Potential effects of mussel farming on New Zealand's marine mammals and seabirds

A DISCUSSION PAPER

Department of Conservation
Te Papa Atawhai

Potential effects of mussel farming on New Zealand's marine mammals and seabirds: a discussion paper

Bryde's whale *(Balaenoptera edeni)* found dead after entanglement in a mussel spat catching farm, Great Barrier Island, August 1996. A spat catching line is caught around the whale's jaw and body. (Photo: Dan Woodcock)

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Cover: Underwater view of mussel growing lines. (Photo: Roger Grace)

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ABSTRACT

Mussel farming is an important and expanding industry in New Zealand. In the year 2000, there were nearly 3000 ha of mussel farms, with proposals for a further 39 000 ha including offshore farms of up to 4000 ha each. There have been no concerted attempts to investigate the effects of mussel farms on marine mammals and seabirds. However, there is growing evidence of adverse effects as these animals are in direct competition for space in the most productive coastal waters. Mussel farms deplete phytoplankton and zooplankton; modify the benthic environment, species assemblages, and local hydrodynamics; increase marine litter; and facilitate the spread of unwanted organisms. Thus, the establishment of mussel farms may lead to loss and degradation of wildlife habitat, either by exclusion or as a consequence of changes to the ecosystem. Thus far, the only adverse effects reported within New Zealand are the exclusion of dusky dolphins from mussel farms areas, and the entanglement and deaths of two Bryde's whales in mussel spat-catching lines. Because of the limited extent of mussel farms to date, effects on wildlife were dismissed as inconsequential. However, the proposed increase in the area used for mussel farming changes the scale of effects and prompts concern. The construction of large offshore farms across the seasonal migration routes of large whales is particularly worrying. An ecologically sustainable mussel farming industry requires a programme to monitor the industry's effects on wildlife and other forms of marine biodiversity. This report provides a resource to assist the mussel farming industry, coastal planners and researchers in the development of an ecologically sustainable industry.

Keywords: Environmental effects, green-lipped mussel, *Perna canaliculus*, sustainable aquaculture, threatened species.

1. Introduction

The decline, and in some instances, collapse of ocean fisheries stocks has encouraged rapid worldwide growth of aquaculture (Naylor et al. 2000). During the 10 year period 1987–97, global production of farmed fish doubled and now accounts for one quarter of all fish consumption (Food and Agricultural Organisation 1999). New Zealand's aquaculture industry is burgeoning, with aquaculture exports currently worth more than half a billion dollars a year and increasing 10% annually.

A wide array of marine species is cultivated within New Zealand, but the dominant species is the green-lipped mussel (*Perna canaliculus*), marketed using the trade-marked name Greenshell® Mussel. Chinook or king salmon (*Oncorynchus tshawytscha*) and Japanese or Pacific oysters (*Crassostrea gigas*) are also commercially important. Other marine species currently being farmed on a small scale, either commercially or experimentally, include: abalone or paua (*Haliotis iris*), rock lobster or crayfish (*Jasus edwardsii*), king fish (*Serolia lalandi*), mullet (*Mugil cephalus*), blue cod (*Parapercis colias*), seahorse (*Hippocampus abdominalis*), seaweeds and sponges. Cultivation techniques are being developed for: paddle crabs (*Ovalipes catharus*), snapper (*Pagrus auratus*), turbot (*Colistium nudipinnus*), tuna (*Thunus* spp.), cockles (*Austrovenus stutchburyi*), clams (*Panopea zelandica*) and scallops (*Pecten novaeselandiae*).

Green-lipped mussel cultivation in New Zealand has expanded massively since it began during the 1970s. In the year 2000, nearly 3000 ha of coastal waters were being used for green-lipped mussel cultivation, and there were proposals for a further 39 000 ha (Jeffs et al. 1999; Lupi 2001). Individual mussel farms have been relatively small (usually <50 ha) and restricted to sheltered inshore waters, but recent technological developments allow large mussel farms to be sited in exposed offshore waters.

A variety of environmental changes occur as a result of marine aquaculture (Kaiser et al. 1998; Cole 2001). It seems probable that these changes affect some of the seabird and marine mammal species dependent on the habitats within and around aquaculture areas. The effects on these species may be detrimental or beneficial. Casual observations indicate that marine aquaculture within New Zealand does affect marine mammals and seabirds. Oyster farms on intertidal flats reduce the area of habitat available for a wide range of wading birds. Salmon farms attract aggregations of Australian gannets (*Sula serrator*) and New Zealand fur seals (*Arctocephalus forsteri*). Gannet deaths result from plunge diving into netted enclosures on salmon farms. Shag species (family: Phalocrocoracidae) habitually roost on mussel farms. In the past, because of the limited extent of areas used for aquaculture, such effects have been dismissed as inconsequential. However, the proposed massive increase in area to be used for mussel cultivation changes the scale of any effects and prompts concern. In particular, the construction of large (2000–4000 ha) mussel farms up to 7 km offshore will extend mussel cultivation into areas used by offshore species (albatrosses, petrels, shearwaters, penguins, dolphins and whales) that have not previously encountered mussel farms.

In this report, a wide array of information on the green-lipped mussel industry and New Zealand's marine mammals and seabirds is presented and used to identify potential effects of mussel farming on marine mammals and seabirds. While this approach is not desirable, it was judged necessary because no research has been undertaken on the effects of mussel farming on marine mammals and seabirds, and consequently there is little reliable information on the topic. This report is intended to draw attention to the potential consequences of large-scale development of mussel farms on wildlife and to provide a resource to assist the mussel farming industry, coastal planners and researchers in the development of an ecologically sustainable industry.

2. Green-lipped mussels

2.1 BIOLOGY

Details are from Jeffs et al. (1999) and Alfaro et al. (2001).

The green-lipped mussel is an endemic New Zealand species, one of several species of mussel (bivalves, family Mytilidae) that occur naturally in New Zealand. Green-lipped mussels are found in a variety of coastal habitats throughout the country, but are most common in central and northern regions. The species is sometimes found in the inter-tidal zone, but is predominantly sub-tidal, occurring most commonly from below low tide level to a depth of about 50 m. It lives in a variety of habitats, anchored either to solid substrates, such as rocky faces or algal holdfasts, or forming clusters on sandy and muddy bottoms in sheltered embayments. The species frequently forms dense beds of up to 100 m^2. Green-lipped mussels feed on phytoplankton and other organic particles, which they filter from water as it circulates through sieve-like gills. The gills are particularly efficient at removing particles in the size-range 3–200 µm. Mucus on the surface of the gills binds the particles into strings. Sorting occurs, with particles suitable for consumption being ingested and the remainder expelled as mucus-bound deposits called pseudofaeces. Suitable food particles are digested and faeces ejected from the anus.

Green-lipped mussels are dioecious broadcast spawners. They begin to mature sexually from 27 mm shell length, and by 40–50 mm, most individuals are sexually mature. Female and male mussels are reproductively synchronized and have consistent gonad cycles of gamete development, discharge, and redevelopment. There is a prolonged spawning season from late spring to autumn, though a small proportion of mussels spawn throughout the year. Sexually mature female mussels produce up to 100 million eggs in a season. Within 48 hours of being fertilised in the water column, the eggs develop into tiny larvae. These drift for 3–5 weeks, feeding on microalgae and dissolved organic material. The larvae may drift several hundred kilometers before attaching themselves to a suitable surface with a byssus thread. Following primary settlement, the larvae, now called spat, often undertake a local post-settlement migration to recruit into an existing mussel bed.

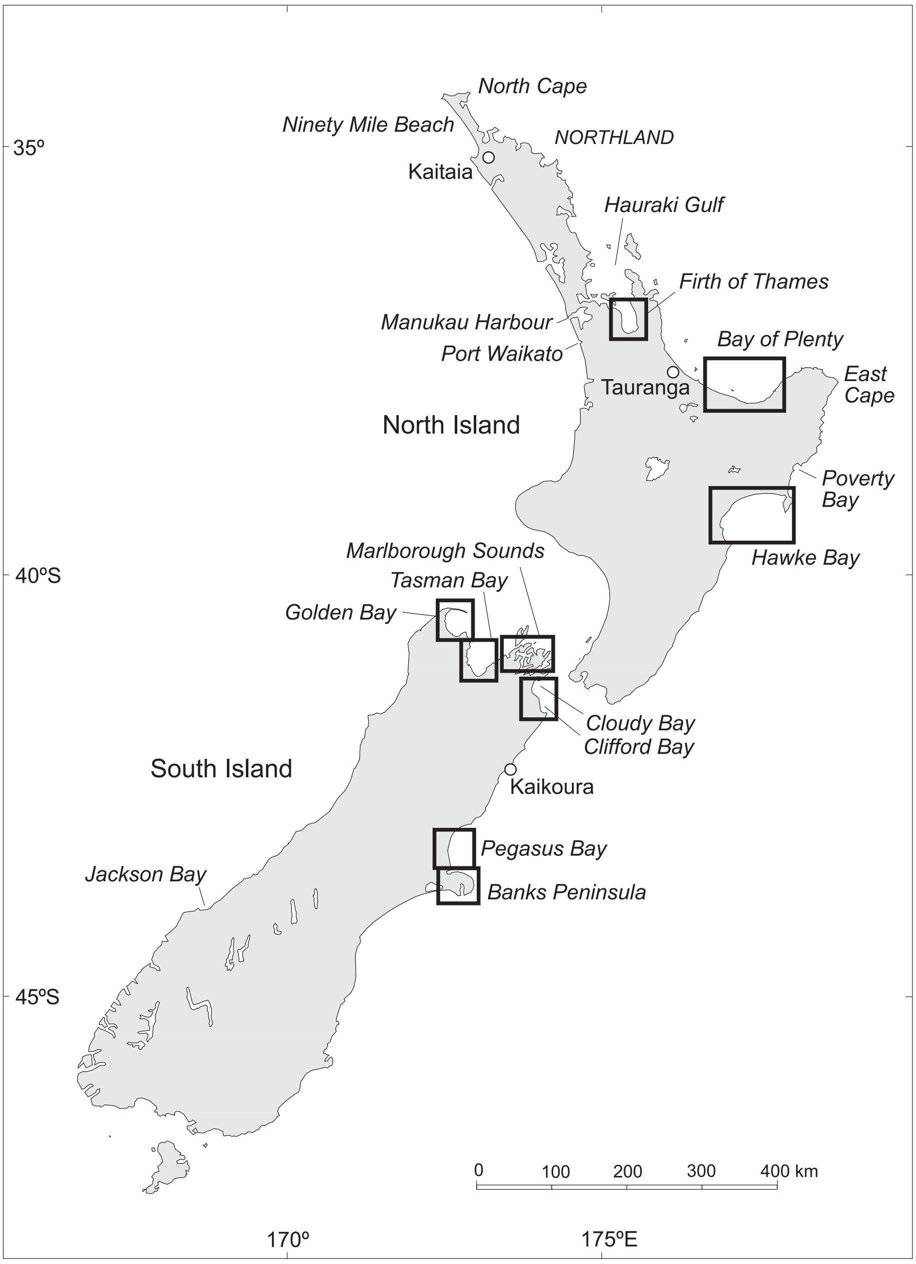
2.2 CULTIVATION

Details are from Jeffs et al. (1999), Lupi (2001), Robb & Davidson (2002) and Spencer (2002).

During the middle of the twentieth century extensive natural beds of green-lipped mussels in Hauraki Gulf, Marlborough Sounds and Tasman Bay (Fig. 1) were harvested commercially by dredging. At its peak, this dredge fishery produced 2 000 tonnes of mussels annually. By 1970, the mussel fishery had collapsed. This collapse led to the development of aquaculture methods for the species.

Mussel species belonging to the related genus *Mytilus* (predominantly *M. edulis*) have been cultivated in other parts of the world for hundreds of years, whereas cultivation of the green-lipped mussel is recent and is unique to New Zealand. Green-lipped mussel cultivation is undertaken using a double long-line

Figure 1. Map of New Zealand with place names referred to in text, and showing locations of detailed maps (Fig. 6).



method (Figs 2–5). A series of large plastic buoys (c. 1.4 × 0.7 m) are typically connected by two ropes (c. 30 mm diam.) to form a backbone, which is retained in place at each end via an anchor warp to either a large concrete block or an anchor (screw, or steel Danforth) embedded in the substrate. It is proposed that in large offshore farms sited in exposed situations, the buoys will be submerged 15 to 20 m below the sea surface to minimise wave action and reduce navigation hazards. Mussels are grown on ropes (c. 16 mm diam.) or droppers suspended from the backbone down into the water column in a series of loops, which hang under the weight of the mussel crop. The droppers are spaced about 1 m apart and, depending on the water depth, may extend down to 30 m, but are normally kept clear of the bottom. The backbones are positioned in parallel rows 15 to 20 m apart in sheltered inshore areas and 50 to 60 m apart in exposed situations.

Growing ropes are seeded with mussel spat. Most (80%) spat comes from Kaitaia, where spat from extensive offshore mussel beds settles on drifting seaweed that periodically washes up on Ninety Mile Beach, allowing easy harvesting of the spat. The remainder of the spat is collected in spat catching farms. The structures of these farms vary considerably. Typically, they resemble mussel farms on the surface. However, below the surface there is a second backbone rope holding spat catching lines, for spat to settle on, 15 to 20 m under water. Materials used for spat collection include plastic mesh and fibrous rope weighted to sink. Spat catching lines may be hung in rows or be wrapped around box-like structures. They remain in place for 4 to 8 weeks. Spat, either from spat catching farms or from Kaitaia, are seeded onto growing ropes by holding them against the ropes with light tubular stocking, until they attach themselves. Growing mussels are removed from ropes and re-seeded on to new ropes twice before achieving harvestable size.

Harvesting is done from specially designed harvest vessels. The mussel-laden growing ropes are hauled onboard the vessel where the mussels are stripped from the rope. The mussels are then washed and any natural detritus is discarded overboard within the mussel farm boundaries. The entire cycle from initial seeding to the harvest of marketable-size (90–120 mm) mussels usually takes 12 to 24 months, depending on the growing conditions.

Mussel cultivation is currently usually undertaken in sheltered embayments, within 200 m of the low-water mark, and in water between 10 and 30 m deep. The farms are usually located over areas of soft sediments to avoid smothering of reef habitats by biodeposits (Department of Conservation 1995). Permit conditions usually exclude areas within 20 m of rocky reef or other significant fish or seabed habitat because of typically high conservation values of these habitats. Individual areas allocated for mussel farming are normally between 1 and 20 ha (average 3–5 ha), though some existing mussel farms extend over 50 ha. Because mussel farming requires clean pollution-free water, the mussel industry seeks to maintain high water quality, and minimise or eliminate any marine pollution. Currently mussel cultivation does not entail the application of any additional nutrients, or chemicals (i.e. fertilisers, herbicides, or pesticides). However, recent research indicates productivity gains could be achieved by increasing concentrations of available nitrogen (Ogilvie et al. 2000) and experimental fertilising of waters within mussel farms in the Marlborough Sounds is being considered (Booth 2000).

Figure 2. Cut-away diagram of typical mussel farm.

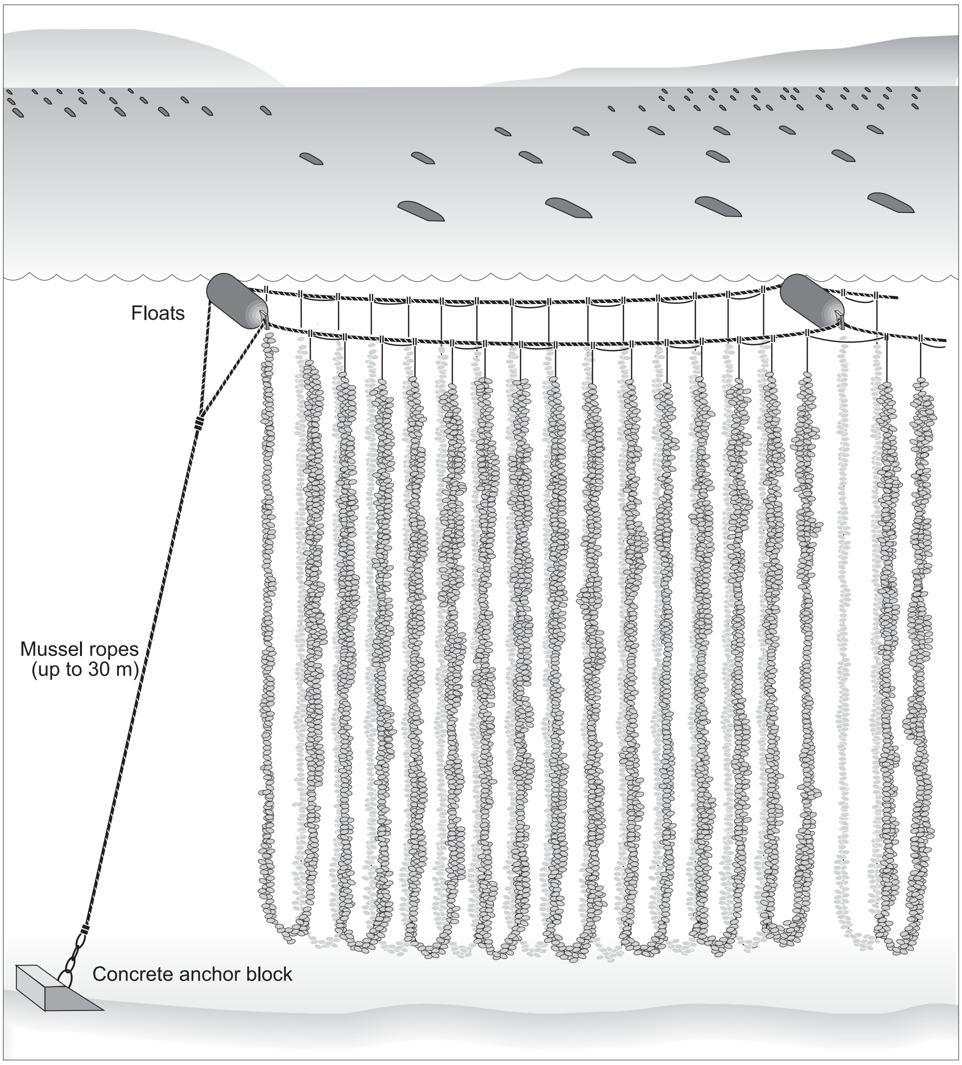


Figure 3. Mussel farm in Admiralty Bay, Marlborough Sounds.

Figure 4. Mussel buoys with backbone rope and attached mussel growing lines.

Figure 5. Underwater view of mussel growing lines.

2.3 EXPANSION OF THE GREENSHELL® MUSSEL INDUSTRY

Green-lipped mussel cultivation began in the 1970s and has expanded massively since that time. The value of Greenshell® Mussel exports grew by 708% during the 12-year period 1988 to 2000, achieving an average annual growth of nearly 18%. In the year 2000, the Greenshell® Mussel industry exported 28 069 tonne of processed mussels worth NZ$170 million. Productivity was calculated to be 9.85 tonne $ha^{-1}yr^{-1}$, or $NZ59,649 $ha^{-1}yr^{-1}$; this is 200 times the productivity of protein from land-based farming (Lupi 2001).

During the 1990s the success of the burgeoning Greenshell® Mussel industry brought massive growth in demand for sheltered inshore areas to be used for mussel cultivation. By the year 2000, there were 605 mussel farms, encompassing 2850 ha of coastal waters, used for long-line cultivation of green-lipped mussels in New Zealand (Jeffs et al. 1999; Lupi 2001). Most farms were in the Marlborough Sounds, Tasman Bay, and the Firth of Thames, but there were small numbers in Northland, Golden Bay, and Stewart Island (see Fig. 1). In 2002, the government imposed a moratorium on aquaculture proposals. There were mussel farms, or proposals for mussel farms, along most of the coast in the Marlborough Sounds available for aquaculture in the proposed resource management plan for the area, as well as proposals for large (>50 ha) farms in the open water in middle of several bays in the outer Marlborough Sounds (Fig. 6A). There were also proposals for large mussel cultivation or spat catching farms in open water in Golden Bay, Tasman Bay, the Firth of Thames and around Bank's Peninsula (Figs 6B–E). More recently the aquaculture industry has promoted mussel cultivation for most embayments on the east coast of Northland (Andrewe Riddell, Department of Conservation, Whangarei, pers. comm.).

In recent years, it has been recognised that there were limits to the availability of suitable sheltered inshore areas. This recognition, together with concern over reduced mussel productivity, caused by phyto-plankton depletion in sheltered waters with high densities of farms, led the mussel industry to develop methods that allow large mussel farms to be placed in exposed offshore water. In 2002, although the new methods had not been tested commercially, there were proposals for large mussel farms in exposed offshore waters in Pegasus Bay, Clifford Bay and Cloudy Bay, Hawke Bay, and the Bay of Plenty (Figs 6F–I).

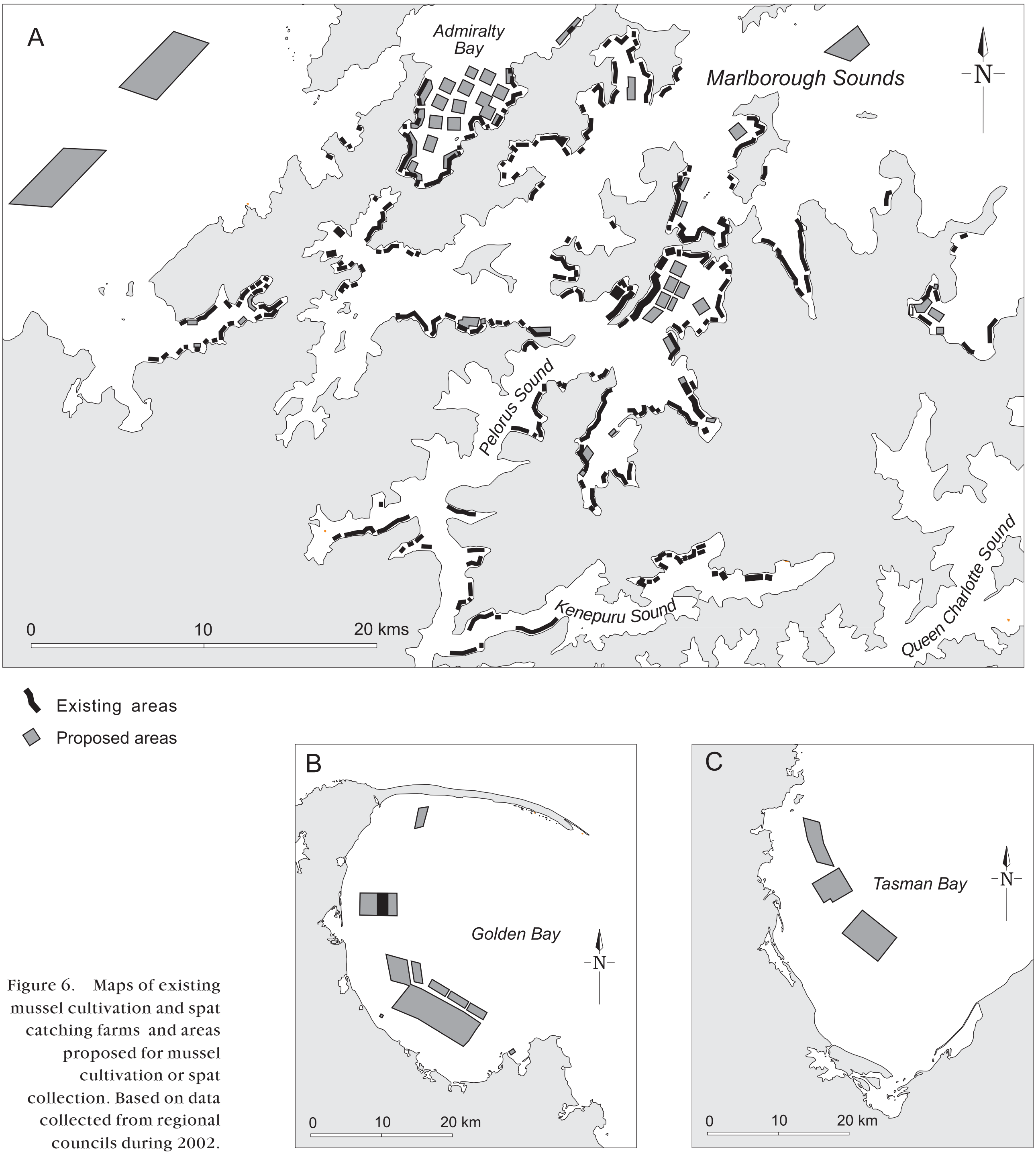


Figure 6. Maps of existing mussel cultivation and spat catching farms and areas proposed for mussel cultivation or spat collection. Based on data collected from regional councils during 2002.

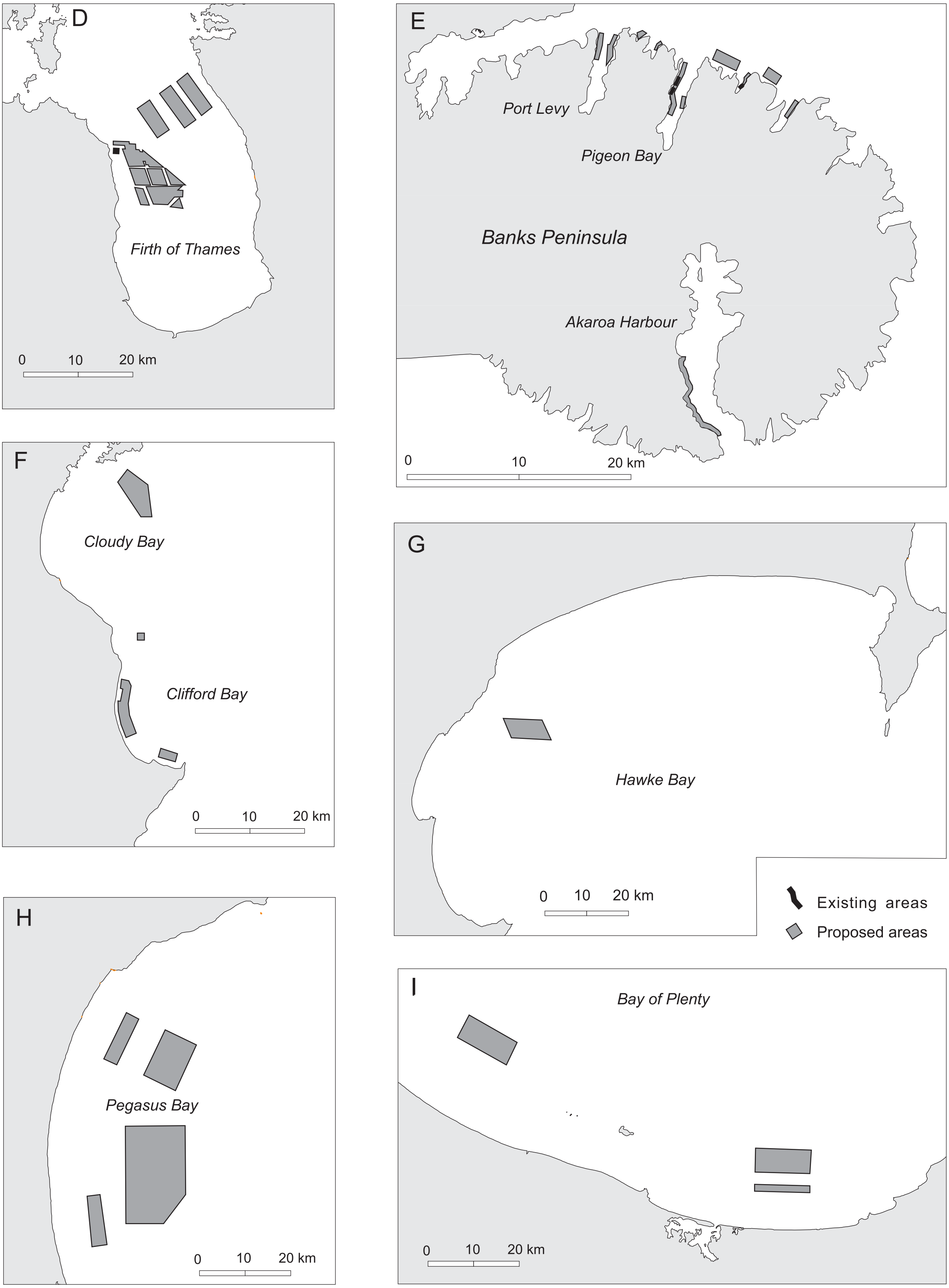


Figure 6. *Continued.*

3. Legislative framework for aquaculture

3.1 EXISTING AQUACULTURE LEGISLATION

Marine aquaculture ventures (i.e. marine farms including mussel farms) established between 1971 and 1991 were licensed under the Marine Farming Act 1971. Renewals and amendments to these licences are still considered under this act. Since 1991, proposals to establish marine farms have been considered under the Resource Management Act 1991 (RMA). Under the existing provisions of the RMA, regional councils both develop coastal plans that set controls for the establishment of marine farms, and assess applications for resource consents for marine farms. When preparing coastal plans and considering resource consents, regional councils must assess the actual or potential effects of marine farming on the environment. Among the effects to be considered are "any effect on ecosystems, including effects on plants or animals and any physical disturbances of habitat in the vicinity" (Schedule 4, RMA). Where marine farming is a restricted coastal activity (e.g. covers a large area, usually > 50 ha, or introduces exotic species into an area) the Minister of Conservation makes the final decision on resource consents. Marine farms also require a marine farming permit under the Fisheries Act 1996, which requires consideration of the farm's effect on wild fisheries (Fisheries 2002).

3.2 AQUACULTURE LAW REFORM

Rapid expansion of the marine aquaculture industry, particularly mussel farming, led to a moratorium on consideration of further aquaculture proposals pending aquaculture law reform. The moratorium, which is administered under the Resource Management (Aquaculture Moratorium) Amendment 2002, was to expire on 28 March 2004 but has been extended until December 2004. By this time, the government plans to have reformed aquaculture provisions of the various acts. Proposals for mussel farms notified before November 2001 are being considered under current legislation.

The central tenet of proposed aquaculture law reform is that Aquaculture Management Areas (AMAs) will be defined in Regional Coastal Plans drafted by regional councils. Regional councils will lead identification of AMAs, with Ministry of Fisheries, Ministry for the Environment, Maritime Safety Authority and Department of Conservation (DOC) providing assistance. DOC's role in the identification of AMAs includes providing information on and advocating for conservation values. Although legislation (e.g. Conservation Act, Fisheries Act, and RMA) has diffused responsibilities for some conservation values (e.g. maintenance of marine biodiversity and marine ecosystems, and protection of areas of special cultural interest) among several agencies, DOC alone has statutory responsibilities for protected species, as defined under the Wildlife Act 1953 and the Marine Mammals Protection Act 1978. Thus, DOC has a special and unique responsibility to advocate for protected species during the AMA identification process.

Implementation of aquaculture reforms involves a multi-agency group comprising Ministry of Fisheries, Ministry for the Environment, and DOC. An Aquaculture Reform RMA Implementation Plan has been prepared, in which lack of information has been identified as a major barrier to identification of AMAs. Proposals to rectify this lack of information are: stocktaking and transfer of existing information, identification of information gaps, and the development of "longer-term" research programmes to fill information gaps.

3.3 PROPOSED AQUACULTURE MANAGEMENT AREAS

Progress towards aquaculture reforms varies regionally. An overview of progress by different councils can be viewed on the Ministry for the Environment's website at:
http://www.mfe.govt.nz/issues/resource/aquaculture/implementation/council-activity.html

Further details for individual councils may be found on their websites.

4. Environmental effects of mussel farming

In this report, only those effects of green-lipped mussel cultivation that may reasonably be expected to affect protected species are considered. Environmental effects on other aspects of marine biodiversity and socio-economic effects (Burbridge et al. 2001), such as displacement of other stakeholders (e.g. fishers), changes in natural character and amenity values, and impediment to navigation, are not considered.

There is a considerable body of research on the environmental effects of mussel farming within and outside New Zealand, reviewed in detail elsewhere (Morrisey & Swales 1997; Kaiser et al. 1998; Inglis et al. 2000; Sinner 2000; Cole 2001; Kaiser 2001; Broekhuizen et al. 2002). Environmental effects may arise from mussel feeding habits, farm structures or activities associated with mussel cultivation. Documented environmental effects include: phytoplankton depletion, modifying the benthic environment and species assemblages, altering local hydrodynamics, increasing marine litter, and facilitating the spread of unwanted organisms. The severity and extent of environmental effects is influenced by many factors including size and age of the farm, stocking densities, water depth and flow regimes, season and climatic conditions.

4.1 EFFECTS ON PLANKTON COMMUNITIES—PHYTOPLANKTON DEPLETION

Green-lipped mussels feed on phytoplankton filtered from the water column. The large concentrations of mussels found in mussel farms can extract a significant proportion of phytoplankton, causing phytoplankton depletion (Waite 1989; Grange & Cole 1997; Inglis et al. 2000; Ogilvie et al. 2000; Cole 2001; Broekhuizen et al. 2002). The magnitude and extent of depletion is poorly understood, but probably vary depending on numerous factors such as farm size, crop density, water depth, currents and season. Phytoplankton can be reduced by up to 60% within farm boundaries (Waite 1989), and a 50 ha farm may consume >20% of phytoplankton passing through it (Broekhuizen et al. 2002). The phytoplankton depletion halos are usually limited to within 80 m of farm (Grange & Cole 1997), but may extend further in some instances (Cole 2001). High current velocities will increase the spatial extent of the halo, but also reduce the degree of depletion (Broekhuizen et al. 2002). There may be reduction in zooplankton levels, either as an indirect consequence of depletion of the phytoplankton on which it depends, or because some zooplankton are filtered from the water by the mussels and ejected as pseudofaeces (Cole 2001).

More complex ecosystem effects have been postulated for extensive areas of mussel cultivation (Inglis et al. 2000; Broekhuizen et al. 2002). Changes in plankton community composition, caused by the reduction in phyto-planktivores and selection of fast growing planktonic species, may affect primary productivity. High concentrations of mussel larvae during spawning periods may also affect plankton community composition as the mussel larvae enhance food supply for some planktivores, but compete with other plankton (Broekhuizen et al. 2002)

4.2 EFFECTS ON THE BENTHIC ENVIRONMENT

Mussel farms modify the benthic environment on the seabed below them in a number of ways. Deposits of live mussels, broken shells, and other farm debris build up below the growing lines (Fig. 7) and, in the absence of strong currents, these deposits increase sedimentation rates by reducing water flow across the seabed. The rain of faeces and pseudofaeces from the mussel crop leads to organic enrichment of the sediments below mussel farms (Kaspar et al. 1985; Gillespie 1989; De Jong 1994; Forrest 1994; Cole & Grange 1996; Inglis et al. 2000; Bolton-Ritchie 2001; Broekhuizen et al. 2002; Grange 2002). This nutrient enhancement may promote algal and phytoplankton growth rates within farms (Tenore et al 1982; Gibbs et al. 1992; Ogilvie et al. 2000). In farms where there is little water flow, organic enrichment of the benthos creates anaerobic and acidic conditions which result in elevated levels of sulphides and ammonium (Dahlbäck & Gunnarsson 1981; Kaspar & Boyer 1985; Kaspar et al. 1985; Tenore et al. 1985; De Jong 1994; Grant et al. 1995). Benthic effects are normally restricted to swathes of seabed directly below growing lines and less than 30 m wide. The extent and intensity of the effects vary seasonally with phytoplankton

Figure 7. Large seastars (*Coscinasterias calamaria*) feeding among debris on the seabed below mussel growing lines. (Photo: Roger Grace).

abundance, and are also affected by other factors such as farm age and size, stocking density and the hydrodynamic environment of the farm (Kaiser et al. 1998; Stenton-Dozey et al. 1999; Cole 2001; Grange 2002). Residual effects may be detectable up to 3 years after a mussel farm has been removed (Stenton-Dozey et al. 1999).

4.3 CHANGES IN SPECIES ASSEMBLAGES

Environmental changes associated with mussel farming (i.e. phytoplankton depletion, organic enrichment, and changed habitat heterogeneity) affect the composition of species assemblages in the water column as well as on, and in, the seabed around mussel farms. Generally, there is a shift in the food webs away from predominantly suspension-feeding organisms to deposit-feeding faunas (Grant et al. 1995; Inglis et al. 2000). Organic enrichment of the sediments beneath mussel farms and resulting anoxic conditions cause declines in the abundance of large, deep-burrowing species of molluscs, echinoderms, crustaceans and polychaetes (e.g. *Lumbrinereis* and *Aglaophamus*) (Inglis et al. 2000). However, organic enrichment, together with the accumulation of debris beneath farms, increases both the food available for scavengers. Where farms are located over seabeds of fine sediment or mud, they do increase habitat heterogeneity. This results in an increase in the abundance of surface-feeding and small, opportunistic species of gastropods, polychaetes, nemerteans and crustaceans on the seabed (Tenore et al. 1985; Grant et al. 1995; Stenton-Dozey et al. 1999; Inglis et al. 2000).

Seabed debris and clumps of live mussels on, and beneath, growing lines are colonised by a variety of organisms: ascidians (including *Ciona intestinalis*), bryozoans (including *Watersipora cucullata*, *Bugula* sp.), sponges, bivalves, calcareous polychaetes, and seaweeds (including *Codium fragile*, *Colpomenia sinuosa*, *Cystophora* spp.) (Kaspar et al. 1985; Davidson 1998; Inglis et al. 2000; Cole 2001). These aggregations provide a reef-like habitat for a variety of mobile fauna including fish, crustaceans, starfish, sea urchins, and other echinoderms (Mattsson & Linden 1983; Tenore et al. 1985; Cole & Grange 1996; Cole 2001). Where mussel farms are located over seabeds of fine sediment or mud, the variety and density of fish and crustaceans is usually greater in mussel farms than in adjacent areas (Carbines 1993; De Jong 1994; Forrest 1994; Grange 2002). Fish species commonly associated with mussel farms include mussel predators such as leatherjackets *Parika scaber*, spotty wrasse *Notolabrus celidotus*, as well as blue cod *Parapercis colias*, and parore *Girella tricuspidata* (in northern New Zealand). The three crabs species *Halicarcinus innominatus*, *Petrolisthes novaezelandiae* and *Notomithrax minor* were particularly abundant beneath mussel farms in the Coromandel. There are high densities of the starfish *Coscinasterias muricata* beneath many mussel farms (Gillespie 1989; De Jong 1994; Cole & Grange 1996).

Exclusion of trawling and dredging by mussel farms also affects the benthic fauna. Sedentary species disadvantaged by trawling and dredging, such as scallops *Pecten novaezelandiae* horse mussels *Atrina zelandica*, bryozoans, brachiopods, sponges, ascidians, and seaweeds, are sometimes more abundant beneath mussel farms than in nearby disturbed areas (Inglis et al. 2000).

It has been suggested that in regions with extensive mussel farms, pre-emptive settlement by mussel spat, as well as the consumption of spat from other invertebrates by farmed mussels, will result in green-lipped mussels displacing other invertebrate species from adjacent coastal waters (Broekhuizen et al. 2002). However, as yet there are no observations to support this postulate.

4.4 REPLICATING HISTORIC NATURAL ECOSYSTEM FUNCTIONS

Extensive natural beds of green-lipped mussels were a normal part of local ecosystems in many of the areas now used for green-lipped mussel cultivation (e.g. Tasman Bay, Marlborough Sounds, and Firth of Thames). Thus in these areas, effects arising from mussel feeding habits such as phytoplankton depletion, modifications to the benthic environment and species assemblages are to some extent replicating historic natural ecosystem functions. It is generally acknowledged that bivalve molluscs, such as mussels, play an important role in the retention of phosphorus and nitrogen in healthy estuarine ecosystems (Kaiser 2001). However, because cultivated mussels are grown in mid-water column, whereas natural beds of mussels were on the seabed, different types of phytoplankton may be filtered from the water column.

4.5 MARINE LITTER FROM MUSSEL FARM STRUCTURES

Although the Mussel Industry Council's Code of Practice (Robb & Davidson 2002) dictates that litter should be placed in bins on board barges, large amounts of litter from mussel farms can be found on the seabed under mussel farms and on nearby shores (Cole 2001). The litter includes rope, growing lines, the ties for securing them to backbones, and whole mussel floats.

4.6 HYDRODYNAMICS

Mussel farm lines and floats reduce wave action and current speeds within farms, but this effect is not well understood (Cole 2001). Current speeds within farms may be 30% of those outside farms (Cole 2001). Shell deposits on the seabed below farms slow the flow across the seabed and increase sedimentation rates (De Jong 1994; Cole & Grange 1996).

4.7 FACILITATING THE SPREAD OF PROBLEM ORGANISMS

Unwanted organisms, such as exotic pest species, harmful algal blooms, parasites and pathogens may be introduced or spread by the transfer of mussel farming equipment and mussel spat among areas (Inglis et al. 2000; Cole 2001; Kaiser 2001). Farms structures and the high density of cultured mussels may also act as reservoirs for the incubation of these or other problem organisms (Beveridge et al. 1994; Fuentes et al. 1995; Inglis et al. 2000). Exotic pest species found on mussel longlines include the ascidian *Ciona intestinalis*, macroalga *Undaria pinnatifida*, and mussels *Mytilus galloprovincialis* (Inglis et al. 2000; Cole 2001). Mussel farming has been implicated in the spread of invasive alien seaweeds such as *Undaria* among areas (Kaiser 2001). In the past, mussel farming activities may have accelerated the spread of harmful algal blooms (Inglis et al. 2000; Cole 2001; Kaiser 2001). Recent controls on the transfer of material between areas, and the development of methods to remove algal cysts from spat, may reduce this risk. It has also been suggested that blooms may be stimulated by increased release of ammonium and other micronutrients from the seabed around mussel farms. Although parasites of shellfish may be transferred in the course of mussel farming (e.g. mudworms and peacrabs), they are unlikely to affect unrelated taxa. The high densities of cultured mussels in mussel farms may facilitate the spread of facultative, or non-specific, pathogens that could spread to wildlife. Pathogens may be bacteria naturally present in the aquatic environment, or be from contamination with faeces (Cole 2001).

4.8 CUMULATIVE EFFECTS OF EXTENSIVE MUSSEL CULTIVATION

Although mussel farms do have adverse effects on their local environment, the industry is generally considered environmentally friendly. Presumably, this is either because the effects of mussel farms are not considered severe, or because although the effects may be severe locally, they are not sufficiently extensive to warrant concern. However, the proposed massive growth in mussel farming warrants re-consideration of the industry’s effect on the environment. The cumulative and diffuse effects of large numbers of small farms, and the effects of very large mussel farms of several hundred hectares, have not been investigated and are not known. Inevitably, growth of mussel farming will increase the extent of affected coastal waters, while the cumulative nature of effects arising from extensive mussel cultivation may increase the severity of effects (Inglis et al. 2000; Broekhuizen et al. 2002).

5. Marine mammal and seabird faunas of New Zealand

The marine mammal and seabird faunas of New Zealand are significant components of global biodiversity. New Zealand has a rich and diverse marine mammal fauna. Of the world's 124 extant marine mammal species, 44 (35%) have been recorded in New Zealand waters. This includes 38 of 83 species of cetaceans (whales, dolphins and porpoises), and 6 of 36 species of pinnipeds (seals, walruses, sea lions and fur seals) (Baker 1983; Bryden et al. 1998; Rice 1998). Two species are endemic to New Zealand (i.e. only occur in New Zealand's waters): Hector's dolphin *Cephalorhynchus hectori*, and the New Zealand sea lion *Phocarctos hookeri*. New Zealand's seabird community is the largest and most complex one in the world (Robertson & Bell 1984; Taylor 2000a, 2000b). Of the worlds 349 seabird species, 140 (39%) have been reported within New Zealand waters. Eighty-four species of seabirds breed in New Zealand and 25 of these species are endemic to New Zealand (Heather & Robertson 1996).

5.1 LEGISLATION PROTECTING MARINE MAMMALS AND SEABIRDS IN NEW ZEALAND

All marine mammals and most seabirds within New Zealand's territorial waters are absolutely protected under the Marine Mammals Protection Act 1978 and the Wildlife Act 1953, respectively[1]. The Department of Conservation has statutory responsibility for administering both acts. Although intentional killing or harm to marine mammals and protected seabirds contravene these acts, incidental killing or harm in the course of legitimate activities such as boating, fishing, or aquaculture does not contravene the acts. The Marine Mammal Protection Act (Section 16) stipulates that anyone killing or harming a marine mammal while fishing, which includes aquaculture, must report the incident to a Marine Mammals Officer or Fisheries Officer.

Sections 15 and 298 of the Fisheries Act 1996 provide some regulation over the effects of fishing on protected species, as they allow regulation to remedy or mitigate any adverse effects on protected species, including prohibiting fishing or fishing methods in an area. These powers are usually exercised in consultation with the Minister of Conservation and have been used to limit non-target effects of wild catch fisheries on protected species, but have never been invoked to control the effects of aquaculture. It remains to be seen whether the powers extend to aquaculture. Sections 15 and 186 of the Fisheries Act authorise the Minister of Fisheries to require information on non-target fishing-related mortality, but Section 186 explicitly includes fish farmers and holders of spat-catching permits.

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[1] Seabirds not receiving full protection are: black shag (*Phalacrocorax carbo*), little shag (*P. melanoleucos brevirostris*), pied shag (*P. varius*), mutton bird (*Puffinus griseus*), grey-faced petrel (*Pterodroma macroptera*) and black-backed gull (*Larus dominicanus*).

6. Mussel farming effects on marine mammals and seabirds

Although there is a large body of evidence on the environmental effects of mussel cultivation in New Zealand and overseas (Morrisey & Swales 1997; Kaiser et al. 1998; Inglis et al. 2000; Sinner 2000; Cole 2001; Kaiser 2001; Broekhuizen et al. 2002), published information on the effects of mussel cultivation on marine mammals or seabirds is sparse. All available information is used to predict such effects in Table 1. Information used includes: details of green-lipped mussel biology and cultivation; the published studies of the environmental effects of mussel cultivation described in the preceding section; the locations and extent of existing and proposed mussel farms (Figs 6A–I); published and casual observations of marine mammals and seabirds around mussel farms; and information on the distribution and behaviour of marine mammals and seabirds. It is important to note that, in most instances, there is no proof that the effects occur; the effects are merely predicted from the best existing information.

There is likely to be considerable variation among species, location and season, in the nature and severity of any effects. Effects on individual species may be either detrimental or beneficial. Possible detrimental effects include: entanglement, ingestion of litter, exclusion from traditional habitat by structures or disturbance, declines in prey abundance due to phytoplankton depletion or changes in the benthic environment, reduced foraging success, and the introduction and spread of pathogens or pest species. Possible beneficial effects include increases in prey abundance or foraging success, and the creation of new resting sites and foraging areas.

TABLE 1. POSSIBLE EFFECTS OF MUSSEL CULTIVATION ON MARINE MAMMALS AND SEABIRDS.

Entanglement in:	mussel farm structures
	spat catching structures
	litter from farms
Ingestion of:	litter from farms
Changed prey abundance due to:	phytoplankton depletion
	changes in benthos
	changed macro-species assemblages
	harvest of natural spat fall
Changed foraging success due to:	farm structures
Exclusion by:	farm structures
	reduced foraging success or prey availability
	disturbance (noise or boat activity)
Facilitate spread of:	pathogens
	pest species (e.g. toxic blooms and *Undaria*)
Creation of resting places:	on floats
	within farms

6.1 ENTANGLEMENT

6.1.1 Cetaceans

Cetacean experts believe that worldwide, about 60 000 cetaceans die each year from entanglement in fishing gear (proceedings of Cetacean Bycatch Workshop January 2002, Annapolis, MD organised by WWF, http://www.cetaceanbycatch.org). Although most cetacean entanglements are in nets, some are in lines. Documented overseas instances of cetaceans being entangled in lines include: 13 sperm whales (*Physeter macrocephalus*) entangled in underwater telecommunications cables (Slijper 1976), grey whales (*Eschrichtius robustus*) entangled and drowned in aquaculture lines in California (Stack pers. comm. in Slooten et al. 2000a), and bottlenose dolphins (*Tursiops truncatus*) entangled in crab-trap lines on the east coast of the United States (Noke & O'Dell 2002).

Within New Zealand waters there are several reports of whales being entangled in lines: in 1985 a southern right whale (*Eubalaena australis*) died entangled in a craypot line (Martin Cawthorn, pers. comm.); since 1996 two Bryde's whale (*Balaenoptera edeni* or *brydei*) reportedly died in separate incidents after entanglement in mussel spat collection ropes (see frontispiece); there have been five instances of humpback whales (*Megaptera novaeangliae*) found entangled in crayfish pot lines near Kaikoura, two during 2001 (Childerhouse 2002), one in 2002 and two in 2003. There have been no reports of dolphin entanglement in lines in New Zealand.

The risk of entanglement is probably greater with thinner or untensioned ropes, such as spat collecting ropes and lost ropes. Because they don't echolocate (Tyack & Clark 2000), baleen whales (e.g. Bryde's, southern right, and humpback) are prone to entanglement. Over 60 percent of northern right whales in the North Atlantic have entanglement scars on them, and at least two deaths during a three-year period could be attributed to entanglements (Hamilton et al. 1998). Because of their echolocation capabilities and small size, there is a lower risk of dolphins becoming entangled in lines.

6.1.2 Pinnipeds

Although pinnipeds frequently become entangled in fishing nets, none have been reported entangled in lines and they are unlikely to be entangled in mussel farm structures. There are reports of pinnipeds being entangled in marine litter.

6.1.3 Seabirds

Incidental capture of seabirds during fishing operation is a significant international problem (Taylor 2000a, 2000b), but there are no reports of seabird deaths as a result of entanglement in fixed lines of the type found in mussel farms or spat catching areas. However, in the Marlborough Sounds adult and young of the Australian gannet have been found entangled in rope ties from mussel farms incorporated into their nests (Butler 2003). Also, giant petrel (*Macronectes giganteus*) and southern black-backed gull (*Larus dominicanus*) are prone to entanglement in marine litter (Taylor 2000a, 2000b).

6.2 INGESTION OF LITTER

Marine litter, particularly plastics, is ingested by many seabirds, especially pelagic species of petrel and albatross (Taylor 2000a, 2000b). Ingested plastic can causes mortality by dehydration, gut blockage or toxins released in the intestines (Auman et al. 1998). Increase in the amounts of marine litter around mussel farms may therefore have a detrimental effect on local populations of seabirds and marine mammals.

6.3 CHANGES IN FORAGING SUCCESS

Mussel farm structures may reduce foraging success for some protected species by interfering with normal foraging behaviour and providing refuges for prey. Curtains of mussel growing lines 50–70 cm apart, extending down to 30 m and encrusted with mussels (Figs 2 and 5) may constitute barriers to underwater foraging for many species.

Together with other farm structures, they are likely to impede collaborative hunting for schooling fish by dolphins (e.g. dusky, common, and Hector's dolphin) and interfere with foraging of seabirds species that feed in open water on schooling fish (e.g. white-fronted tern *Sterna striata*, Hutton's and fluttering shearwater *Puffinus huttoni* and *P. gavial*). The effect is likely to be pronounced for dolphins, as the mussel-encrusted growing lines will interfere with dolphins' sonar signals and communication sounds, reducing dolphin's ability to hunt successfully within mussel cultivation areas.

6.4 TROPHIC EFFECTS—CHANGES IN PREY ABUNDANCE

Changes in components of lower trophic levels within the water column and on the seabed around mussel farms were described in preceding sections (e.g. phytoplankton depletion, organic enrichment of the benthos, and changes in species assemblages). These will affect prey abundance for apex predators such as marine mammals and seabirds. It may be expected that diversion of coastal ecosystem's primary production to cultivated mussels over extensive areas will reduce prey availability. However, there have been no studies of this issue and it is difficult to predict how changes at lower trophic levels will affect populations at higher levels (Grant 1996; Smith & Holliday 1998). Increases in the abundance and diversity of some prey species around mussel farms (Grange 2002) may increase available food supplies for some marine mammals and seabirds, while declines in abundance of preferred prey species may decrease food supplies for others.

6.5 DISTURBANCE

Increased human activity associated with mussel farms can have detrimental effects on seabirds and marine mammals. Roosting and nesting shags are disturbed by boat activity, though this disturbance may not be detrimental to shag populations (Butler 2003). There are several documented examples outside New Zealand where increases in human activity have led to decreased use, or abandonment, of areas by cetaceans, including: grey whales (Gard 1974; Bryant et al. 1984), humpback whales (Herman 1979; Glockner-Ferrari & Ferrari 1990), killer whales (*Orcinus orca*) (Morton & Symonds 2002) and Chilean dolphin (*Cephalorynchus eutropia*) (Dr Jorge Oporto, Corporation Terra Austalis for Nature Conservation, Valdivia, pers. comm.). Many cetacean species do not accommodate to noise and boat activity though some do become habituated (Richardson et al. 1985; Richardson & Wursig 1997). Some individuals are attracted to boats; dolphins often approach boats for play, while seals and seabirds both congregate around boats for food. Increased boat activity brings increased risk of boat strikes, which is a significant cause of injury or death for many cetaceans, especially large whales. Hector's dolphins are attracted to boats, which predisposes them to boat strike and entanglement in nets set from boats (Stone & Yoshinga 2000).

6.6 EXCLUSION

It is thought that some species of marine mammals and seabirds may avoid areas used for mussel cultivation. Avoidance of mussel farms could be a consequence of several factors including: behavioural preferences for open water, disturbance by high levels of human activities, and reduced food supply caused by farms interfering with foraging or reducing prey availability. There are observations of dolphins swimming within mussel farms in New Zealand (e.g. Slooten et al. 2001; Markowitz et al. in press), however a number of reports indicate some dolphin species avoid areas used for long-line cultivation of bivalves. In New Zealand, dusky dolphins (*Lagenorhynchus obscurus*) avoid areas of Admiralty Bay, in the Marlborough Sounds, occupied by mussel farms (Markowitz et al. 2002 and in press). In Australia, bottlenose dolphins (*Tursiops* sp.) were excluded from parts of their home range where long-lines for oyster cultivation were placed (Mann 1999; Mann & Janik 1999). In Chile, during the period 1980–90, the Chilean dolphin disappeared from bays where mussel farms were developed; however, recent observations of dolphins in the area indicate they may develop tolerance of mussel farms (Dr Jorge Oporto, pers. comm.). The Chilean dolphin is Hector's dolphin's closest relative, and exhibits similar behaviour and preference for inshore habitat.

Habitat fragmentation, resulting from exclusion from traditional areas within a species home range, can produce abrupt and dramatic shifts in distribution and abundance patterns that may affect local populations more profoundly than might be predicted from the extent of lost area. Habitat fragmentation can pose particularly high risk for threatened or vulnerable species with populations adversely affected by other factors. Isolation of populations following habitat fragmentation can result in inbreeding and reduced reproductive success.

6.7 CREATION OF RESTING PLACES

Mussel farms provide resting-places for seabirds (Fig. 8) and cetaceans. Gulls and shags frequently roost on mussel floats (Butler 2003). There are reports of dolphins resting in the relatively sheltered water within mussel farms (Martin Cawthorn and Ken Grange pers. comm.).

Figure 8. Seabirds resting on mussel buoys.

7. Threatened species in coastal waters

Five marine mammal taxa and 44 seabird taxa, classified as nationally threatened (Hitchmough 2002) occur in coastal waters where mussel farms exist or are proposed (Table 2). Sixteen of these taxa are acutely threatened (5 cetaceans and 11 seabirds). A further 13 seabird taxa are chronically threatened, and 20 seabird taxa are at risk. Two cetacean taxa and 19 seabird taxa are also classified as globally threatened in the IUCN Red List (IUCN 2002) (Table 2). Differences between the New Zealand national classifications (Hitchmough 2002) and global classifications (IUCN 2002) reflect differences in the scale being considered. The sub-categories for acutely threatened taxa in the New Zealand system (Nationally Critical, Nationally Endangered and Nationally Vulnerable) roughly equate with the three categories for threatened species used in the IUCN Red List (Critically Endangered, Endangered or Vulnerable). In either system, taxa in these three categories are facing a very high risk of extinction in the wild.

The management and conservation of populations of threatened species, particularly cetacean species, is problematic and requires precautionary approaches unnecessary for other species (Mayer & Simmonds 1996; Thompson

TABLE 2. THREATENED SEABIRDS AND MARINE MAMMALS FOUND IN COASTAL WATERS OF THE MAIN ISLANDS OF NEW ZEALAND.

New Zealand threat categories (Hitchmough 2002): 1, Critical; 2, Endangered; 3, Vulnerable; 4, Serious decline; 5, Gradual decline; 6, Range restricted; 7, Sparse. IUCN global threat categories: (IUCN 2002) 1, Critically endangered; 2, Endangered; 3,Vulnerable; 4, Data deficient; 5, Lower risk.

GROUP	COMMON NAME	TAXON	NZ	IUCN
Penguin	Eastern rockhopper penguin	*Eudyptes chrysocome filholi*	4	
	Fiordland crested penguin	*E. pachyrhynchus*	5	3
	Erect-crested penguin	*E. sclateri*	2	2
	White-flippered penguin	*Eudyptula minor albosignata*	3	
	Northern little blue penguin	*E. minor iredalei*	5	
	Southern little blue penguin	*E. minor minor*	5	
	Yellow-eyed penguin	*Megadyptes antipodes*	3	2
Albatross	Antipodes albatross	*Diomedia antipodensis*	6	3
	Southern royal albatross, toroa	*D. epomophora*	6	3
	Gibson's albatross	*D. gibsoni*	6	
	Northern royal albatross, toroa	*D. sanfordi*	3	2
	Light-mantled sooty albatross	*Phoebetria palpebrata*	5	4
	Southern Buller's mollymawk	*Thalassarche bulleri*	6	3
	Grey-headed mollymawk	*T. chrysostoma*	4	3
	Northern Buller's mollymawk	*Thalassarche* sp.	6	
	Salvin's mollymawk	*T. salvini*	6	3
	Shy mollymawk	*T. steadi*	6	
Petrel	Fulmar prion	*Pachyptila crassirostris crassirostris*	6	
	Lesser fulmar prion	*P. c. eatoni*	6	
	Antarctic prion	*P. desolata*	5	
	Kermadec white-faced storm petrel	*Pelagodroma marina albiclunis*	1	
	South Georgian diving petrel	*Pelecanoides georgicus*	1	
	White-chinned petrel	*Procellaria aequinoctialis*	6	3
	Grey petrel	*P. cinerea*	5	4
	Black petrel	*P. parkinsoni*	5	3
	Westland petrel	*P. westlandica*	6	3
	Chatham petrel	*Pterodroma axillaris*	2	1
	Cook's petrel, titi	*P. cookii*	5	2
	Mottled petrel	*P. inexpectata*	6	4
	Pycroft's petrel	*P. pycrofti*	6	3
	Buller's shearwater	*Puffinus bulleri*	6	3
	Flesh-footed shearwater	*P. carneipes*	5	
	Sooty shearwater	*P. griseus*	5	
	Hutton's shearwater	*P. huttoni*	2	2
	Wedge-tailed shearwater	*P. pacificus*	6	
Shag	New Zealand king shag	*Leucocarbo carunculatus*	6	3
	Stewart Island shag	*L. chalconotus*	3	3
	Black shag	*Phalacrocorax carbo novaehollandiae*	7	
	Little black shag	*P. sulcirostris*	7	
	Pied shag	*P. varius varius*	7	
Skua	Southern skua	*Catharacta antarctica lonnbergi*	7	
Tern	Black-fronted tern	*Sterna albostriata*	4	2
	Caspian tern	*S. caspia*	3	
	Fairy tern	*S. nereis davisae*	1	
Baleen whale	Bryde's whale	*Balaenoptera edeni*	1	4
	Southern right whale	*Eubalaena australis*	2	5
Toothed whale	North Island Hector's dolphin	*Cephalorhynchus hectori maui*	1	2
	South Island Hector's dolphin	*C. hectori hectori*	3	2
	Killer whale	*Orcinus orca*	1	4

et al. 2000). Typically threatened species are suffering from the cumulative effects of several stresses, which may be either natural or human-induced, and an additional stress may have disproportionate consequences. Furthermore the small population sizes, typical of threatened species, together with difficulties inherent in studying threatened species, can lead to low statistical power for any attempts to detect effects. By the time an effect can be demonstrated with a high level of confidence, the effect will be so large that it may be too late to recover from (Taylor & Gerrodette 1993).

Four threatened species have been identified as being particularly vulnerable to the detrimental effects of extensive areas of mussel cultivation in New Zealand: Hector's dolphin, Bryde's whale, southern right whale, and king shag (*Leucocarbo carunculatus*).

7.1 Hector's dolphin

Hector's dolphin, which is endemic to New Zealand, is probably the world's rarest marine dolphin. The species is classified as endangered on the IUCN Red List (IUCN 2002) and as acutely threatened nationally by Hitchmough (2002). Two subspecies are recognised: *Cephalorhynchus hectori hectori* from South Island waters, and *Cephalorhynchus hectori maui* or Maui's dolphin from the west coast of the North Island (Baker et al. 2002). The South Island Hector's dolphin is classified as nationally vulnerable, whereas Maui's dolphin is classified as nationally critical, which is the highest level of endangerment (Hitchmough 2002). Best estimate for the total population of the species is 7270 individuals (Slooten et al. 2002). Recent estimates of the Maui's dolphin population are 75 (Ferreira & Roberts 2003) and 134 (Martien et al. 1999) individuals. Hector's dolphins are slow breeders, achieving reproductive status between 7 and 9 years of age, and subsequently breeding at irregular intervals of 2 or more years (Slooten 1991; Slooten & Lad 1991). They can live up to 20 years, but have a high mortality rate, largely due to entanglement in fishing nets (Slooten et al. 2000b). Hector's dolphins are a coastal species, living mostly within 7 km of the shore in shallow water (<100 m) (Dawson & Slooten 1988). Extensive mussel farms are being proposed in many of the semi-sheltered embayments on the coast of the South Island (Banks Peninsula, Pegasus Bay, Clifford Bay, and Jackson Bay: Fig. 1) known to be important to Hector's dolphins.

Hector's dolphins feed on bottom-dwelling organisms such as crabs and mollusks, as well as demersal and pelagic fishes (Baker 1983; Slooten et al. 2000a). Changes in benthos and water column caused by mussel farms will change prey availability, but it is not possible to predict whether the changes will be beneficial or detrimental. It seems probable that curtains of mussel-encrusted growing lines will interfere with dolphins' sonar signals and communication sounds, reducing their ability to hunt successfully. Extensive mussel farms in traditional home ranges of dolphin groups could restrict their movement and eliminate areas for nursing, basking, or foraging, and cause habitat fragmentation. There is currently limited overlap between marine farms and Hector's dolphin habitat throughout New Zealand; however, there are reports of Hector's dolphins seen within mussel farms (Slooten et al. 2001; Martin Cawthorn pers. comm.). Genetic variation in Hector's dolphin exhibits a high degree of geographical structure (Pichler 2002) which is presumed to have arisen from the small home ranges (<100 km) of populations and limited dispersal between geographical areas. Habitat fragmentation caused by the construction of extensive mussel farms could further isolate local populations and result in inbreeding and reduced reproductive success.

7.2 Bryde's whale

Bryde's whales are rorqual whales (length c. 14 m) found in tropical and subtropical oceans throughout the world (Rice 1998). In New Zealand waters, the larger form of Bryde's whale, presumably *B. brydei*, are relatively common in the warm waters of Northland, the Hauraki Gulf, and Bay of Plenty (Baker 1983). The species is classified as data deficient on the IUCN Red List (IUCN 2002), and as acutely threatened and nationally endangered by Hitchmough (2002). Bryde's whales are thought to be semi-migratory, making local seasonal movements to follow schools of fish (O'Callaghan & Baker 2002). The Hauraki Gulf appears to be an important habitat for a population of Bryde's whales (O'Callaghan & Baker 2002). Despite the smallness of the population of whales and the extremely limited area of existing mussel spat catching farms present within their range, two Bryde's whales reportedly died following entanglement in spat catching lines since 1996 (frontispiece). In the absence of effective mitigation, planned massive increases in the extent of mussel farms and associated spat catching farms within Bryde's whales range will probably lead to further entanglement-induced mortality.

7.3 Southern right whale

Southern right whales are large stocky baleen whales (length c. 14 m) with a circumpolar distribution, from about 30º to 60ºS. They migrate between breeding areas in warmer coastal waters in lower latitudes during winter, to feeding areas in higher latitudes in summer. The species is classified as acutely threatened and nationally endangered by Hitchmough (2002), but as being "at lower risk of extinction/conservation dependent" on the IUCN Red List (IUCN 2002). The IUCN classification means that the species recovery is dependent on ongoing conservation programmes.

Historically, southern right whales were abundant within New Zealand waters, with a population estimated at 10 000 individuals (Dawbin 1986). The population was nearly extirpated by whaling, which began in the nineteenth century and persisted until 1970. Dawbin (1986) suggested that there were two populations in New Zealand waters, with separate winter calving grounds: one around the mainland and Kermadecs, and the other in the New Zealand subantarctic. More recently Richards (2002) proposed that there was a single population, with individuals visiting waters around the mainland and the Kermadecs in the course of seasonal migrations. The New Zealand subantarctic population is now between 740 and 1140 individuals and increasing slowly (Patenaude 2000). In contrast, the low number of sightings in waters around New Zealand mainland indicates the local population is small, probably containing only 4–11 reproductive females (Patenaude 2003). If there were two separate populations, the population in mainland waters has failed to recover and is extremely vulnerable; alternatively if there was a single New Zealand population it has suffered extreme range contraction (Patenaude 2003).

Genetic data indicate the New Zealand subantarctic population is isolated from other populations (Patenaude 2000), but the genetic provenance of the animals seen around the New Zealand mainland is unknown (Patenaude 2003).

Southern right whales are adapted to living close to the shore. They use coastal migration routes; females calve in shallow, sheltered waters (Baker 1983). The shallow, sheltered, coastal waters preferred by southern right whales are identical to the conditions required for mussel cultivation. Thus, recovery of southern right whales in waters around the New Zealand mainland is likely to be compromised by the extensive mussel farms proposed for Pegasus Bay, Hawke Bay, and Bay of Plenty. These farms are proposed for important habitats for the most critical component of the New Zealand mainland population (Patenaude 2003). They overlap the whale's coastal migration routes and traditional calving areas. Entanglement or exclusion are both likely. Entanglement-induced mortality of a single female could have a severe impact on the viability of the small population found in waters around the New Zealand mainland.

7.1.4 King shag

The king shag (*Leucocarbo carunculatus*) is an endemic New Zealand species. It is ranked as vulnerable on the IUCN Red List (IUCN 2002), and as nationally at risk because of its restricted range (Hitchmough 2002). The entire population of about 650 birds is confined to the outer Marlborough Sounds. There are many existing mussel farms throughout the species range, but they are generally small (2–5 ha) and in shallow water within 200 m of shore. King shag forage in water between 20 and 40 m deep, where they feed on bottom-feeding fish, such as flounder, caught by deep diving. Existing mussel farms extend along the inshore fringe of the deeper water used by foraging king shags, but there are proposals for extensive mid-bay mussel farms to be anchored in the deeper waters where they will overlap the king shag's foraging area. Changes in benthos and water column around farms that reduce prey availability could affect the king shag population (Butler 2003). King shags use mussel floats for roosting and have been observed feeding within mussel farms (Butler 2003). However, underwater mussel farm structures may impede foraging. It has also been suggested that increased level of human activity associated with additional mussel farms could adversely affect nesting king shags (Butler 2003).

8. Areas of special significance for wildlife

Currently there is little overlap between mussel farms and important wildlife habitats (Fig. 9). The proposed extension of mussel farms into important wildlife habitats will increase the risk of adverse effects. Some areas around the New Zealand coast have special significance for a wide range of wildlife. For instance: the waters from Tauranga to North Cape are used by many large breeding colonies of seabirds and are on important migratory routes; they are therefore particularly important for New Zealand's seabird community. The waters off East Cape, Kaikoura and south-west South Island, where the continental shelf comes close to the shore, are also important for a variety of pelagic seabirds and marine mammals. Other areas are significant for smaller numbers of species. Hauraki Gulf is important for cetaceans, particularly Bryde's whale and common dolphin (*Delphinus delphis*) (O'Callaghan & Baker 2002). The north-west coast of the North Island (especially between Manukau Harbour and Port Waikato) contains the remaining population of the critical endangered North Island Hector's or Maui's dolphin (Ferreira & Roberts 2003). Coastal waters around Banks Penisula are important for the South Island Hector's dolphin (Dawson & Slooten 1988). Hawke Bay is an area of global significance for calving and nursing pygmy sperm whale (*Kogia breviceps*) (Debbie Freeman, Department of Conservation, Napier, pers. comm.). Admiralty Bay in the Marlborough Sounds is an important wintering area for dusky dolphin from the east coast of the South Island (Harlin et al. 2003). The shallow coastal waters of Poverty Bay, Hawke Bay, Cloudy Bay and Pegasus Bay, were historically major calving areas for southern right whales. Large offshore mussel farm areas proposed for these areas lie across seasonal migration routes of southern right whales and humpback whales.

Figure 9. Areas of special significance for marine mammals in New Zealand. From poster researched by Rob Suisted and Nadine Gibbs, and drawn by Chris Edkins, Department of Conservation, Wellington.

9. Conclusion

9.1 ADVERSE EFFECTS OF MUSSEL FARMING

"Absence of evidence of an effect is not evidence of absence of the effect"

The only reported adverse effects of mussel cultivation on marine mammals or seabirds in New Zealand are the exclusion of dusky dolphins from mussel farms (Markowitz et al. in press), and the entanglement and deaths of two Bryde's whales in mussel spat-catching lines. Unfortunately, absence of evidence for other adverse effects can not be interpreted as evidence that there are none, as there have been no concerted attempts to investigate the effects of mussel cultivation (or any other form of aquaculture) on wildlife or biodiversity *per se*, either in New Zealand or overseas. Although there has been considerable effort to monitor and model the environmental effects of aquaculture (Morrisey & Swales 1997; Silvert & Cromey 2001; Broekhuizen et al. 2002), this effort has been almost exclusively undertaken from the point of view of the seafood industry, not the environment. In New Zealand, monitoring and modelling have focused on determining the carrying capacity of the environment for the farmed animal (Morrisey & Swales 1997) and more recently identifying far-field effects on wild catch fisheries resulting from the cumulative effects of extensive areas of aquaculture (Broekhuizen et al. 2002).

The available information, presented in this report, indicates that there are reasonable grounds to believe that, mussel cultivation has adverse effects on marine mammal and seabird populations in New Zealand. Wildlife and mussel farms are in direct competition for space in the shallow, sheltered and most productive coastal waters (Würsig & Gailey 2002). Loss and degradation of wildlife habitat may be a consequence of either exclusion by the mussel farm structures, or by changes to the ecosystem, rendering habitats unsuitable. Although declines in marine mammal and seabird populations resulting from loss and degradation of habitat are not as dramatic or as easily documented as fishing by-catch mortality, they are serious threats to these populations (Whitehead et al. 2000). When large areas of mussel farms intrude into important wildlife habitat, there is potential for reduction in biodiversity as the farms affect populations of marine mammals and seabirds (and presumably other natural biota). Indeed, because resources are removed for human consumption and replaced by a waste-stream, aquaculture usually reduces biodiversity (Beveridge et al. 1994).

Proposed large offshore mussel farms along the east coast of the two main islands of New Zealand represent a special threat to large whales, because the proposed farms lie across their seasonal migratory routes and in historic calving areas. Entanglement of endangered southern right whales or other large whales in mussel farms in New Zealand waters would be damaging to New Zealand's international credibility as a proponent of cetacean conservation.

Ecotourism is an important component of the New Zealand tourism industry, which is one of New Zealand's most lucrative industries. According to the World Tourism Organization, ecotourism is the fastest growing sector of the tourism market, growing 5% annually worldwide (www.gdrc.org/uem/eco-tour/etour-define.html). New Zealand's marine mammals and seabirds are significant attractions for many ecotourists (i.e. whale-watching, swimming with dolphins, and bird watching). Widespread detrimental effects on marine mammal and seabird resulting from the expansion of aquaculture could have detrimental effects on the ecotourism industry.

9.2 ENVIRONMENTAL DEGRADATION CAUSED BY AQUACULTURE

Aquaculture, most commonly in the form of mussel farming, is now an established use in many of New Zealand's sheltered coastal waters. The industry engenders significant economic benefits and has the potential to become an ecologically sustainable industry, providing a harvest of high-quality protein from the sea to replace declining harvests from wild fisheries (Naylor et al. 2000). Although there is potential for aquaculture to be ecologically sustainable, experience outside New Zealand has shown that this is often not the case. Rapid expansion of aquaculture in recent years has frequently caused large-scale environmental degradation. Large areas of mangroves have been converted to shrimp farms (Choo 2001; Kaiser 2001). Surplus nutrients and toxic chemicals used on fin-fish farms have caused localised marine pollution (Pearson & Black 2001). The cultivation of carnivorous fish fed on fishmeal has contributed to declining wild fisheries (Naylor et al. 2000) and salmonid cultivation is believed to have contributed to the decline of local wild salmonid populations (Pearson & Black 2001). There have been culls of marine mammals and seabirds to prevent predation on cultivated species (Nature Conservancy Council 1989; Davenport et al. 2003). Predator exclusion nets around fin-fish enclosures have caused significant numbers of entanglements and death of marine mammals and seabirds (Gibbs & Kemper 2001). Cetaceans have been forced to abandon extensive areas (>3 km) around fish farms by the use of underwater acoustic harassment devices (Johnston 2002; Morton & Symonds 2002; Olesiuk et al. 2002; Davenport et al. 2003).

The absence of similar examples of environmental degradation in New Zealand probably reflects the low input requirements for bivalve cultivation (green-lipped mussels and oysters) which dominates the local industry. However global trends of increasing demand for seafood, and declining wild fisheries (Naylor et al. 2000), ensure expansion of aquaculture in New Zealand. This will entail increases in both the extent of coastal areas devoted to aquaculture and the variety of cultivated species. As the New Zealand aquaculture industry grows and diversifies, the potential adverse effects of aquaculture on marine mammals, seabirds, and other aspects of marine biodiversity will become more severe.

9.3 ECOLOGICAL SUSTAINABLE AQUACULTURE

There is growing international awareness of the need for aquaculture to be ecologically sustainable (Black 2001). The Code of Conduct for Responsible Fisheries produced by the Food and Agriculture Organisation of the United Nations (Food and Agricultural Organisation 1995) encourages governments to ensure that aquaculture development is ecologically sustainable. The New Zealand Biodiversity Strategy (Anon 2000), drafted to fulfill the New Zealand government's commitments under the Convention of Biological Diversity, Rio de Janeiro 1992, recognises the need for harvesting or development in the marine environment to be undertaken in an informed, controlled and ecologically sustainable manner.

Although there has been some debate over definitions of ecological sustainability, there is general acceptance that an ecologically sustainable industry should only exploit environmental resources in ways that: do not interfere with other users of the environment; do not reduce the scope for future users to benefit from the environmental resources; and do not significantly alter environmental quality and biodiversity (Black 2001).

9.4 MONITORING AND MODELLING

Monitoring and modelling the ecological effects of aquaculture are essential components of the process of planning and regulating aquaculture to achieve sustainable outcomes (Donnan 2001; Silvert & Cromey 2001). Properly designed monitoring programmes provide a method to determine: whether there are detrimental effects on the environment; whether the effects are significant, or acceptable and reversible; and how any effects can be minimised (Fernandes et al. 2001). Predictive models based on empirical evidence obtained by scientifically rigorous monitoring programmes can provide the best advice on possible results from different management decisions (Silvert & Cromey 2001). To be effective, monitoring programmes should be informed by research to develop suitable methodologies (Fernandes et al. 2001). Different forms of aquaculture affect the environment in different ways; therefore monitoring programmes must be tailored to suit the form of aquaculture as well as natural characteristics of the local environment (Fernandes et al. 2001).

Because green-lipped mussel cultivation is by far the most common form of aquaculture in New Zealand, development of a programme to monitor and model its environmental effects should be accorded the highest priority. The programme's objective should be to provide information to ensure that further expansion of mussel farming is regulated and managed to achieve a sustainable industry with minimal effects on environmental quality and biodiversity, not just those components of the environment that influence productivity of farmed and wild-caught fisheries. A successful high-quality monitoring programme for mussel farming is likely to provide a model for future programmes to monitor other forms of aquaculture.

9.5 AQUACULTURE LAW REFORM

The current aquaculture law reform process provides an opportunity to design a legislative framework to ensure that further development of New Zealand's aquaculture industry is ecologically sustainable. Thus far, aquaculture law reforms focus on the approval process for new aquaculture areas to be administered by local councils under the RMA. The strategy depends on anticipating detrimental effects and avoiding placing aquaculture in areas where it is likely to have adverse environmental effects. It is unrealistic to expect to anticipate all detrimental effects. Thus, it is important to ensure that there are legislative powers to regulate aquaculture methods in order to remedy or mitigate detrimental effects whenever they become evident. This is most likely after aquaculture ventures are operational. To ensure that aquaculture develops in New Zealand in a sustainable manner, reformed legislation should:

- authorise and resource effective monitoring of the effects of aquaculture on all aspects of marine biodiversity
- regulate aquaculture methods to remedy or mitigate any detrimental effects whenever they become evident.

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