992 for ecological risk assessment which involves identifying the ecosystems at risk, evaluating the potential stressors and ecological effects, and selecting assessment endpoints. Data on ecological effects and response to exposure to stressors are analysed, and the risk is then characterised from the integration of information on exposure and effects, and an evaluation of the ecological significance of observed or predicted changes. However, this framework was not generally applicable for all ecological stressors, (chemical, physical and biological), because biological stressors are much more unpredictable, and the potential ecological effects are very complex (Hayes, 1997).

The Terms of Reference for this project required a qualitative analysis to be undertaken of the likelihood and significance of identified impacts associated with shellfish culture on the Tasmanian marine environment. Because of the subjective nature of risk assessment, it is important to clarify all aspects of the risk assessment process.

For this risk assessment, the Tasmanian marine environment is taken to be the estuarine and coastal waters where shellfish farms are located. Only risks which have the potential for adverse effects on the environment are assessed. These hazards (potential risks) have been identified from the overseas literature (see section 7.1).

The qualitative risk assessment is based on the 1999 edition of the joint Australian/New Zealand Standard for Risk Management. This Standard specifies the elements of the risk management process which can be applied to any situation where an undesired or unexpected outcome could be significant or where opportunities are identified (Australian/New Zealand Standards, 1999). The Standard is generic and independent of any specific industry or economic sector.

Risk management is defined by Australian/New Zealand Standards (1999) as ‘a logical and systematic method of establishing the context, identifying, analysing, evaluating, treating, monitoring and communicating risks associated with any activity, function or process in a way that will enable organizations to minimize losses and maximize opportunities'.

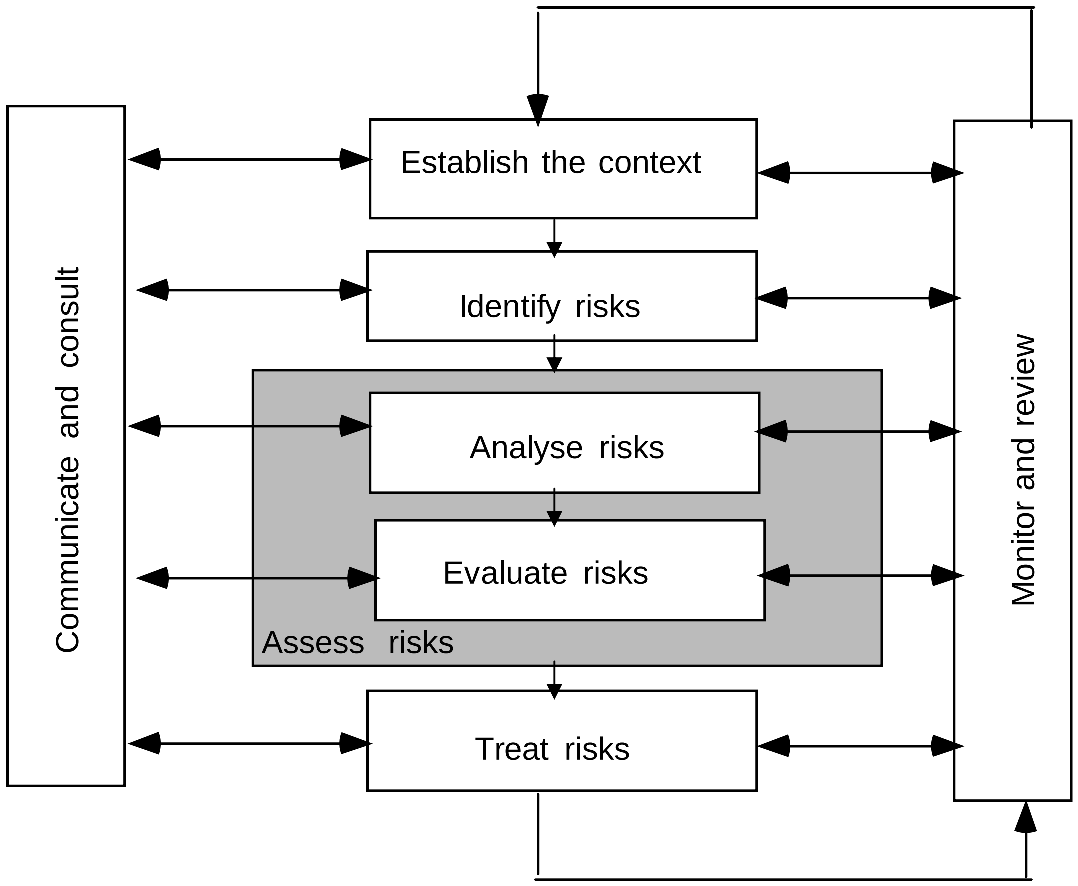

Fig. 1. The Risk Management Overview Process (adapted from Australian/New Zealand Standards, 1999)

The risk management process consists of several main elements as shown in Fig. 1. For this project on the assessment of the risk of detrimental effects of shellfish farming on the environment, only the first three elements of the risk management process have been included, i.e.

1. Establish the context - define the structure of the analysis.

This assessment was to qualitatively assess the risk of shellfish farming activities having a detrimental impact on the Tasmanian estuarine and coastal marine environment, based on levels of shellfish farming and impacts that have been recorded elsewhere compared with the Tasmanian situation.

2. Identify risks - identify what, why and how undesirable events arise.

Environmental hazards of shellfish farming activities include (see previous sections):

- organic enrichment of the sediment around shellfish farms
- reduction in food supplies for other filter feeding organisms
- habitat disturbance and degradation
- introduction and spread of pests and pathogens

3. Analyse risks - analyse risks in terms of their probable consequences and the likelihood of these consequences occurring, and combine consequences and likelihood to produce an estimated level of risk.

The risks have not been evaluated against pre-established criteria and have not been classified as acceptable or unacceptable.

8.2 Risk definition and classification

Under the Terms of Reference for this project, a quantitative analysis of the likelihood and significance of identified impacts is to be conducted.

Significance is defined in the New Shorter Oxford Dictionary, 1993 edition as:

1. (Implied or unstated) meaning, 2. Importance; consequence, or 3. The level at or extent to which a result is statistically significant.

For this project 'significance' is taken to mean the importance or consequence of an event, and the Australian/New Zealand Standards (1999) procedure of assessing likelihood and consequences of risk is adopted.

A classification of the levels of consequence, i.e. environmental harm, is difficult because of the complex nature of ecosystems. In order to evaluate the significance of change in a system, degrees of change, which are based on the scale of impact, need to be predetermined. However, few such standards for ecological change have been formulated. Also, there is generally no consensus of opinion on what degree of ecological change constitutes a negative impact (Gowen, 1991). Thus, to a large extent, the classification of levels of consequence is dependent on an individuals understanding and perception of detrimental ecological effects. For this reason, evaluation of consequences and likelihood by a multi-disciplinary group of expert is often recommended. A detailed description of the qualitative levels of consequences of shellfish farming that has been developed for this risk assessment is provided in Table 5. There are 4 levels, from 1 - Insignificant to 4 - Major.

The Likelihood of these consequence occurring has been assessed using the standard format from Australian/New Zealand Standards (1999), shown in Table 6. The level of likelihood ranges from A - Almost certain through to E - Rare.

These two measures, consequence and likelihood, have been combined in a qualitative risk analysis matrix developed by Australian/New Zealand Standards (1999), Table 7. This matrix ranks levels of risk based on the consequence and likelihood of a damaging activity as either L = low, M = moderate, H = high or E = extreme.

Table 5. Qualitative measures of consequence of shellfish farming.

Level	Descriptor	Detailed Description
1	Insignificant	Changes to the environment are not readily detectable and are short term.
2	Minor	Minor adverse environmental effects on and near the lease, including nonsignificant changes in species diversity and abundance of infauna and epibenthos.
3	Moderate	Medium environmental impact around the lease area, characterised by changed environmental conditions such as significant changes to species composition and abundance, reduced abundance of endemic species, lower sediment redox, reduction in growth and abundance of other filter feeders.
4	Major	Large and widespread environmental damage, major changes to biota and highly degraded physical environment, characterised by at least one of the following :anoxic sediments, infauna dominated by pollutant indicator species, low species diversity, epibenthic fauna very different to reference sites, loss of endemic species, major decline in abundance of other filter feeders.

Table 6. Qualitative measures of likelihood (from (Standards, 1999))

Level	Descriptor	Description
A	Almost certain	Is expected to occur in most circumstances
B	Likely	Will probably occur in most circumstances
C	Possible	Might occur at some time
D	Unlikely	Could occur at some time
E	Rare	May only occur in exceptional circumstances

Table 7. Qualitative risk analysis matrix - level of risk (from (Standards, 1999))

	Consequence			
	Insignificant	Minor	Moderate	Major
Likelihood	1	2	3	4
A (almost certain	H	H	E	E
B (likely)	M	H	H	E
C (moderate)	L	M	H	E
D (unlikely)	L	L	M	H
E (rare)	L	L	M	H

Legend: **E**: extreme risk, **H**: high risk, **M**: moderate risk, **L**: low risk

8.3 Level of Risk of Environmental Impact from Shellfish Farming in Tasmania

The assessment of levels of risk in Tasmania has been based on information available in unpublished thesis, on research currently in progress, on personal communications and observations, and on the level of production, stocking densities, and known husbandry practices in Tasmania compared to farm operations and levels of impact observed overseas. The shellfish culture activities presenting a risk and the characterisation of the levels of risk are presented in Table 8.

Table 8. Risk register for shellfish aquaculture.

Activity: Shellfish Aquaculture			
Risk	**Consequence Rating**	**Likelihood Rating**	**Level of Risk**
Organic enrichment of the sediment	**2**	**D**	**L**
Reduced food for other filter feeders	**2**	**D**	**L**
Spread of pests &/or pathogens	**3**	**C**	**H***
Habitat disturbance	**2**	**C**	**M**

* Also High risk due to other activities such as recreational and commercial fishing and sea transport.

Several marine pests have become established and proliferated in regions of Tasmania and could be inadvertently transferred to other parts of Tasmania during shellfish aquaculture activities. Both Pacific oysters and mussels are moved around Tasmania as part of standard culture procedures. Spat are either produced at hatcheries or collected from mussel seed collecting areas and transferred to marine farms around Tasmania for ongrowing. Pacific oysters may also be relocated to a more favourable growing area for final grow out to market size. The introduced pests, which have the potential to cause ecological and economic damage if they become established in new locations, include the Japanese seastar *Asterias amurensis*, the European shore crab, *Carcinus maenas*, the toxic dinoflagellate *Gymnodinium catenatum*, and wakame, *Undaria pinnatifida*. The likelihood of spread of these and other pests in Tasmania with movements of shellfish was considered to be possible, and the consequences were rated overall to be moderate. Thus the level of risk of spread of pests and diseases during shellfish aquaculture activities was determined to be high.

The toxic dinoflagellate, *Gymnodinium catenatum* has already had a major impact on shellfish aquaculture in Southeastern Tasmania because shellfish which consume this alga become unfit for human consumption, and farms are prohibited from selling shellfish during blooms. It can be relatively easily dispersed through viable dinoflagellate cells or resting cysts in the guts and faeces of oysters (Hallegraeff & Bolch, 1991). Oyster farmers in southern Tasmania have voluntarily agreed to restrict the movement of shellfish between growing areas when toxic dinoflagellates are abundant.

There is also a high level of risk that pests and diseases can be spread by other means, such as on commercial and recreational vessels for fishing and sea transport. The new Australian Commonwealth Government policy for the translocation of live aquatic resources should assist to minimise the risks of spread of pests and pathogens if it can be appropriately implemented in Tasmania. This policy requires a risk assessment to be conducted for all translocations of each species. A staged process is to be followed in the assessment of risk for each translocation, including addressing the likelihood and consequences of pests and diseases escaping/being released, surviving and becoming established.

The growth rate and condition of Pacific oysters has been observed to decrease in one Tasmanian oyster growing area over time, most likely due to the food resources becoming limited (Crawford *et al*., 1996). Thus endemic filter feeding populations may also have been affected by reduced food supplies. However, the oysters farmers in the area responded by voluntarily introducing lower stocking densities to increase the growth rate of the cultured shellfish. Shellfish farmers generally endeavour to keep stocking densities below the carrying capacity of the area so that annual production, and hence profits, per area are maximised. Thus, the potential for reduced food resources for other filter feeders in Tasmanian shellfish growing areas was rated as unlikely (could occur at some time). The consequences of reduced food supplies would be expected to be similar for all filter feeders, i.e. a reduction in growth rate and condition, and were rated as minor. The level of risk of depleting food resources for other filter feeders was therefore rated as low.

Because of the low shellfish stocking densities in Tasmania, the likelihood of accumulation of faeces and pseudofaeces causing organic enrichment of the sea bed was rated as unlikely (could occur at some time). Consequences of organic enrichment were ranked as minor because an unpublished study of the effects of several intertidal shellfish farms on the environment recorded relatively low levels of organic matter at the farms. Studies conducted in Europe and North America have also mostly shown minimal effects on the environment from organic enrichment, especially outside the culture areas. Thus there is a low level of risk of organic enrichment due to shellfish farming.

The likelihood of alteration of the habitat due to shellfish aquaculture was rated as possible because intertidal culture, in particular, can alter the benthic environment. Water movements, for example, can be changed due to the culture infrastructure, and can affect the sediment structure. However, the ecological consequences were considered to be minor, based on observations over several decades of shellfish farming in Tasmania. The level of risk of habitat disturbance was thus rated as moderate. However, changes to the habitat are generally localised, and unlikely to occur outside the area farmed. Thus the level of risk outside the lease area would be low. Habitat alteration under longlines should also be reassessed when the results from current research are available.

It should be noted that this risk assessment is based on shellfish farming occurring at a site suited to that type of aquaculture, i.e. appropriate current flows, water depths, away from the influence of other activities, and with industry standard management protocols. If a shellfish aquaculture operation is sited in an inappropriate location with inadequate farm practices, then the risk of detrimental environmental impact is much higher.

8.4 Risk Management Process

The next step to be conducted in the risk management process is risk evaluation whereby the levels of risk determined during the risk assessment are compared with any previously established risk criteria. The risks are then ranked in order of priority for management action. Evaluation of risks of environmental effects of shellfish aquaculture should take into account the wider context of risk and include economic and social aspects, as well as ecological aspects. If the levels of risk are low or acceptable, further treatment may not be required other than periodic monitoring. For other risk levels, the development and implementation of a specific management plan is recommended by Australian/New Zealand Standards (1999).

Monitoring and periodically review of all levels of risks are also recommended to ensure effectiveness of the risk management system.

Although the greatest risk to the environment from shellfish farming was shown to be the spread of introduced pests and/or pathogens, there is an equally high risk of spread with many other human activities in the marine environment. Thus, management of this risk would need to be considered in a much broader context than just shellfish farming.

This risk management process provides a framework for standardising the assessment and treatment of risks, and appears suited to a variety of aquaculture activities. In this example only a qualitative risk assessment was conducted, because of limited information on environmental conditions around shellfish farms in Tasmania. The objectivity of the risk assessment would be greatly enhanced by conducting a quantitative assessment, whereby levels of change are quantified, for example, as a percentage. Nevertheless, a qualitative risk assessment can play a very important role in identifying risks and documenting relevant data, rather than personal perceptions of environmental impact.

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