Marine farming in Canterbury: biophysical issues associated with suggested aquaculture management areas

NIWA Client Report: CHC2003-045
May 2003

NIWA Project: ENC03512

Marine farming in Canterbury: biophysical issues associated with suggested aquaculture management areas

Graham D. Fenwick
Alex H. Ross
Gavin James
Paul M. Sagar

Prepared for

Environment Canterbury

NIWA Client Report: CHC2003- 045
May 2003

NIWA Project: ENC 03512

National Institute of Water & Atmospheric Research Ltd
10 Kyle Street, Riccarton, Christchurch
P O Box 8602, Christchurch, New Zealand
Phone +64-3-348 8987, Fax +64-3-348 5548
www.niwa.co.nz

Contents

Reviewed by:	*Approved for release by:*
Jeanie Stenton-Dozey	Barry Biggs

Executive Summary

Marine farming in New Zealand has grown rapidly recently, but the aquaculture permit system has created considerable frustration and expense for applicants. Thus, central Government has declared a two-year moratorium on aquaculture applications to overhaul the permit system. Following the reform, marine farming will be confined to Aquaculture Management Areas (AMAs) to facilitate development of this industry. Environment Canterbury's first step in establishing AMAs was to identify candidate AMAs based on industry consultation. This report was requested to identify any environmental constraints on marine farming activities within the suggested AMAs, and to recommend management strategies aimed at overcoming these environmental constraints and minimising any adverse ecological effects. The report attempts to do this using the very limited scientific data relevant to the local Canterbury situation and extrapolating findings from research elsewhere.

The Pegasus Bay coastal environment is characterised by open, sand and gravel shores and gently sloping sediment bottoms reaching 25-30 m depth some 10 km from shore. The coastal environment of Banks Peninsula varies widely from exposed rocky headlands to sheltered, shallow muddy inlets. All exposed shores experience considerable wave action in all seasons, as well as tidal and some influence from the Southland current. Although there is scant information available on the ecologies of the area, three broad coastal environments are apparent based on exposure to currents and wave action:

1. Harbour or semi-sheltered bay environments hold diverse soft bottom benthic communities that vary from location to location, depending on hydrodynamic conditions and sediment particle size composition. Hard bottom communities are equally variable and diverse, also changing in response to hydrodynamic conditions. A small number of fish species is known from these habitats. Dolphins are uncommon, except in some eastern and southern bays, and in Akaroa Harbour. Seals are generally rare. At least three at risk or endangered bird species inhabit semi-sheltered shores, especially in Akaroa Harbour.

2. Exposed coastal environments near headlands experience high wave exposure. These shores are usually steep, plunging to 10-16 m depth where they intercept a gently sloping sand or mud bottom. The fauna inhabiting these muddy bottoms is broadly similar to and intergrades with that inhabiting more sheltered mud bottoms in harbours and bays. Rock bottom biota tends to be dominated by large brown seaweeds, and have dense animal communities dominated by mussels, ascidians, sponges, bryozoans and hydroids. The abundant reef fishes comprise species that are relatively common around much of the South Island coast. Hector's dolphins frequent these waters, especially off the eastern headlands, outer Akaroa Harbour and west of Peraki Bay. Several species of birds feed along these exposed shores and some oceanic species venture into these waters.

3. Offshore environments are characterised by muddy bottoms supporting abundant and diverse benthic communities, which provide nursery areas to commercially important crabs and fishes. Worms, crustaceans and molluscs dominate this community. The diverse pelagic fish fauna includes several species important for commercial and recreational activities. Penguins, terns, shags and oceanic birds all forage in these offshore waters, along with Hector's dolphins.

Several potential ecological effects of marine farming are evaluated for the AMAs suggested in each of these three broad coastal environments.

- Depletion of phytoplankton may interfere with natural populations of filter feeders and reduce the supply of planktonic larvae returning to adjacent benthic and shore communities. Currents and wave action are the primary factors likely to reduce this impact.

- Sedimentation of organic particles from farmed species' faeces and pseudofaeces can affect bottom faunas, either positively or negatively, depending upon water movement, water depth and bottom sediment characteristics.

- Shell drop and accumulation can alter bottom communities, especially if extensive mussel reefs develop. Although poorly understood, the effects of shell drop and accumulation seem generally adverse for fishes, birds, and ecosystem functioning.

- Marine farm structures and mussels support substantial growths of fouling, suspension-feeding organisms. Their presence may exacerbate depletion problems and contribute to shell drop.

- Marine farming may facilitate the spread of alien marine species by transporting them on vessels and equipment, as well as providing hard substrates and rich food sources.

- Marine farms provide refuges that attract fishes, among other organisms, as well as protecting some habitat from other harmful human activities, such as bottom trawling.

- Translocation of farmed or farm-associated species from one location to another may disrupt natural evolutionary processes by altering gene frequencies. Translocation of green-lipped mussel spat has altered natural gene frequencies in native populations at one location and, probably, at others also.

- Marine farming fragments the coastal area. This may interfere with the normal activities of dolphins, whales and birds, as well as creating entanglement hazards, disturbance from farm-related noise and activity, and problems associated with marine debris.

Scale and cumulative effects seem significant for marine farming in the region. The main concerns are changes to benthic habitats and communities through shell drop, plankton depletion and potential cumulative effects arising from marine farms occupying a significant proportion of specific habitat types, such as the near-shore marginal strip overlying the sediment-rock boundary.

Ecological monitoring of marine farms and their development is useful only if undertaken within an appropriate management framework that uses the monitoring information to improve decision-making. Monitoring must be carefully planned and executed to ensure appropriate variables are monitored and that farming-induced changes can be reliably distinguished from natural variation.

Because we lack so much the knowledge about marine farming and its ecological effects in the region, especially just how much change is ecologically acceptable, two models for managing ecological impacts in the absence of a significant body of scientific knowledge are outlined.

Based on the review of ecological constraints on marine farming in the region, it is recommended that marine farming is excluded from 50 m seaward to the boundary between sediment and rock bottoms (>100 m from shore), that farms and AMAs are developed incrementally, that discharges during harvesting be strictly controlled to minimise environmental impacts, and that farms are relocated periodically to allow benthic recovery where significant sedimentation occurs. It is also recommended that monitoring plays a key role in evaluating the ecological effects of each successive stage of farm and AMA development before implementation of the next stage is approved, consistent with a precautionary approach to the industry's growth.

Detailed review of the suggested AMAs include the principal ecological constraints and any mitigating factors, the nature and severity of scale and cumulative effects, a preliminary evaluation of the AMA's overall suitability, and development and critical information gaps that should be filled before any development. This review indicates that there are significant ecological constraints on most of the suggested AMAs, mainly because they are located too close to shore, are too large relative to their surrounding water mass, or because they almost completely enclose adjacent shores or embayments. AMA size and stocking density are key factors determining scale effects. Also, information gaps are substantial for all AMAs.

A precautionary approach to AMA establishment and development is urged because so little is presently known about the biophysical effects of marine farming in the region. Scientific knowledge gained through monitoring and employed within an adaptive management approach is seen as the best way to establish a sustainable, ecologically sound marine farming industry in the region.

1. Introduction

1.1. Aquaculture development in New Zealand

Aquaculture has become a major industry in New Zealand, employing large numbers of people and earning significant export revenue. Growth of this industry, especially green-lipped mussels, has been rapid with total industry revenue increasing from $25 million in 1989 to over $200 million in 2000. Expansion of mussel culture is predicted to continue, with export earnings projected to exceed $1 billion by 2020 because of unsaturated market demand and the presence of several undeveloped markets (http://www.ecan.govt.nz/coast/marine-farms/bm-introduction.html).

This potential saw a rapid increase in numbers of applications for establishing marine farms in the Marlborough Sounds during early development of the industry. More recently, as new favourable sites became scarce and as mussel growth rates declined in Marlborough Sounds, numbers of applications to farm elsewhere, notably along the Canterbury coast, increased. Over the whole country, some 200 applications for some 50,000 hectares of marine farms had been lodged by November 2001 (ECan 2002). Concomitantly, conflict between marine farming and public concerns over loss of access to coastal space and environmental concerns emerged.

Competing uses of coastal space are managed under the Resource Management Act (RMA), the Marine Farming Act 1971 and the Fisheries Acts 1983, 1986. Under this present legislative framework, marine farming requires a coastal permit in order to occupy space, erect structures and disturb the seabed. In evaluating applications for coastal permits, the regional council must consider the usual resource management issues, but impacts on fishers and fishery resources are specifically excluded form consideration. Consequently, communities cannot raise concerns over potential marine farm effects on recreational, customary or commercial fishing during the RMA process. Once a coastal permit is granted, the Ministry of Fisheries evaluates fisheries matters before issuing a marine farming permit (ECan 2002). Although the RMA process is open and can be appealed via the Environment Court, the marine farming permit process is closed, with no right of appeal, except via judicial review. This second step, therefore, also frustrates industry because an applicant must undertake the expensive resource management consent process, even if the application is subsequently declined at the marine farming permit stage. Consequently, Central Government imposed a two-year moratorium on marine farm applications to reform the aquaculture laws. Following the reform, aquaculture will be confined to Aquaculture Management Areas (AMAs), the Ministry of Fisheries participation in permitting will involve evaluation of the effects of the proposed farm on fisheries issues, and a single permit only will be required from the regional council (ECan 2002).

1.2. Environment Canterbury's approach to AMAs

Acknowledging that the dearth of existing and high cost of new ecological and environmental information on the region's coastal zone made AMA selection on purely ecological and other environmental grounds difficult, Environment Canterbury opted for a different approach. An initial set of candidate AMAs was selected based on those areas that marine farmers identified, through consultation, as favourable for marine farming. This was followed by public consultation to communicate the detail of the need for AMAs and the locations of these candidate areas. At the same time, NIWA has been commissioned to review existing information to help evaluate the suitability of these areas in relation to potential ecological and physical impacts of mussel farming and to provide guidance on their ecologically sustainable development. Note, this report summarises all available scientific information on the ecology of the Pegasus Bay – Banks Peninsula marine environment.

1.3. Purpose of this investigation

The objective of this report is to identify any environmental constraints on marine farming activities within the suggested AMAs.

The report does this by:

- drawing together available scientific information on the environments of these AMAs,
- identifying known and potential ecological effects of mussel farming,
- evaluating how the physical environment within each AMA might modulate the usual ecological effects of marine farming,
- identifying potential scale and cumulative effects, and
- identifying any factors that may constrain marine farming in an AMA for ecological and physical reasons (i.e., ecological constraints[1]).

The suitability of these candidate AMAs is then evaluated, in terms of likely ecological effects. Specific issues associated with AMAs in different environments are

---

[1] An ecological constraints is defined as any ecological effect, often mediated via some physical change, that limits or constrains the ecological carrying capacity (*sensu* Inglis et al. 2000) of an area where the primary management concern is the effects of farming and farm-related activities on the surrounding ecosystem.

next assessed and a general management strategy for the AMAs in relation to ecological and physical effects is proposed. The report also identifies some significant ecological information gaps and recommends management strategies for these AMAs. Issues concerned with the growth rates of farmed mussels and the financial viability of marine farming within these areas are beyond the scope of this report.

1.4. Scope

This report utilises information published in scientific journals and unpublished information provided by Environment Canterbury to examine biophysical[2] issues associated with marine farming in the region. Long-line mussel culture in shallow (<100 m depth) coastal waters is the primary focus of this review, although some consideration of sea-based abalone and sea cage salmon aquaculture is included to encompass present small-scale activities in Akaroa Harbour. Geographically, the review is confined to the North Canterbury region: Pegasus Bay and northern Banks Peninsula bays (Motunau to Long Lookout Point plus Akaroa Harbour, Figs 1-6).

2. Canterbury region coastal environment

2.1. Pegasus Bay

Pegasus Bay is a gently curved stretch of coastline, some 50 km long and running essentially south-north from Banks Peninsula to Motunau. Banks Peninsula and the cliffs and rocky shores of the Teviotdale Hills in the north create the embayment, providing some shelter for the Bay's sand and mixed sand-gravel beaches. Two larger rivers flow into the bay: the Waimakariri and Ashley rivers supply considerable quantities of greywacke sediments to the near-shore environment.

2.1.1. Shores, sediments and bathymetry

The Pegasus Bay shores are rocky in the north, but consist of finer sediments (fine gravels to fine sands) south of the Waipara River. Steep cliffs of limestone, silt/mudstone and sandstone characterise the shores between the Waipara River and Motunau (Suggate 1978). Wave-cut platforms and boulder beaches are variously developed at the foot of these cliffs, presenting a rugged and exposed shore.

---

[2] The term “biophysical” is used here to encompass biological, ecological and physical phenomena, most of which have ecological consequences. In this respect, it is largely synonymous with “ecological”.

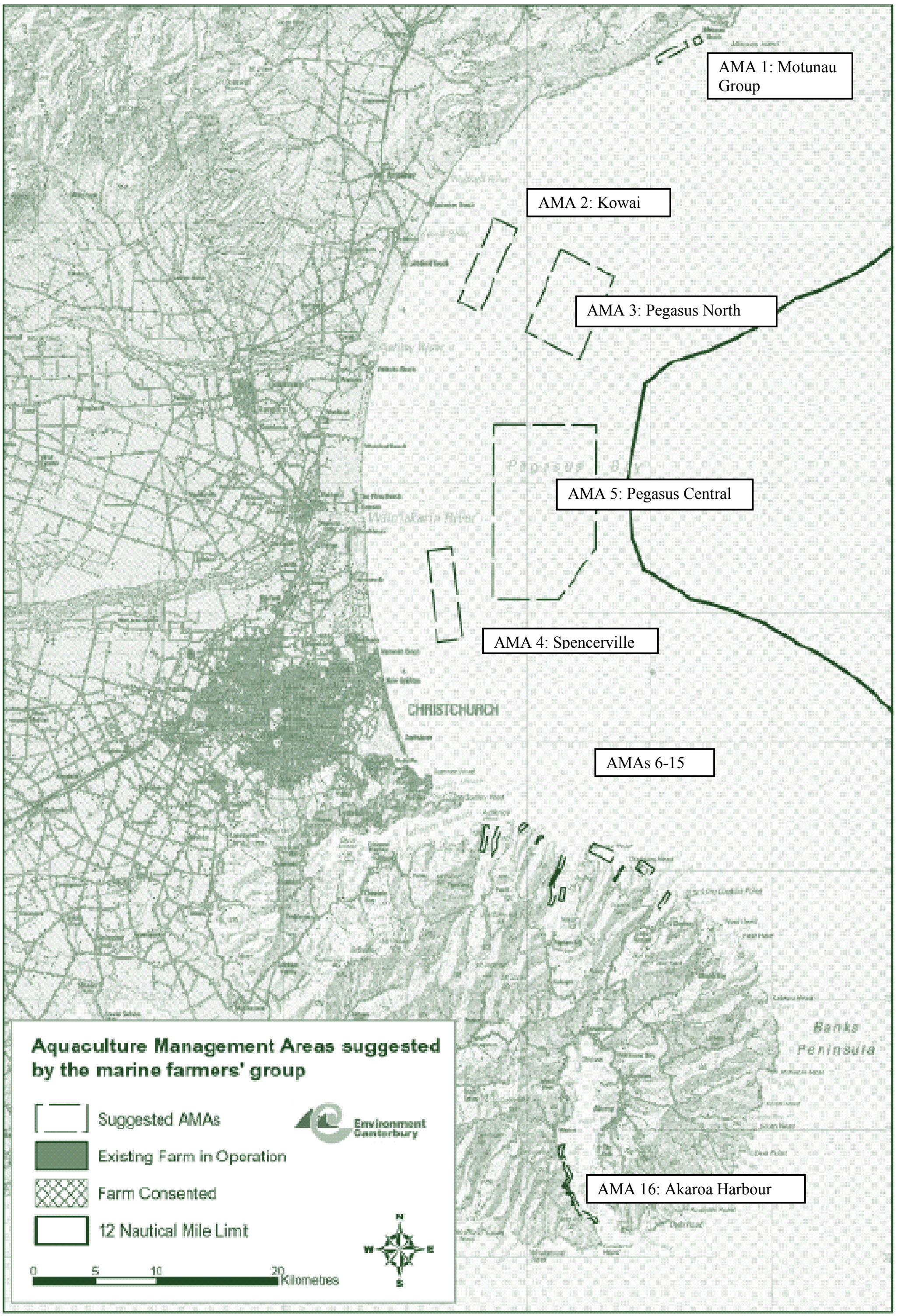

Figure 1. **Location of suggested AMAs in the Canterbury region (modified from ECan 2002). See Figs 2-6 for more detail on AMAs 6-16.**

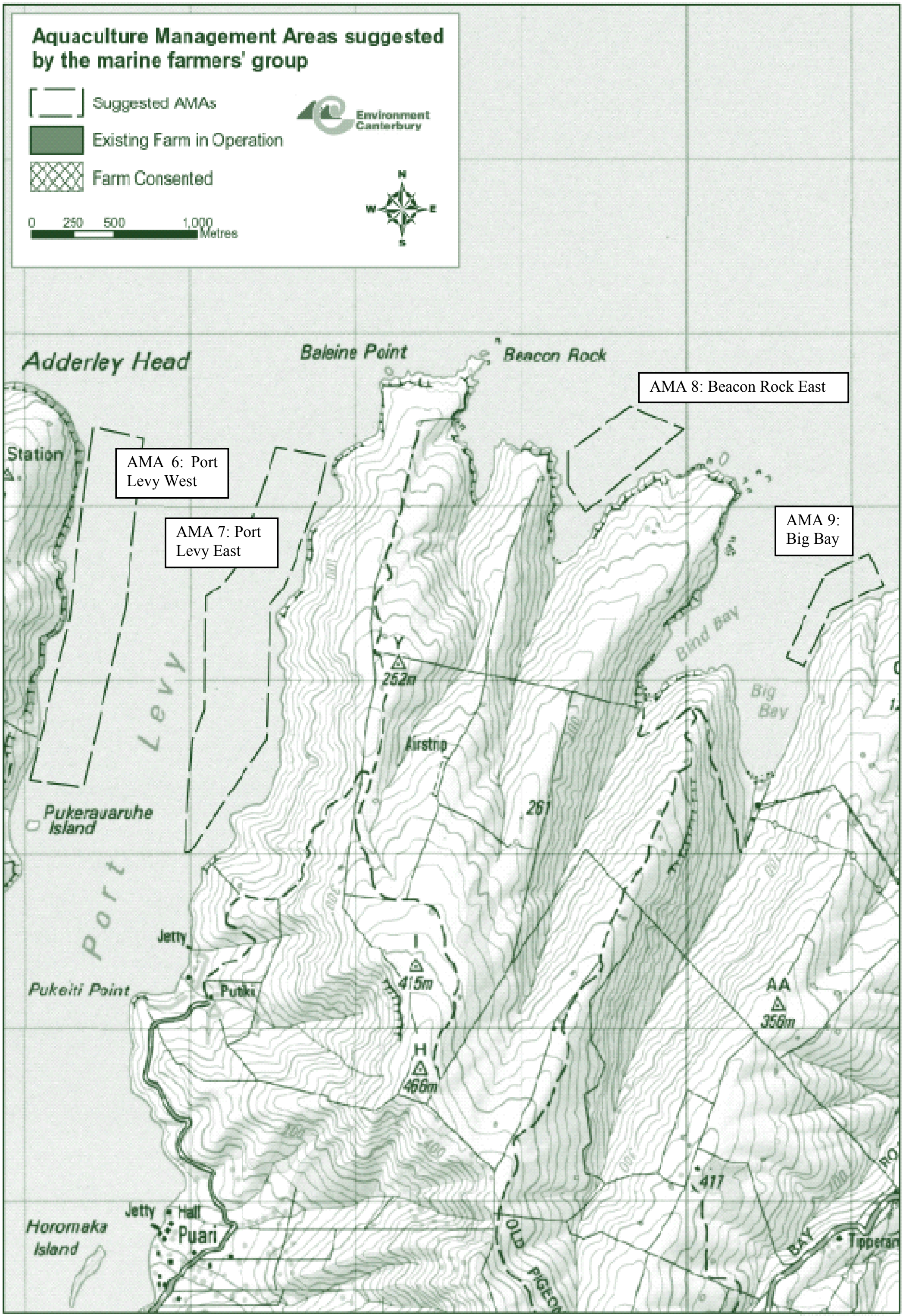

Figure 2. **Locations of suggested AMAs 6-9, Port Levy West to Big Bay, on northern Banks Peninsula (modified from ECan 2002).**

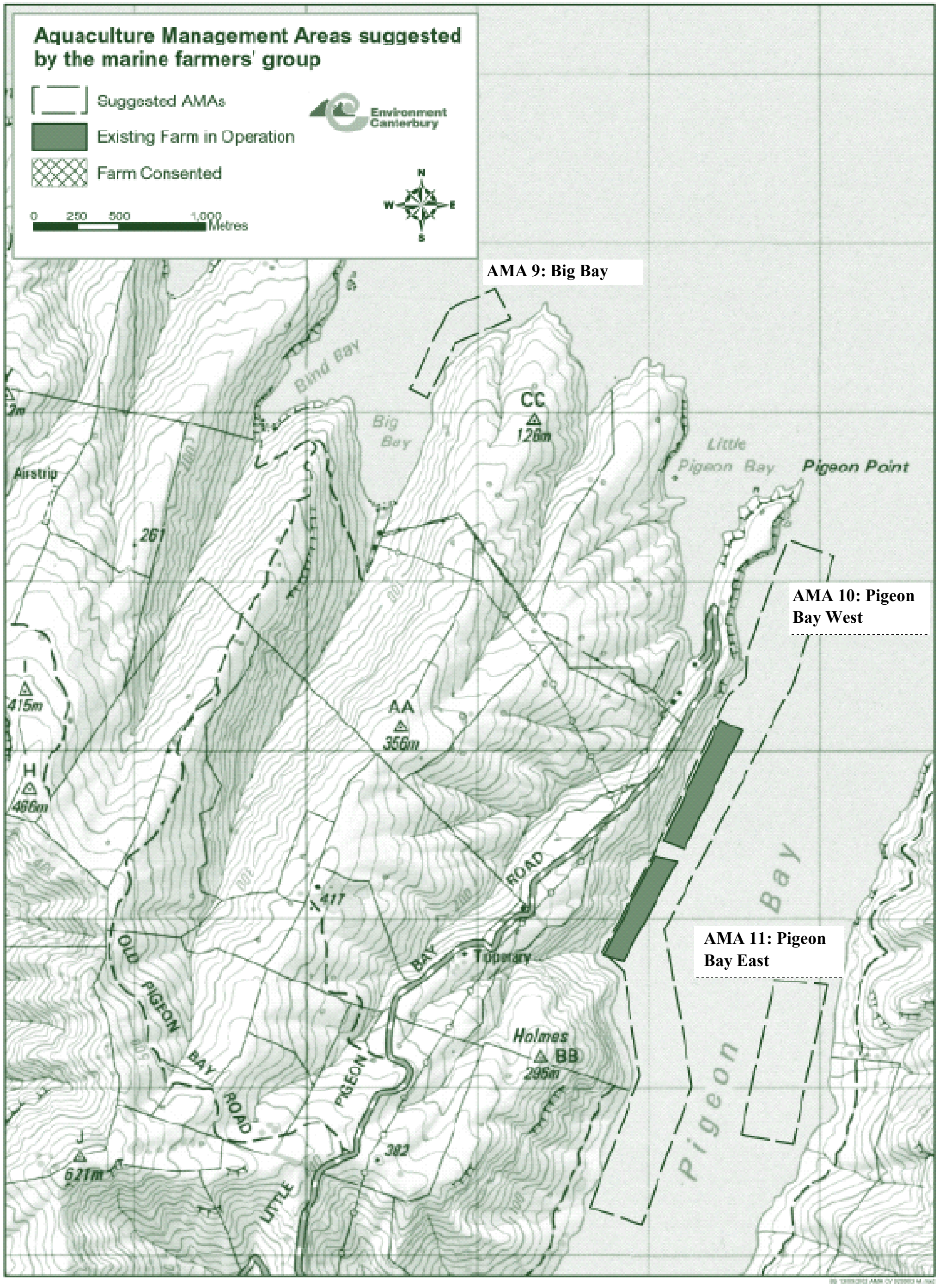

Figure 3. Locations of suggested AMAs 9-11, Big Bay to Pigeon Bay East on northern Banks Peninsula (modified from ECan 2002).

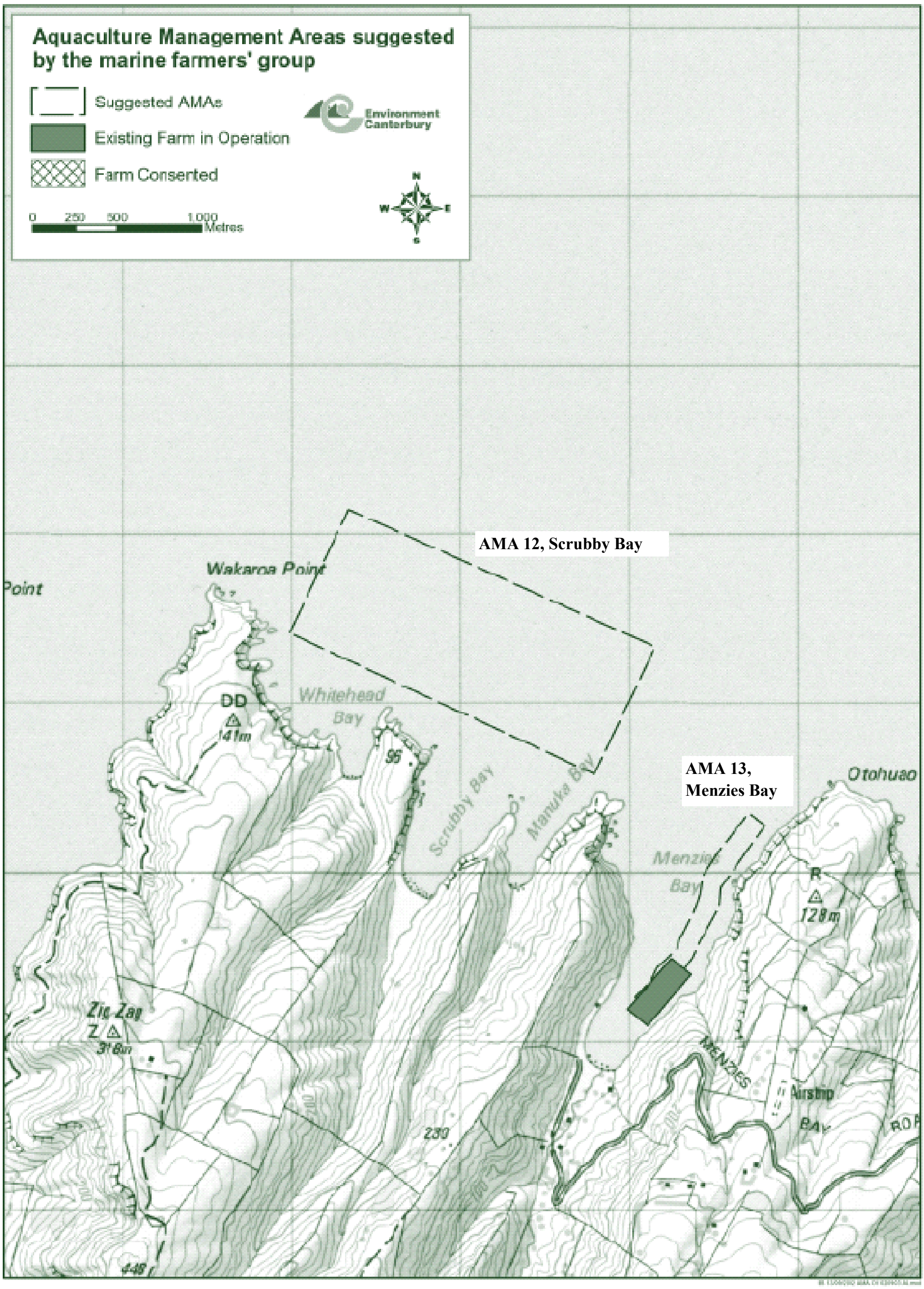

Figure 4. Locations of suggested AMAs 12-13, Scrubby (Scrubby, Whitehead and Manuka) Bay and Menzies Bay on northern Banks Peninsula (modified from ECan 2002).

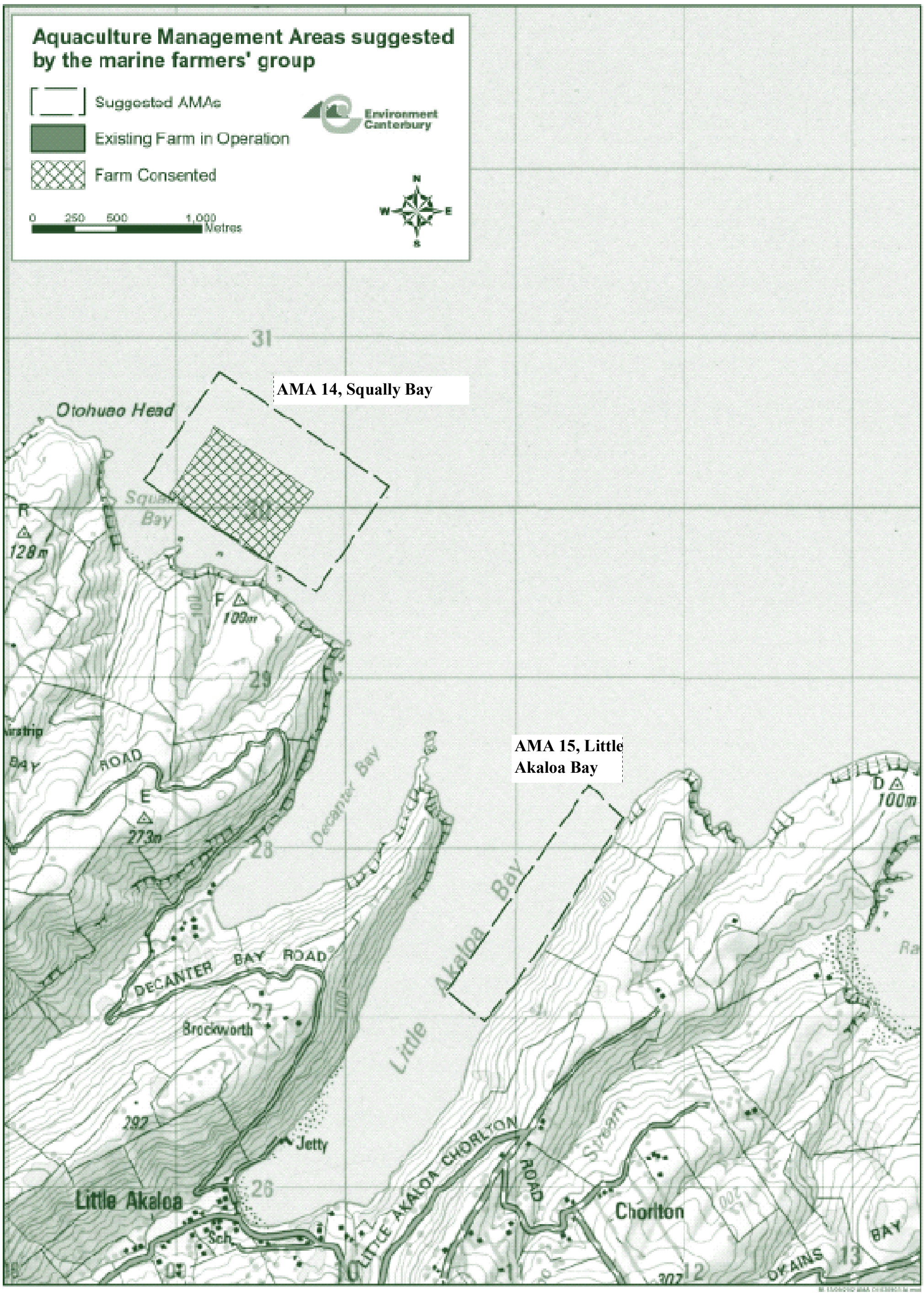

Figure 5. Location of suggested AMAs 14-15, Squally Bay and Little Akaloa Bay on north-eastern Banks Peninsula (modified from ECan 2002).

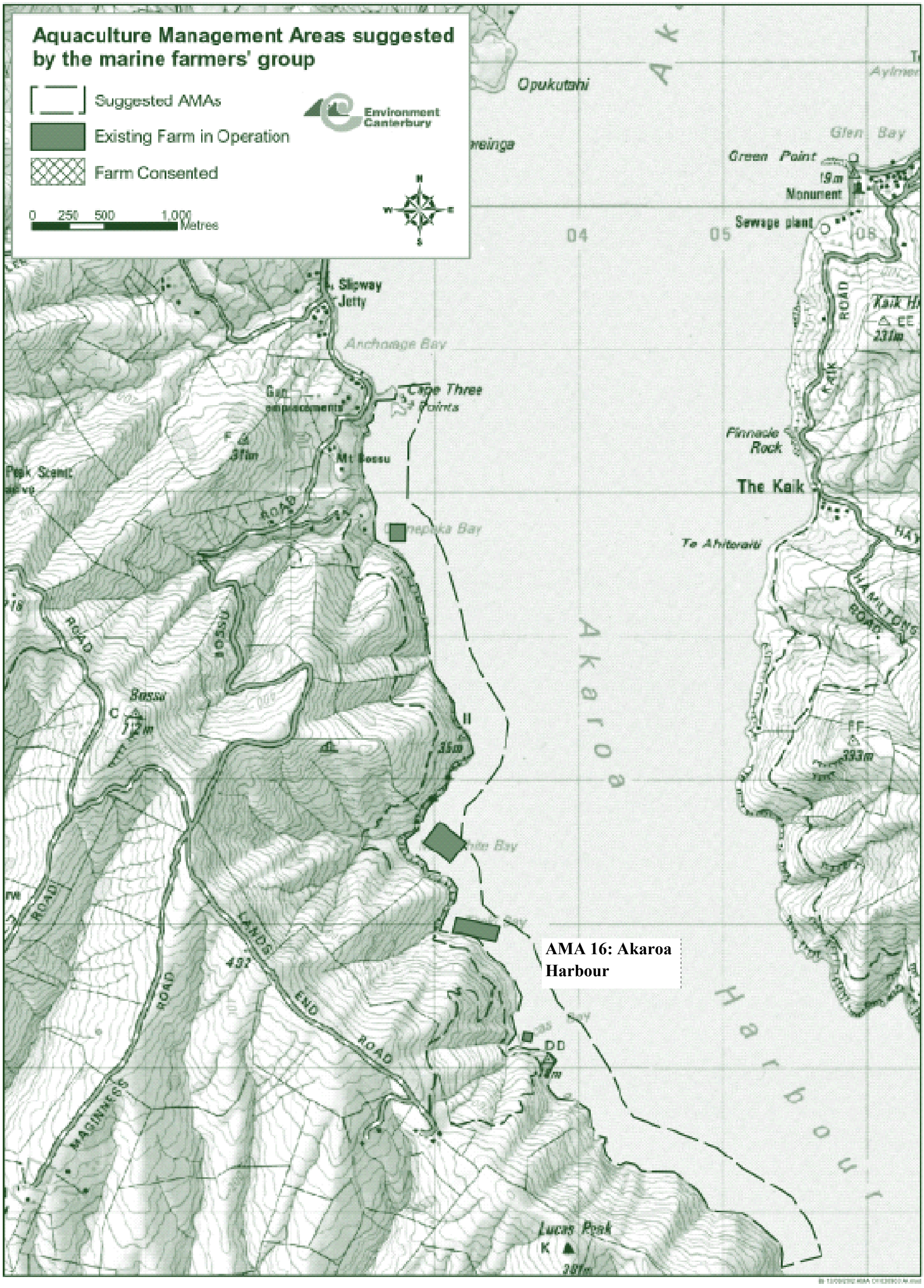

Figure 6. Location of suggested AMA 16, Akaroa Harbour on southern Banks Peninsula (modified from ECan 2002).

The seabed at depths of 9-15 m within 1-1.5 km of the rugged northern Pegasus Bay shores comprises four types: rocky reefs of bedrock, areas of low lying boulders, cobbles and compacted pebbles, low lying outcrops of mudstone, and rippled sand (Davidson 2001).

The beaches of Pegasus Bay (Waipara River to Brighton Spit) are generally prograding (advancing seaward) at an increasing rate over the last 60 years (Allan et al. 1999). In the vicinity of South Brighton, the rate of this progradation was estimated at 2.6 m y^{-1} over 1978-1988 and 6.4 m y^{-1} since 1989 (Allan et al. 1999). Off Brighton, the fine sand beach slopes moderately steeply (3.3°) to 4 m depth and more gently (0.5°) to about 10 m depth (Allan et al. 1999). Beyond this, the bottom slope continues to decrease at gradients of about 1 in 3000 (0.17-0.02°) to at least 30 m depth (Brown 1976; Allan et al. 1999).

Intertidal sediments change along the Bay from poorly sorted sand-fine gravels (Wentworth size classes) in the north, to well-sorted, medium to fine sands in the south (Blake 1968). Seven subtidal sediment groups were identified within Pegasus Bay by Campbell (1974). That investigation reported a transition from fine sands inshore, very fine sands at about 10 m depth, to very fine sand with silt and clay extending to about 25-30 m depth (Campbell 1974). Near-shore, subtidal sediments (5-16.5 m depth) off Spencerville, about 2 km south of the Waimakariri river mouth, were predominantly very fine sand (Knox et al. 1978). Clay and silt increased with depth and distance from shore, but their percentages varied appreciably (Knox et al. 1978). A recent survey off South Brighton (Allan et al. 1999) reported a small decrease in mean sediment particle size to 14 m depth. There was also an increase in sorting to 9 m deep, followed by a decline to about 12 m, and an apparent increase deeper than 12m. Another recent investigation reported predominantly (61-88%) fine sands from 3 to 14 m depth and an abrupt change to predominantly silt (80%) by 18 m depth (Fenwick 1999).

Further (5 km) offshore, the seabed slopes more gently and finer sediments predominate. A side-scan sonar survey of the bottom between 18-23 m depth off the Kowhai River mouth and off Spencerville reported “a featureless seabed … of fine dark sandy silts” (Gibbs 2002: 2-3). A more extensive survey 10-20 km offshore revealed that sediments were quite similar across the entire area, comprising moderately well sorted muds (PBAL 2001). Coarse silt was the predominant particle size fraction, with medium and fine silt forming the subdominant fraction. The exceptions were towards the north-east and south where finer fractions co-dominated, with coarse silt being a subdominant or minor component. Mud fractions, thus, made up 95 to almost 100% of sediments. Organic carbon content of the sediments was uniformly low (1-3%).

2.1.2. Hydrodynamics

The hydrodynamics of the region are complex (Fig. 7), being influenced by winds, tides and other large-scale oceanographic processes, such as the Southland current, which strongly influence Pegasus Bay (Heath 1972). Inflows from rivers, notably the Rakaia and Waimakariri, add to the complexity of the region's hydrodynamics, especially during flood flows when large volumes of silt-laden freshwater enter the near-shore zone (Fig. 7). As the Southland current sweeps around Banks Peninsula, it appears to drive a counter-clockwise eddy or gyre within Pegasus Bay on occasions, but at other times northward flow predominates (PBAL 2001). Although detail of currents over the entire bay is lacking, there are some data available for central Pegasus Bay, based on sampling in the vicinity of the large Pegasus Central AMA (4) (PBAL 2001) and for the ocean outfall (URS 2001). In these studies, the predominant current directions are NNE-SSE travelling at mean velocities of 10-13 cm sec^{-1} at all depths (PBAL 2001). Peak velocities of up to 33 cm sec^{-1} occur over high water, during the latter part of rising tides or early to mid ebbing tides (PBAL 2001). Highest velocities occur during southerly winds, which result in northerly-flowing currents. Net flows in central Pegasus Bay were found to be westerly by c. 10 km over 17 days (PBAL 2001).

Despite gentle offshore gradients, the near-shore environment is one of high energy (Burgess 1968). Based on shore-based observer records, waves in southern Pegasus Bay are predominantly from the north-east and east in summer (81% vs 65% in winter) and from the south-east in winter (34% vs 19% in summer) (Single and Fitzgerald 2001). In contrast, wave data from a buoy moored 17 km east of Steep Head from 24 October 2000 to 24 October 2001 showed that waves from the south-east and south predominated (61%), with waves from the north-east and east occurring just 25% of the time (PBAL 2001). Wind waves and ocean swells, generated over essentially unlimited fetches arriving in southern Pegasus Bay from the north-east, east and south-east, averaged 0.8-1.0 m in height (range 0.3-2.6 m) (Allan et al. 1999; Single and Fitzgerald 2001), whereas the average height of the largest third of all waves (average significant wave height or H_s) was 1.7-2.0 m at the wave buoy off Steep Head (PBAL 2001). Waves reaching northern Pegasus Bay beaches are, apparently smaller than those reaching southern beaches (e.g., mean wave heights at Waikuku were 0.25 in summer and 1.5 m in winter). Deepwater waves may potentially attain heights of 4.9-6.6 m (Goring and Macky 1997).

In addition, tides and currents create further circulation. Counter-clockwise eddies of the north-flowing Southland Current flow southwards along the shore and back out to sea (Dawson 1954; Brodie 1960), but this eddy is neither permanent nor extends through the entire water column (Single and Fitzgerald 2001). Consequent long-shore currents and rips, along with tidal streams, create a turbulent near-shore environment with considerable water mixing and sediment movement. This means that the seabed itself is highly mobile at shallower depths (Allan et al. 1999). Preliminary investigations (Allan et al. 1999) suggest that sand levels at any one point fluctuate by as much as 2.2 m vertically at about 7 m depth and by 1.0 m at 14 m depth (about 0.9 and 2.2 km offshore, respectively). Such dramatic temporal changes in bottom topography are unlikely further offshore.

Figure 7. Oblique view of the Pegasus Bay-Banks Peninsula region (NASA satellite image, 3 April 2001) showing the very turbid coastal zone with complex hydrodynamics.

Water movement due to wave action is considerable in all seasons. Over summer months, the Canterbury coast experiences moderate to strong sea breezes and accompanying wind waves from the north-east occur on many days. At any time of the year, but more frequently during winter, swells (up to 5 m height) and storm waves approach from the south-east. Banks Peninsula only partially shelters Pegasus Bay from waves approaching from southerly directions because waves are refracted around the Peninsula (Dingwall 1974; PBAL 2001).

Turbidity is a striking feature of seawater along the Canterbury coast, especially near Banks Peninsula. The combination of large braided alluvial rivers with high sediment loads when in flood, proximity to Banks Peninsula with its high loess inputs to the coastal system, the gently sloping bottom of the Bay and seasonal weather patterns of protracted periods of relative calm seas results in a continual supply, deposition and re-suspension of very fine sediment within the near-shore environment (Fig. 7). Sediment is transported from south to north around the Peninsula (Fig. 7), especially when the northerly-flowing coastal current, flood tidal streams and south-easterly swells coincide (Dingwall 1974). The frequent wind and wave-induced moderate water movement continually re-suspends this material both off Banks Peninsula and within Pegasus Bay. There are no indications that these high sediment loads pose any problems for the natural biota or farmed marine species, based on the abundant soft and hard-bottom biotas through out the region and the high growth rates reported for farmed mussels in Pigeon Bay.

2.2. Banks Peninsula

2.2.1. Shores, sediments and bathymetry

Banks Peninsula, a large promontory on the east coast of the South Island, was formed by two large, extinct volcanoes, now covered with very fine greywacke loess carried in by winds from the Canterbury glaciers and rivers (Dingwall 1974). As a result of erosion over millions of years, the Peninsula's present day topography is characterised by a series of high peaks (some exceeding 800 m) and radiating deep valleys. The coastline is made up of numerous long, deeply indented embayments, almost radial in orientation and separated by high rocky headlands. The seaward sides of the Peninsula's two craters have collapsed and the resulting harbours, Lyttelton and Akaroa, are some 15 km long. Other long, narrow embayments include Port Levy, Pigeon Bay, Little Akaloa, Otanerito, Peraki and Te Oka Bay, each with different orientations to prevailing seas and winds. Typically, the shores of these bays change from gently sloping beaches at their inland extremities, through rocky shores that increase in steepness to seaward, to rugged shores and high cliffs to seaward. Between each bay, headland cliffs rise directly from the gently sloping seabed, some 12-15 m deep, to more than 100 m above sea level.

Subtidal habitats below headland cliffs are equally rugged. Large boulders and dissected unbroken bedrock form the steep bottom to depths of c. 15 m (Nairn 2001a-c). Here the rocky bottom gives way to an almost level muddy bottom, with few rocky outcrops. This level muddy bottom extends for several kilometres to seaward, north, east and south of these bays (Hydrographer RNZN 2000).

2.2.2. Hydrodynamics

Currents close to shore along Banks Peninsula's open northern coast are predominantly tidal, flowing east-west (parallel to the general shore orientation) with each tide and generating a net north-easterly flow. In surface (4 m depth) waters, this net flow is about 2.6 km day^{-1} (18 km over 7 days), but slower (1.4 km day^{-1} or 10-11 km over 7 days) at the middle of the water column (8 m depth) (Ross and Image 2001b). Current speeds peak at 13-14 cm sec^{-1} at both 4 and 8 m depth just before the turn of the tide (Ross and Image 2001b).

Within Banks Peninsula bays, currents appear to resemble estuarine current patterns with strong tidal inflows in bottom water and the upper half of the water column flowing out of the bay. In the middle of Pigeon Bay, one of the long, narrow embayments, current velocities averaged 7-8.5 cm sec^{-1}, peaking at c. 18 cm sec^{-1} (Fenwick et al. 2001; Fenwick and Ross 2002; Ross and Image 2001a), with moderate flushing rates reported at times in Pigeon Bay (Fenwick and Ross 2002).

Tidal ranges in the Banks Peninsula area are about 2.0-2.5 m. Surface water movement due to wave action is considerable in all seasons, however. Over summer months, the Canterbury coast experiences moderate to strong sea breezes and accompanying wind waves from the north-east on many days. During winter, as well as at other times of the year, swells (up to 5 m height) and storm waves approach mainly from the south-east, entering south-eastern bays (between Hickory to Flea Bays) without interruption over very long fetches, depending upon the direction of their approach. Along the eastern and northern margins of the Peninsula, these storm swells are deflected by the shoaling bottom to approach more perpendicularly. As a result, swells exceeding 2 m in height commonly approach the seaward extremities of east and north-facing embayments.

Turbidity is a striking feature of the Banks Peninsula marine environment (see Fig. 7). The combination of deforested hills and periods of substantial run-off at the ends of long embayments result in a continual supply of very fine sediment to the near-shore environment from Banks Peninsula soils (Dingwall 1974). Sediment is transported from south to north around the Peninsula, especially when the northerly-flowing coastal current, flood tidal streams and south-easterly swells coincide (Dingwall 1974). Under these conditions, fine sediments are transported into and trapped by the Peninsula's bays (Dingwall 1974), as well as settling out in deeper water (< c.12 m depth). The frequent wind- and wave-induced water movement continually re-suspend this material, particularly from shallower bottoms, but this water movement is insufficient to reduce the amount of fines present. Consequently, inshore waters around the entire Peninsula are characteristically turbid, usually carrying high sediment loads.

2.3. Three types of coastal environments

Beyond intertidal zones and the immediate surf zone on exposed beaches, the Canterbury coastal environment comprises three broad habitat types that lie along gradients of increasing depth and exposure to wave action. These intergrading or overlapping habitat types are: sheltered to semi-sheltered harbour and bay habitats, open coast habitats, and offshore habitats. Each of these is also divisible into soft or sediment bottoms and hard or rocky bottoms, based on the nature of the substrate; a primary factor determining the composition of benthic communities at any location.

These habitat types lie along continua of distance from shore, depth, wave exposure and sediment grain size. Sometimes, boundaries between adjacent habitat types are abrupt (e.g., between sandy and unbroken bedrock bottoms beneath headlands), but mostly there are no distinct boundaries (e.g., soft bottoms of sheltered harbours intergrade to seaward with semi-sheltered and offshore habitats). These transitions also vary in width and depth, so that it is impractical to establish set boundaries based on physical factors alone. Nonetheless, these categories provide a meaningful framework for understanding benthic communities that may be quite variable, even within a single habitat type.

2.3.1. Harbour or semi-sheltered bay environments

Little is known of plankton ecology of these waters, nor of their nutrient status and dynamics, apart from short-term surveys for a few marine farms and monitoring for nuisance phytoplankton in Akaroa Harbour. However, a recent report (Fenwick and Image 2002) collated data showing periodic high nutrient concentrations and several phytoplankton blooms, including some involving known toxic species. The sources of these nutrients were not determined, although outflows from groundwater, Lake

Ellesmere Te Waihora (plus possibly Lake Forsyth) and the Rakaia River may be implicated (see Fig. 7). Importantly, the potential for blooms to occur within these long, narrow harbours, where water exchange may be poor during long calm periods (Fenwick and Image 2002), and their potentially dramatic effects on marine farming should be noted. Further, there is no reason to suspect that the frequency and severity of these problems will lessen in the foreseeable future, largely because land-use intensification and population growth is continuing in contributing catchments.

(a) Soft bottom benthos

Benthic biotas of soft bottoms in harbours vary with water movement and the resulting variations in sediment size composition. Four different macrobenthic communities or assemblages were identified in Lyttelton Harbour from an analysis of species abundances (Knight 1974). These communities were associated with sediment characteristics, but invariably intergrade with each other, sharing some species, as well as each having some distinctive combinations of taxa[3] (Knight 1974). The four communities were characterised as follows:

***Chione*[4] *stuchburyi* community:** Cockles (*Austrovenus stutchburyi*) dominated locally in shallow, sheltered waters, where it attained biomasses of up to 9 kg m^{-2} (Knight 1974). Associated species included the shrimp *Pontophilis australis*, an anemone (*Anthopleura aureoradiata*), another bivalve (*Myadora striata*) and three amphipods.

***Macrophthalamus*[5]*-Virgularia* community:** More widespread on sheltered, sandy mud bottoms was an assemblage dominated by the mud crab *Macrophthalamus hirtipes* and sea pen *Virgularia gracillima*, with gastropods (*Xymene plebeius*, *Micrelenchus huttoni*), an ophiuroid (*Ophiomyxa brevirima*), a polychaete worm (*Platynereis australis*) and the ubiquitous shrimp, *Pontophilis australis* (Knight 1974).

***Zeacolpus-Pectinaria* community:** A third community occurred widely on sandy harbour bottoms. A gastropod (*Zeacolpus vittatus*) and a tube-worm (*Pectinaria australis*) co-dominated. Other characteristic taxa included gastropods (*Trochus tiaratus*, *Zegalerus tenuis*), bivalves (*Myadora striata, Nucula hartvigiana, Spisula*

---

[3] The term taxa (singular = taxon) refers to any group of the same type of organisms, such as species in a family or species in a genus. Many of the studies reviewed here identified animals to differing levels, so that the terms taxon and taxa are used as the collective terms for these disparate entities.

[4] The New Zealand species *stutchburyi*, previously assigned to the genus *Chione*, is now placed in the genus *Austrovenus*.

[5] The species to which this refers (*hirtipes*) was previously assigned to the genus *Hemiplax*.

aequilateralis), a small cuttlefish (*Sepioloidea pacifica*), the seastar *Patiriella regularis*, and a tube-worm (*Owenia fusiformis*).

***Ostrea-Sigapatella* community:** Small, dispersed patches of the oysters (*Ostrea heffordi*) and associated slipper limpet (*Sigapatella novaezealandiae*) were present wherever there were hard surfaces for settlement. This assemblage was more restricted than the others, its only other member being the small crab *Halicarcinus whitei*.

Knight (1974) compared his findings for Lyttelton Harbour with those from other benthic investigations in New Zealand. Although direct comparisons were difficult due to differences in sampling methods, the sizes of areas investigated and the spatial scales of sampling, broadly equivalent communities could be identified elsewhere. Species diversity and species composition differed appreciably between similar communities, but many of the taxa occurred widely.

Subsequent investigations of soft-bottom benthos in the Banks Peninsula-Pegasus Bay region[6] focussed more on smaller macrofauna, rather than on the larger macrofauna (emphasized by Knight (1974) in Lyttelton Harbour. The larger sampling effort for the Lyttelton investigation (69 samples using box dredge, orange-peel grab and epibenthic sled) produced further disparities, and Knight (1974) did not report the relative abundances of most species found. These differences made it impractical to match the fauna in other bays with the Lyttelton Harbour soft bottom communities. However, the benthos in many other Banks Peninsula bays included species that Knight (1974) regarded as characteristic of at least two of the Lyttelton communities, suggesting that the benthic fauna of this habitat intergrades with adjacent assemblages or communities (Fenwick and Cole 2001; Fenwick 2002b) over quite small spatial and temporal scales. For example, infaunal species compositions and abundances differed appreciably on apparently homogeneous, almost level muddy bottoms over distances of 200-300 m in Pigeon Bay (Fenwick and Ross 2002). Meaningful comparisons between bays, therefore, require replicate sampling and statistical analysis of quantitative data. In the absence of such data, comparisons developed here focus on dominant species and the general composition of the benthos.

A few benthic species occurred abundantly and consistently in sheltered, soft-bottom habitats around the Peninsula. The mud crab (*Macrophthalamus hirtipes*) and mud shrimp (*Pontophilus australis*) were widespread, often comprising the most abundant larger animals in benthic communities in the northern Banks Peninsula bays (Fenwick and Cole 2001; Fenwick 2002a, b; Fenwick and Ross 2002), as well as in Lyttelton

---

[6] Davidson (1989) described the shallow benthos just off beaches at Brighton, Taylors Mistake and Little Akaloa. Because his sites were in areas unsuitable for aquaculture, Davidson's (1989) work is not included.

Harbour (Knight 1974). Polychaete worms were characteristically abundant, especially species belonging to the families Sigalionidae, Spionidae, Trichobranchiidae and Nephtyidae. The small exotic bivalve, *Theora lubrica*, also was characteristic, along with ampeliscid amphipods and cumaceans.

There are several studies on the infauna of Akaroa Harbour, but all are very superficial. Soft bottoms along the seaward half of the harbour's western shore (Ohinepaka to south of Lucas Bay) are typically gently sloping silty mud (Schiel 1993; Davidson 1999a-b, d, 2000 a-c). The benthos is dominated by mud crabs (*Macrophthalamus hirtipes*) at mean densities of up to 200 m^{-2} (Schiel 1993). Other inhabitants of these bottoms include horse mussels (*Atrina zelandica*) (mean densities 0.04-0.13 m^{-2}), with scattered green lipped mussels and small cushion stars (*Patiriella regularis*) (Schiel 1993; Davidson 1999a-c, 2000a-c). Notably, areas of increased horse mussel density occurred 60-100 m offshore south of Ohinepaka Bay (mean 0.3 m^{-2}) (Davidson 2000b), 40-80 m offshore at Titoki Bay and just north of Mat White Bay (mean 0.5 m^{-2}) (Davidson 1999a, 2000c), and between Titoki and Mat White Bays (mean 0.7 m^{-2}) (Davidson 1999b).

Seaward of Lucas Bay (east of Lands End Road), the sediment bottom changes from muds to sand, apparently within about 150 m (Davidson 1999c), presumably with a concomitant change in the fauna. Horse mussel densities decreased at this site to 0.04 m^{-2}, compared with mean densities of up to 0.7 m^{-2} further with inshore (Davidson 1999b-c) and were completely absent seaward of this location (Davidson 2000d-e). However, there is no other reliable information on changes in the benthos of these soft bottoms along the western side of Akaroa Harbour.

(b) Hard bottom benthos

Rocky shores in Akaroa Harbour descend variously from the intertidal, through a zone of unbroken bedrock to 4 m depth, thence a mix of bedrock, boulders and cobbles gives way to cobbles, shell and sand by 10 m depth. A zone of dead whole and broken shell overlying muddy to sandy sediments occurs at 12-15 m depth, some 80-100 m from shore (Davidson 2000a). The widths of these zones differ from place to place depending on substrate slope (Davidson 1999a-c, 2000b-c).

Brown algae (*Durvillaea antarctica, D. willana, Carpophyllum maschalocarpum, C. flexuosum, Cystophora torulosa, Marginariella sp., Lessonia variegata, Macrocystis pyrifera, Ecklonia radiata*) dominate the biota to 6 m depth, with kelp beds (*Macrocystis pyrifera*) forming a narrow ribbon (<50 m wide) parallel to shore along much of the western side[7] of Akaroa Harbour seaward of Wainui (Schiel 1993; Davidson 2000b). These shallower rocky bottoms support several typical rocky shore invertebrates (>45 species reported by Davidson 2000b). Notable amongst these are large herbivorous gastropods (*Cookia sulcata, Haliotis iris*) and echinoderms (*Evechinus chloroticus, Astrostole scabra, Coscinasterias calcamaria, Pentagonaster pulchellus*) (Schiel 1993). In Titoki Bay and seaward, green-lipped mussels and the sea tulip (*Pyura* sp.) dominate the fauna of the shallow, brown algae zone (Davidson 1999a). Sea tulips appear absent from the shore seaward of the end of Lands End Road (Davidson 2000d). Boulders at the deeper margin of the rocky bottoms also support abundant sponges, sea squirts, *Perna canaliculis* and the topshell, *Trochus viridis* (Schiel 1993). Red algae, notably *Lenormandia chauvinii*, replace browns on rocky bottoms below about 6-8 m depth (Davidson 2000b). Fishes also are abundant and diverse on these bottoms, with as many as 19 species recorded at any one location (Davidson 1999a, b, d,). These include several widespread reef fishes (spotties *Notolabrus celidotus*, banded wrasse *N. fucicola*, leather jackets *Parika scaber*), as well as blue cod, blue moki, butterfish and tarakihi (Schiel 1993; Davidson 2000a).

(c) Fishes

Fish species recorded from Akaroa Harbour by divers are listed in Table 1. Only a small number of the more abundant fishes in Akaroa Harbour are important to recreational fisheries. As for exposed coastal environments, the most important fishes are blue moki, blue cod, and greenbone (or butterfish), all of which occur close to rocky reefs. Red cod are also caught in these harbours and embayments, but are of lesser value. Blue cod and red cod are widespread and abundant in deeper water, whereas blue moki and greenbone are markedly less common and are more restricted to rocky reefs near shore, where they are more vulnerable to fishing pressure.

It seems unlikely that any of these species would be adversely affected directly by marine farming. It is quite possible that blue cod, blue moki, and greenbone could benefit from the additional cover and food associated with marine farms.

(d) Marine mammals

Whales and dolphins, other than Hector’s dolphins, are reported infrequently Banks Peninsula harbours and embayments. Hector’s dolphins, however, are common. They enter most harbours and embayments, but their densities, as inferred from numbers of sightings and sightings standardised by effort (Slooten et al. 2000) are quite variable. These data show highest densities in coastal waters outside most embayments and

---

[7] There is almost certainly a change from *Macrocystis* and *Carpophyllum* dominated algal communities closer to Wainui to *Duvillaea* dominated communities further seaward, but these changes cannot be elucidated from Davidson’s various reports.

harbours, except for high densities found in Akaroa Harbour and isolated bays along the peninsula's south coast (Slooten et al. 2000). With the exception of Akaroa Harbour, therefore, very low densities of Hector's dolphins were reported from embayments for which AMAs are suggested (DuFresne et al. 2000; Slooten et al. 2000).

Table 1. **Marine fishes recorded from Akaroa Harbour with indices of relative abundance: C = common, O = occasional, R = rare. Sources of data are Davidson 1999a-d, and Davidson 2000a-e.**

Scientific name	Common name	Relative abundance
Aplodactylus arctidens	Marblefish	R
Chelidonichthys kumu	Red gurnard	O
Congiopodus leucopaecilus	Southern pigfish	R
Forsterygion lapillum	Common triplefin	O
Forsterygion varium	Variable triplefin	C
Forsterygion malcolmi	Mottled triplefin	C
Forsterygion flavonigrum	Yellow-black triplefin	O
Hemerocoetes monopterygius	Opalfish	C
Hippocampus abdominalis	Seahorse	R
Hypoplectrodes huntii	Red-banded perch	R
Latridopsis ciliaris	Blue moki	O
Notoclinops segmentatus	Blue-eyed triplefin	R
Nemadactylus macropterus	Tarakihi	R
Notolabrus celidotus	Spotty	C
Notolabrus fucicola	Banded wrasse	C
Obliquichthys maryannae	Oblique triplefin	R
Odax pullus	Greenbone	O
Parapercis colias	Blue cod	O
Pseudolabrus miles	Scarlet wrasse	C
Pelotretis flavilatus	Lemon sole	O
Raja sp.	Skate egg case	R

New Zealand fur seals are increasing in abundance and distribution on Banks Peninsula (PBAL 2001), but appear to be rare visitors to harbours and embayments along the eastern and northern coasts.

(e) Birds

Three endemic subspecies of seabirds breed in and frequent the bays and inlets of Banks Peninsula. White-flippered penguins enter most, if not all, harbours and embayments, with about 550 pairs breeding around the shoreline of the Banks Peninsula (Challies 1998). The abundance of white-flippered penguins on Banks Peninsula has declined in recent years, primarily because of predation at breeding sites

(Challies 1998). Brager and Stanley (1999) studied the distribution of white-flippered penguins in the waters of southern Banks Peninsula between November 1993 and March 1997. The birds were not evenly distributed, but appeared to concentrate in several bays. In Akaroa Harbour, the relative abundance of white-flippered penguins varied considerably at different times of the year with monthly averages ranging from 0.8 to 11.0 individuals; peak numbers occurred in April and November, with relatively few sightings from December to March and from August to September. Within Akaroa Harbour, white-flippered penguins almost exclusively used only the southern (outer) half of the bay.

Spotted shags breed in caves and on headlands of Banks Peninsula and they have increased in abundance in recent years. In 1960, Turbott and Bell (1995) counted <10,000 breeding pairs, but a repeat survey in 1996 revealed about 22,000 pairs (Doherty and Brager 1997) out of a total estimated New Zealand breeding population of less than 30,000 pairs (Taylor 2000). They appear to feed inshore during summer, when large numbers may enter harbours and bays (Lalas 1983; Hawke 1998). White-fronted terns also breed around the coastline of Banks Peninsula and usually forage for small shoaling fish (Heather and Robertson 1996), which they obtain by plunge diving. The population of white-fronted terns has probably declined markedly in recent years because of human disturbance to breeding colonies. In 1998, the total population was estimated at 12,000-15,000 pairs (Taylor 2000).

In addition, black shags, little shags, southern black-backed gulls, red-billed gulls, black-billed gulls, and black-fronted terns also feed in sheltered bays. Black shags, red-billed gulls and black-backed gulls breed on rocky headlands of Banks Peninsula, but feed mostly at nearby Lakes Ellesmere Te Waihora and Forsyth (black shag) or exposed coastal and shoreline environments (gulls).

2.3.2. Exposed coastal environments

Headlands between the embayments and harbours of Banks Peninsula are exposed coastal environments. They are open to the full force of waves, especially storm waves approaching from easterly and southerly quarters. Similarly, south and east facing shores just inside the heads of the major harbours are also exposed to significant wave action. Refraction of waves around the Peninsula result in headlands along the north-eastern coast also being exposed to severe wave action during storms. All of these headlands are rocky, but soft bottoms occur at the foot of these steeper shores, usually at 14-20 m depth, depending upon location. Rock types determine the structure and profile of shores and the near-shore environments along these headlands.

Harder rock types result in steep, unbroken bedrock extending from above the intertidal to at least 5-7 m depth. Beyond this depth, the bedrock is increasingly dissected into crevices, cave and erratic rocks up to 3 m across (e.g., at Squally Bay) (Nairn 2000, 2001b-c) or it may plunge directly to the flat sea floor (e.g., at Jacobs Ladder in Akaroa Harbour) (Davidson 2000d-e). An abrupt transition from sloping rock to gently sloping sandy sediment occurs at about 14-16 m depth or deeper off these headlands (Nairn 2000, 2001b-c). A conspicuous zone of broken and unbroken shell accumulated at the boundary between rock and sediment. Occasional erratic outcrops or boulders emerge from the near-level sediment bottom, but these are less common further from shore (Nairn 2001b).

Softer or more fractured rocks are cut back further and broken into boulders, many of which are almost spherical. The resulting beaches consisting of uniform, closely packed boulders (c. 300-500 mm diameter), slope moderately steeply to 1-2 m depth. These boulders become more variable in size and shape, and more widely spaced with increased depth, with pebbles and coarse sand filling the spaces between subtidal boulders (Nairn 2001b). Some of these boulders are up to 3 m diameter. The transition to a uniform sandy sediment bottom takes place some 40-60 m from shore at about 6-7 m depth, and is marked by a zone of accumulated whole and broken shell. Thereafter, the sand slopes steeply (c. 1:45) away to over 10 m depth (Nairn 2001b).

(a) Soft bottom benthos

Information on more exposed soft bottom biotas around northern Banks Peninsula is scant. Towards the lower limits of hard substrates (6-15 m depending upon situation), fine sediment covers rock surfaces and some larger deposit feeders characteristic of more sheltered waters (e.g., the sea cucumber *Stichopus mollis*, cushion stars *Patiriella regularis*) occur here (Nairn 2000, 2001b-c). Occasional horse mussels are wedged amongst boulders in sandy sediments interspersed between boulders at about 5-7 m in Squally Bay (Nairn 2001b). In deeper water, 12-15 m below unbroken bedrock at Scrubby, Squally and Double Bays, and 5-7 m below boulder bottoms at Squally Bay, there is a transitional zone between rock and sediment substrates. Dead mussel and rock oyster shell accumulate in this zone, and faunas characteristic of both hard and soft bottoms, co-exist. Nairn (2000, 2001b-c) referred to this as the shell drop zone.

Cushion stars, sea cucumbers and occasional horse mussels congregate in this zone, along with abundant scavenging whelks, cancer crabs (*Cancer novaezelandiae*), hermit crabs and blue cod (Nairn 2000, 2001b-c). The true soft bottom biota appears on the gently sloping muddy sand to sandy bottoms beyond the rocky slopes, usually at about 12-15 m, but shallower off boulder shores (Nairn 2000, 2001b-c). The fauna here includes paddle crabs (*Ovalipes catharus* and probably *Liocarcinus corruratus*[8]), burrowing worms, sparse horse mussels, whelks, and sand dollars (*Fellaster zealandica*). Further from the rocky bottoms, mud crabs (*Macrophthalamus hirtipes*) and burrowing mantis shrimps (probably *Lysiosquilla spinosa*[9]) become relatively common, with heart urchins (*Echinocardium chordatum*) also present beneath the sediment surface (Nairn 2000).

The infauna of deeper, brown muddy bottoms 1-2 km from exposed shores appears to be a further variant of Knight's (1974) *Macrophthalamus hirtipes – Virgularia gracillima* community. Here the sediment is a very fine sand-silt mix (58: 42%). Although not strictly comparable because of different sieve sizes were used, the infauna of these bottoms is similar to that described above for semi-sheltered waters of Banks Peninsula (Fenwick and Ross 2002). These assemblages include mud crabs, the small nut clam (*Nucula nitidula*) and amphipods as fairly consistent members, but are dominated numerically by nephtyid (*Aglaophamus* sp.), lumbrinereid and terebellid/trichobranchiid[10] polychaete worms (Grange 2001; Fenwick and Ross 2002). Appropriate sampling devices also catch abundant shrimp (*Pontophilis australis*) and other smaller crustaceans (cumaceans, amphipods) on these bottoms (Fenwick et al. 2001). The slightly lower diversity reported from exposed compared with more sheltered soft bottoms (34 taxa cf 35-58) appears due to differences in levels of identification, rather than true differences in the faunas, because sampling of expose bottoms was more intense and used a smaller mesh size.

(b) Hard bottom benthos

The biota on exposed unbroken bedrock shores is quite strongly zoned, at least in the immediate upper sublittoral. Green-lipped mussels (*Perna canaliculis*) form a dense covering over rock surfaces dominating the sublittoral fringe on these shores, but interspersed with bull kelps (*Durvillaea* spp) in extremely exposed situations (Nairn 2000, 2001b-c). Sea tulips (*Pyura pachydermatina*) are abundant in this zone also. Another large brown seaweed, *Ecklonia radiata*, grows ubiquitously at 2-5 m depth, and bladder kelp (*Macrocystis pyrifera*) occurs at about this depth wherever the shore is slightly sheltered from full exposure. Clumps of large green-lipped mussels are common at 7-11 m depth, interspersed with rock oysters, tunicates and sponges (Nairn 2001b-c). Mussels appear to persist beyond this zone on most exposed shores, but are absent by 12-14 m depth. Accumulations of dead mussel and oyster shell lie at the transition between rocky and sediment substrates and the associated fauna is described above.

---

[8] Nairn (2001c) provided no identification for his "Hairy red swimming crab".

[9] Nairn's (2000) identification of Squilla sp. is probably erroneous.

[10] Terebellids and trichobranchiids are easily confused and may not have been distinguished in these investigations.

Several other large invertebrates occur over these mussel-covered, rocky shores, including chitons (*Cryptoconchus porosus, Eudoxochiton nobilis*), gastropods (*Haliotis iris, H. australis, Scutus breviculus, Turbo smaragdus, Cookia sulcata, Buccinulum* sp.), urchins (*Evechinus chloroticus*), crayfish (*Jasus edwardsii*), anemones and hydroids. Starfish, in particular, are very diverse (*Astrostole scabra, Allostichaster insignis, Asterodon millaris, Coscinasterias calcamaria, Pentagonaster pulchellus, Stichaster australis*), probably due to the abundant mussels for food.

(c) Fishes

Species of fishes reported by divers at these exposed situations include: blue and red cod, spotties, scarlet wrasse, banded wrasse, various triplefins, leather jackets, sea horses, spiny dogfish, common roughy (Nairn 2000, 2001b-c) (Table 2). Important fisheriesspecies are blue moki and blue cod, both of which occur close to rocky reefs. In addition, greenbone (or butterfish) *Odax pullus* occurs in similar habitats and is a desired target species. Blue cod are widespread and abundant in deeper water, whereas blue moki and greenbone are markedly less common and are more restricted to rocky reefs near shore, where they are more vulnerable to fishing pressure.

Commercially important species

Blue cod (*Parapercis colias*)

Blue cod are widespread, especially around the South Island, and are amongst the most important recreational finfish species in New Zealand. Invariably found close to rocky reefs or rough bottom, they grow at moderate rates, and spawn both in inshore and deeper waters over an extended season in late winter and spring. Although the juveniles migrate into rocky inshore areas to grow, small individuals are rarely seen.

Blue moki (*Latridopsis ciliaris*)

Blue moki (or moki) are closely associated with rocky reefs, and are usually caught by set netting. Only one spawning ground is known (between East Cape and Mahia Peninsula), with adults migrating there to spawn, and juveniles subsequently dispersing back to other areas.

Butterfish or Greenbone (*Odax pullus*)

Butterfish are relatively common around New Zealand, but are more abundant around the South Island where they are caught by set netting. They are strongly associated with the shallow rocky zone, generally less than 15 m depth, feeding principally on brown seaweeds. Spawning occurs over a long period from late winter to early summer, and juveniles live in shallower water amongst the kelp.

It seems unlikely that any of these species would be adversely affected by marine farming. On the contrary, it is quite possible that juveniles and/or adults might benefit from the additional cover and food provided by the hard structures associated with longline farms, leading to increases in densities of some reef-dwelling species.

Table 2: Marine fishes present in near-shore exposed habitats along the mid-Canterbury coast with indices of relative abundance: C = common, O = occasional, R = rare. The sources of data are: 1 = Bolton and Ritchie 1997, 2 = Cole et al. 2000, 3 = Davidson 1999a-d, 4 = Davidson 2000a-e, 5 = Nairn 1999, 6 = Nairn 2000, 7 = Nairn 2001a, 8 = Nairn 2001b, 9 = Nairn 2001c.

Scientific name	Common name	Relative abundance	Sources
Acanthoclinus fuscus	Olive rockfish	R	5
Acanthoclinus rua	Little rockfish	O	5
Conger verreauxi	Conger eel	R	5
Forsterygion lapillum	Common triplefin	C	1, 5, 6, 7, 8, 9
Forsterygion varium	Variable triplefin	C	1, 5, 7, 8
Forsterygion malcolmi	Mottled triplefin	O	1, 2, 7, 8, 9
Grahamichthys radiata	Graham’s gudgeon	O	5
Helicolenus percoides	Sea perch	R	5
Hemerocoetes monopterygius	Opalfish	R	6
Hippocampus abdominalis	Seahorse	R	5, 6
Latridopsis ciliaris	Blue moki	O	7, 8
Nemadactylus macropterus	Tarakihi	R	5
Notolabrus celidotus	Spotty	C	1, 2, 5, 6, 7, 8, 9
Notolabrus fucicola	Banded wrasse	O	1, 5, 6, 7, 8, 9
Parapercis colias	Blue cod	O	8, 9
Paratrachichthys trailli	Common roughy	O (in caves)	6, 8
Parika scaber	Rough leatherjacket	O	1, 2, 5, 6, 7, 8, 9
Pseudolabrus miles	Scarlet wrasse	C	6, 8
Pseudophycis bachus	Red cod	R	1, 5, 6, 7
Raja nasuta	Rough skate	R	7
Rhombosolea sp.	Flounder	R	7
Squalus acanthias	Spiny dogfish	R	6, 7
Trachelochismus pinnulatus	Lumpfish	R	5

(d) Marine mammals

Hector's dolphins are most commonly encountered along the exposed coasts of Banks Peninsula outside embayments and harbours (Slooten et al. 2000). AMAs suggested for exposed coast environments (e.g., Scrubby Bay, Squally Bay) are in areas where dolphins occur in low densities only (Slooten et al. 2000). Hector's dolphins are far more abundant along exposed coasts between Okains Bay and Pompey's Pillar and from Peraki Bay to well along Kaitorete Spit (Slooten et al. 2000). Other species of dolphins and whales appear to be infrequent transients within Banks Peninsula's exposed coastal environments.

NZ fur seals are increasing in abundance on Banks Peninsula as their population size and range continues to increase (PBAL 2001). They are becoming common at isolated, exposed promontories, especially along the peninsula's southern coast, but are infrequent on the peninsula's north-eastern coast.

e. Birds

Spotted shags, white-fronted terns, black-billed gulls, red-billed gulls and black-backed gulls were observed within a nautical mile of the coast, and their abundance declined rapidly thereafter (Hawke 1998). Thus, they are rarer in offshore environments. The same is probably true for white-flippered penguins (e.g., Gales et al. 1990; Brager and Stanley 1999), but little information is available. In contrast, Hawke (1998) found that the abundance of Hutton's shearwaters, Buller's shearwaters and fluttering shearwaters increased with distance offshore to the extent that >40% of these species were counted 3-4 nautical miles off Banks Peninsula. Other oceanic seabirds are also likely to be more abundant offshore, although large numbers may move inshore during storms (pers. obs. PMS).

2.3.3. Offshore environments

(a) Soft bottom benthos

The fauna inhabiting the almost level, mud bottoms more distant from shore in Pegasus Bay is quite diverse. Living in or on the sediment surface are more than 68 taxa, apparently distributed in patches (PBAL 2001). Many of these taxa were polychaete worms living within the layer of fine brown silt overlying the more compacted mud, and more properly regarded as members of the infauna. Crustaceans dominated the epibenthos, with four molluscs also widespread. Most widespread and conspicuous among the molluscs are the large scavenging whelk *Austrofusus glans*. Other molluscs include the small bivalve *Mactra ordinaria*, its likely predator *Philine* *auriformis*, and the circular slipper limpet *Zegalerus tenuis* (PBAL 2001). Crab larvae recently settled from their planktonic development occur widely on these bottoms, along with mysid shrimps, the small predatory shrimp *Pontophilus* sp. and several epibenthic amphipods (*Photis nigrocula*, Oedicerotidae, *Meridiolembos* sp.) and cumaceans (*Diastylopsis* sp. 1, *Diastylis* sp.). Scavenging, epibenthic hermit crabs (*Diacanthus spinulimanus*) are abundant in patches (PBAL 2001), presumably wherever there is food. Juvenile flatfish (sole, *Peltorhamphus* sp.; two flounders, *Rhombosolea* sp., *R. retaria* (rare?)) are widespread and abundant, at least in spring off the Waimakiriri River mouth (PBAL 2001).

The diversity of offshore mud bottom infauna appears similar to that of inshore bottoms, with differences in taxonomic resolution probably accounting for the differing diversities reported by the various investigations. Eighty-five taxa were distinguished in mid Pegasus Bay, with diversity at any one point ranging between about 25 and 48 taxa (PBAL 2001). Polychaete worms are the most diverse, followed by crustaceans, principally small amphipods and cumaceans. Polychaetes also are the most abundant group present in these bottoms, with densities ranging from >1000 to almost 4000 m^{-2} usually contributing more than 60% of individuals to the total benthos (PBAL 2001). Crustacean densities are usually much lower (400-500 m^{-2}), but range up to 2000 m^{-2}, so that this group's contribution to the total number of infaunal animals is more modest (10-30% but up to 75%) (PBAL 2001).

The most widespread taxa among the infauna are polychaetes (Flabelligeridae, Goniadidae, Nephtyidae, Onuphidae, Sigalionidae), amphipods (Ischyroceridae sp. 1, *"Proharpinia"* sp., Oedicerotidae,), cumaceans (*Diastylopsis* sp. 1, *Diastylopsis* sp. 2, Pseudocumidae) and the whelk *Austrofusus glans*. Also widespread are further members of these groups (polychaetes: Terebellidae, Lumbrinereidae, Capitellidae, *Spiophanes kroyeri*, Ampharetidae; amphipods: *Photis nigrocula*, *Meridiolembos* sp., *Ampelisca* sp.; cumaceans: *Diastylis* sp.; molluscs: *Nucula nitidula*, *Mactra ordinaria*, *Philine auriformis*). A brittle star (Amphiuridae) was also widespread, but patchily distributed, reaching densities as high as 1200 m^{-2} at some points, whilst absent from others (PBAL 2001).

Even with this limited understanding of the offshore benthos, it clearly differs from the four communities described from Lyttelton Harbour (Knight 1974), even though some taxa occur in both situations (e.g., *Sepioloidea pacifica, Virgularia gracillima, Pontophilus* sp.). It also differs from the benthos found within Banks Peninsula bays, principally in the absence of mud crabs and the increased importance of smaller crustaceans, notably amphipods and cumaceans.

(b) Hard bottom benthos

No hard or rocky bottoms are known in any of the suggested offshore AMAs.

(c) Fishes

Fishes present in offshore environments can be grouped by relative abundance as determined from the NIWA research trawl survey data (Table 3). Abundant species include barracouta, red cod, sand flounder, spiny dogfish, and two-saddled rattail. Common species include elephant fish, hapuku, New Zealand sole, red gurnard, rig, rough skate, and school shark. Species that were present or uncommon included ahuru, brill, carpet shark, chinook salmon, common warehou, electric ray, giant stargazer, globefish, hake, hoki, kahawai, leatherjacket, lemon sole, southern pigfish, sand stargazer, silver warehou, slender sole, spotted stargazer, spotty, sprats, witch, and yellow-eyed mullet. Abundant or common fishes are listed below.

Barracouta (*Thyrsites atun*)

Barracouta were abundant in Pegasus Bay throughout the year, being recorded in both summer and winter trawl surveys in moderate quantities. This important, commercially valuable species is widespread along the Canterbury continental shelf and is mostly taken by bottom trawl, but is also observed in surface schools at times, as well as in midwater.

Elephant fish (*Callorhinchus milii*)

Elephant fish are most common along the east coast of the South Island and are confined to waters of the inner continental shelf less than 100 m, with highest abundance in waters less than 30 m deep. Historically, they were an important commercial resource in Pegasus Bay (Coakley 1971; Annala et al. 2002), with catches increasing again in recent years following the introduction of quotas in the mid 1980s (Annala et al. 2002). The commercial catch along the east coast of the South Island in recent years has been about 900 t (Annala et al. 2002).

Adults move into shallow water (between the surf zone and about 30 m depth) in spring where they aggregate for mating and egg-laying (Coakley 1971). It is then that they are most vulnerable to fishing. Several large yellow-brown egg cases are laid in sand or mud, and incubation takes at least 5-8 months (Gorman 1963). Juveniles hatch at about 10 cm in length, and remain in shallow waters for up to three years. Males mature at 50 cm and three years of age, and females at 70 cm and 4-5 years of age (Annala et al. 2002).

Table 3: Marine fishes present in the Pegasus Bay area, with indices of relative abundance: A = abundant, C = common, O = occasional. Data from the NIWA research trawl survey database.

Scientific name	Common name	Relative abundance
Aldrichetta forsteri	Yellow-eyed mullet	O
Arnoglossus scapha	Witch	O
Arripis trutta	Kahawai	O
Auchenoceros punctatus	Ahuru	O
Caelorinchus biclinozonalis	Two-saddled rattail	A
Callorhinchus milii	Elephant fish	C
Cephaloscyllium isabellum	Carpet shark	O
Chelidonichthys kumu	Red gurnard	C
Colistium guntheri	Brill	O
Congiopodus leucopaecilus	Southern pigfish	O
Contusus richei	Globefish	O
Crapatalus novaezelandiae	Sand stargazer	O
Galeorhinus galeus	School shark	C
Genyagnus monopterygius	Spotted stargazer	O
Kathetostoma giganteum	Giant stargazer	O
Macruronus novaezelandiae	Hoki	O
Merluccius australis	Hake	O
Mustelus lenticulatus	Rig	C
Notolabrus celidotus	Spotty	O
Oncorhynchus tshawytscha	Chinook salmon	O
Parika scaber	Rough leatherjacket	O
Pelotretis flavilatus	Lemon sole	O
Peltorhamphus novaezelandiae	NZ sole	C
Peltorhamphus tenuis	Slender sole	O
Polyprion oxygeneios	Hapuka	C
Pseudophycis bachus	Red cod	A
Raja nasuta	Rough skate	C
Rhombosolea plebeia	Sand flounder	A
Seriolella brama	Blue warehou	O
Seriolella punctata	Silver warehou	O
Sprattus spp.	Sprats	O
Squalus acanthias	Spiny dogfish	A
Thyrsites atun	Barracouta	A
Torpedo fairchildi	Electric ray	O

Hapuku (*Polyprion oxygeneios*)

This species is usually associated with rocky substrate and, although common in deeper waters, occurs infrequently in this area.

New Zealand Sole (*Peltorhamphus novaezelandiae*)

This flatfish is common on sandy substrates in depths less than 30 m along the Canterbury coast. It was frequently taken in moderate quantities during the research trawl surveys in Pegasus Bay. New Zealand sole is likely to form an important part of the catch by inshore trawlers working in depths of 10 to 30 m in Pegasus Bay (at least seasonally).

Red cod (*Pseudophycis bachus*)

Red cod is an important commercial species along the east coast of the South Island. The distribution tends to be patchy and unpredictable between years, although the highest trawl survey catch rates were in depths of about 100 m and south of Banks Peninsula. Within Pegasus Bay, red cod were usually common and sometimes abundant.

Commercial catches in recent years have varied considerably, from 5,000 to 14,000 t annually along the South Island east coast (Annala et al. 2002). Red cod are seasonally abundant, with schools appearing in the Canterbury Bight and Banks Peninsula area around November (Annala et al. 2002). These feeding aggregations disappear into deeper waters after about June.

Red gurnard (*Chelidonichthys kumu*)

This commercial species is common along the inner continental shelf of the South Island east coast, and is most abundant in depths of around 30 m. It was regularly recorded in moderate quantities in the Pegasus Bay area.

Rig (*Mustelus lenticulatus*)

Rig is a commercially valuable species of shark with a patchy distribution in shallow waters along the east coast of the South Island. This species was frequently taken in moderate quantities in Pegasus Bay. Rig are caught mostly in shallow waters, often harbours and estuaries, where they aggregate during spring and summer, and where the females give birth to live young some 25-30 cm long (Annala et al. 2002). The commercial catch from southern New Zealand and along the east coast of the South Island has been around 400 t in recent years.

Rough skate (*Dipturus nasutus*)

This species is widely distributed by depth and location along the east coast of the South Island. Within Pegasus Bay, rough skate were regularly taken in moderate quantities.

Sand flounder (*Rhombosolea plebeia*)

Sand flounder is an important flatfish species in inshore waters around New Zealand, and were abundant within Pegasus Bay. Mundy (1968) concluded that there was a major spawning ground for sand flounder in depths of 20-40 m off the Waimakariri and Ashley River mouths (The Flounder Patch)(in the vicinity of the Pegasus Central AMA and probably elsewhere), with fish aggregating and spawning here in winter and spring. Sand flounder probably form a major component of the flatfish catch by inshore commercial trawlers in this area, at least seasonally. Combined landings for all eight flatfish species for the eastern and southern South Island are around 2000 t, but there are no detailed data on sand flounder catch in this area.

School shark (*Galeorhinus galeus*)

School shark is a commercially valuable species, found in inshore waters along the east coast of the South Island in summer and outer shelf waters in winter. Live young are released in spring and early summer, and the pups remain in shallow nursery grounds (harbours, bays, and sheltered coasts) during the first one to two years of life. This species was regularly taken in moderate quantities (up to 15.6 kg km^{-2}) in the area of the offshore AMAs (Table 3). The commercial catch of this species along the east coast of the South Island in recent years has been about 300 t (Annala et al. 2002).

Spiny dogfish (*Squalus acanthias*)

Spiny dogfish are widely distributed and very common along the East Coast of the South Island in depths of 50-150 m. They have limited commercial value and a sizeable proportion of the catch is discarded by commercial fishers. Spiny dogfish were abundant in trawl catches in Pegasus Bay. Females give birth to live young over an extended period, mainly on the shelf edge in depths of 200-300 m. Spiny dogfish landings have been about 3000 t along the east coast of the South Island in recent years (Annala et al. 2002).

Two saddle rattail (*Caelorinchus biclonozonalis*)

Like most rattails, this species is generally found in deeper water, and is of no commercial value.

Sprat (*Sprattus* sp.)

Sprats, small pelagic fish (similar to sardines), are most common in the Canterbury Bight, with an estimated biomass of at least 60 000 t (Colman 1979). Two species are now known to be present (Whitehead et al. 1985) and are probably important food for many species of fish (e.g., chinook salmon (James and Unwin 1996)) and seabirds. Only small quantities were taken in the bottom trawl surveys.

Kahawai (*Arripis trutta*)

Kahawai are present in the area over the warmer months. They are taken as a by-catch in the commercial fishery and targeted by recreational fishers. Kahawai often form schools and are frequently found around river mouths such as the Waimakariri River. Unfortunately, reported catches of kahawai are lumped for the entire South Island and South West Coast of the North Island, so catches for Pegasus Bay are unknown. Kahawai are wide-ranging, probably moving along the East Coast of the South Island seasonally.

Kingfish (*Seriola lalandi*)

Kingfish are sometimes present in small numbers in Pegasus Bay when sea temperatures are high in late summer. A large pelagic species that is often associated with floating seaweed or structures, kingfish have become a desirable target species for recreational fishers.

(d) Marine mammals

Hector's dolphins are considered coastal in habits, "normally sighted within half a mile of the coast and rarely venture further than 5 nautical miles from shore" (Slooten et al. 2000: 5; see also duFresne et al. 2000). At times, however, they are common up to 20 km (c. 11 nm) off shore within Pegasus Bay (pers. obs, GDF). A small, separate sub-population of these dolphins is reported for the Pegasus Bay-Motunau area (Slooten et al. 2001) and the AMAs suggested for central and northern Pegasus Bay are probably within their range.

A few NZ fur seals are found along the northern coast of Pegasus Bay, where they haul out in rocky promontories in the vicinity of Motunau (PBAL 2001). Other seal species also are sighted in the general area (e.g., leopard seals, elephant seals), but these are rare visitors (PBAL 2001). Various whales (humpback, right, minke, sperm, sei, pilot, killer, pigmy right, beaked) occur infrequently in offshore Pegasus Bay waters, although only the first two have been recorded swimming within the bay in recent times (PBAL 2001).

(e) Birds

Many species of seabird feed in the exposed coastal environment off Banks Peninsula and in Pegasus Bay. White-flippered penguins were observed frequently in the near-shore waters around Banks Peninsula (Brager and Stanley 1999). Although there is no available information on feeding and foraging habits of white-flippered penguins, other species of blue penguins are often seen in shallow inshore waters close to the breeding grounds. On short-term trips blue penguins tend to forage within 5-10 km of the coast and within 15 km of their nesting burrow (Gales et al. 1990). This appears to be the case with white-flippered penguins also, which were observed feeding in the vicinity of the proposed Pegasus Bay Marine Farm (AMA 5, Pegasus Central) (PBAL 2001).

Spotted shags exhibit seasonal change in foraging habitat. They usually forage communally out to 15 km for most of the year, but, during summer, most feed closer inshore (Lalas 1983). During aerial surveys of flying seabirds up to 18.3 km off Banks Peninsula in February and July-August 1996, Hawke (1998) recorded about 50% of the 299 spotted shags that he observed within 1 nautical mile of shore. He attributed this to them feeding close to their breeding colonies. Likewise, white-fronted terns, red-billed gulls, black-billed gulls and black-backed gulls occurred primarily within 1 nautical mile of shore, with >50% of these species observed in this area (Hawke 1998).

Oceanic seabirds such as southern royal albatross, Salvin’s mollymawk, shy mollymawk, northern giant petrel, Snares cape pigeon, sooty shearwater, fluttering shearwater, Hutton’s shearwater, and Buller’s shearwater also feed in this exposed coastal environment (Hawke 1998; PBAL 2001).

3. Biophysical effects of marine farming and mitigating factors

Several potential biophysical effects of mussel farming have been identified by various reviews (e.g., Gillespie 1989; Forrest 1995; Cole 2000). These effects are outlined briefly below, with more detailed information available in the various publications cited. The magnitudes and relative importances of these and other effects are difficult to predict, given the scant knowledge of mussel farm effects on benthos in New Zealand and the diverse locations and scales of the suggested AMAs. Good farm management practice can minimize some of these adverse effects, such as droppers lost to the seafloor and debris on the nearby seashore. However, almost all of the ecological effects cannot be predicted with any degree of certainty. There are also potential physical effects that may have ecological consequences. These, too, cannot be predicted with certainty.

This section outlines various potential effects and describes the possible ecological outcomes generally. The likely magnitudes of each effect for each of the suggested AMAs, and their potential ecological consequences, are addressed elsewhere (Section 5).

3.1. Plankton depletion

Mussels feed by pumping water through their inhalent siphon onto their gills, where small, hair-like, cilia filter out most particulate material, including plankton. Much of the filtered material is bound in mucus and carried to the palps, where some sorting takes place before material enters the mouth. Any unwanted material and, when food concentrations are very high, surplus food is bound in mucus and ejected via the exhalent respiratory stream as pseudofaeces. Thus, mussels produce faeces (ejected from the anus) and pseudofaeces. Once ejected, these sink to the bottom, either directly beneath the farm where currents are weak, or further a field wherever there is sufficient current to disperse the material (Gillespie 1989; Stenton-Dozey et al. 2001; Chamberlain et al. 2001). Smaller *Perna canaliculus* pump seawater at $<0.2\ \mathrm{l\ h^{-1}}$, whilst larger mussels pump $>8\ \mathrm{l\ h^{-1}}$ (James et al. 2001). A preliminary study suggested that *P. canaliculus* is a non-selective feeder, ingesting phytoplankton ranging in size between 5 and 100 microns (James et al. 2001). Studies on the blue mussel in Scotland and Ireland found that almost all sizes of zooplankton were ingested to some extent, in both laboratory and field situations (Davenport et al. 2000, Clare and Davenport 2002).

3.1.1. Ecological effects

Farmed mussels are known to deplete phytoplankton and other particulate material from seawater. Various field observations have shown that both the green-lipped mussels (*Perna canaliculus*) and the blue mussels (*Mytilus* spp.) may remove much of the available phytoplankton (Waite 1984; Smaal 1991, Frechette and Grant 1991, Newell 1994; Newell and Richardson 2000; Ogilvie et al. 2000).

Several investigations of potential phytoplankton depletion by small (<5 ha) farms provided varying results. Ogilvie et al. (2000a) provided the first reliable measures of phytoplankton depletion associated with mussel farms. Their seasonal study included four small farms in Beatrix Bay (Marlborough Sounds), compared phytoplankton concentrations between (i) the region within the backbones of the mussel long-lines, and (ii) external to the farm. Depletion of up to 60-80% within the backbones was observed during winter, but there was no depletion in summer, although initial surveys had found no depletion between the long-lines (Ogilvie 2000). A further, intensive study repeatedly mapped water currents and phytoplankton abundance (by fluorescence measurement) over a few tidal cycles in and around two small farms nearby (Clova Bay, Marlborough Sounds), but failed to find any significant depletion (Ross and Image 2002).

One study within a large mussel farm (160 ha) in Golden Bay, suggested more extensive phytoplankton depletion (Ogilvie et al. 2000b). However, in that case, only three surveys were conducted, and the influence of the Aorere River confused the result to the extent that no definite conclusion could be drawn on the source of apparent depletion.

In addition to the farmed mussels, many organisms within fouling communities associated with mussels are suspension feeders (Thiel and Ullrich 2002), probably further depleting plankton within the water column. This could be particularly significant in relation to blue mussels, which often foul the near-surface crop lines, including the backbones.

The ecosystem effects of such depletion are uncertain, but, conceivably, include reducing food available for other suspension feeding animals. Phytoplankton depletion from small farms is highly variable within and between farms, due to the effects of a number of factors (e.g., local hydrodynamics, the density of back-bones and droppers, phytoplankton growth rates, etc.) and, generally, seems to be localised (Ogilvie et al. 2000a,b). Some depletion does occur during the winter months (Ogilvie et al. 2000a) and may affect suspension-feeders in the water-column (zooplankton), and also in the benthos (bivalves and polychaetes) in some situations (e.g., Tenore et al. 1982).

Whilst mussels deplete phytoplankton on one hand, on the other, they may also stimulate increased phytoplankton productivity by increasing the availability of scarce nutrients. Readily used nitrogen (nitrate or ammonium) often limits phytoplankton productivity in coastal waters (e.g., Gibbs and Vant 1997). Like most aquatic animals, mussels excrete ammonium (c. 150 μg d^{-1} 60 mm mussel^{-1} according to James et al. 2001), which may stimulate increased phytoplankton productivity in situations where nitrogen is limiting (usually during summer). By ingesting and partially retaining particulate material, mussels are, however, net consumers of nitrogen. Thus, their excretion of nitrogen is, therefore, unlikely to be noticeable, except in situations of low nitrogen and low phytoplankton.

Recent research has shown that even small (24-47 mm shell length) Mytilus edulis are significant predators of zooplankton, capturing adult and larval invertebrates up to 6 mm long, and fish eggs (Davenport et al., 2000, Lehane and Davenport 2002). Captured zooplankton that are not ingested are ejected as pseudofaeces bound in mucus and do not survive (Davenport et al. 2000). New Zealand green-lipped mussels are highly efficient at capturing small zooplankton (similar to efficiency to capturing phytoplankton) (Robinson et al. 2002), but their efficiency at capturing larger zooplankton is reduced (J. Zeldis, pers. comm. February 2003).

These findings indicate that feeding by farmed mussels may have further ecological impacts in addition to depletion effects. First, because mussels are generally non-selective in the size of particles taken, they may significantly alter the composition of planktonic communities over the medium to longer term (e.g., the Zebra mussel; see Munawar et al. 1999) (Horstead et al. 1988). Second, mussels may also have significant effects on recruits of benthic invertebrates available to settle on nearby hard surfaces and soft bottoms. Barnacle and bivalve larvae were among the most common animals found in Mytilus guts, but larvae of most other benthic phyla also were present (Davenport et al. 2000). The availability of such animal prey items is likely to vary seasonally with reproductive cycles. There is scope for mussel feeding to influence the availability of final stage larvae to settle on adjacent substrates (Davenport et al. 2000), especially where areas farmed are large and/or intercept the predominant currents reaching the substrate.

3.1.2. Mitigating factors

- High advection and turbulence resulting in less intense depletion of plankton.
- High plankton productivity.
- Absence of suspension feeders that compete with nearby farmed (filter-feeding) species.
- Less intensive farming resulting in lower demand for plankton.

3.2. Increased sedimentation of organic and inorganic particles

Sedimentation rates beneath mussel farms are often 2-3 times higher than in adjacent, unfarmed situations (Dahlback and Gunnarsson 1981; Grenz et al. 1990; Hatcher et al. 1994; Grant et al. 1995; Stenton-Dozey et al. 1999), with absolute values dependent on natural sedimentation rates (Chamberlain et al. 2001). The mussel lines themselves may passively reduce water movement and increase sedimentation rates (e.g., Eckman et al. 1989). The main cause of increased sedimentation, however, is due to mussel feeding activities. Sediment accumulation rates are difficult to predict and there is little research pertinent to the Canterbury situation. Inevitably, some faeces and pseudofaeces do reach the seabed in most situations, at least where there is weak advection and turbulence.

Organic sedimentation from mussel (and other bivalve mollusc) farms consists of deposition of concentrated, naturally occurring organic matter, usually in quite small particles that are readily carried on currents. Caged fin-fish farming relies upon adding high value food from other sources, so that organic sedimentation from culture cages comprise concentrated organic matter from distant sources. Thus, faeces and uneaten pellets constitute net additions of organic matter to the environment. Over time, these additions can accumulate in thick layers on sediments beneath the cages and have severe impacts on the benthic fauna, among other adverse ecological effects. Bottom sediments affected by sedimentation from overlying fish cages usually take several years to recover and the rate of recovery appears correlated with current velocity (Morrisey et al. 2000). Food fed to caged salmonids contains about 7-8% nitrogen (GESAMP 1996; Gillibrand et al. 2002), of which 60-70% is excreted (GESAMP 1996; Davies 2002). Nitrogen excretion rates are considerably higher for other species of farmed fish (Gillibrand et al. 2002). Most of the waste nitrogen eventually re-enters the water column as ammonium, where it may stimulate phytoplankton growth (Kaspar et al. 1988). Nitrogen from cage-cultured fish has, therefore, been implicated in nuisance phytoplankton blooms overseas and in New Zealand (Rhodes et al. 2000).

3.2.1. Ecological effects

Faecal and pseudofaecal matter reaching the sea bottom contains both organic and inorganic matter. Inorganic matter is relatively inert, but not innocuous. Sediment particle size composition may be altered, in turn, leading to changes in the composition of the benthos. Under high sediment accumulation rates, some sessile organisms, especially attached invertebrates, may be buried or smothered. Alternatively, this inorganic matter may simply create unfavourable conditions for some suspension feeders by over-loading their filtering structures and mechanisms.

A detailed New Zealand investigation of the effects of sedimentation from mussel farms on the benthic environment showed finer textured sediments containing more organic matter, especially organic nitrogen, beneath farms in Marlborough Sounds compared with nearby control sites (Kaspar et al. 1985). The benthic community under these farms also changed. Polychaete worms only comprised the lower diversity farm-site benthos, whereas polychaetes, echinoderms, crustaceans and molluscs occurred at reference sites (Kaspar et al. 1985). Further, an epibiota developed beneath the farm site, aggregating dead and living shell material into reef-like structures (Kaspar et al. 1985) (see below).

Biodeposition at the mussel farm sites investigated by Kaspar et al. (1985) was considered moderate. Investigations elsewhere show that light to moderate organic enrichment generally may increase abundances of most marine benthic species inhabiting soft sediments. With increased organic inputs, however, the fauna tends to become increasingly dominated by higher densities of fewer species. Under extreme enrichment more typical of sea pen fin-fish (Morrisey et al. 2000) and abalone (e.g., McShane 1997) aquaculture, a black and sulphurous anoxic layer of sediments up to 30-40 cm thick and covered with bacterial mats may develop beneath the farm, completely excluding most animals (e.g., Morrisey et al. 2000).

In another investigation beneath mussel farms sited in differing depths and hydrodynamic conditions in Marlborough Sounds, the benthos on mud bottoms under farms in sheltered, deeper waters differed appreciably from that just beyond the farm boundaries, whereas there was no difference in sand bottom benthos beneath and beyond the farm at the shallower, more exposed site (Hartstein and Rowden 2003). Although the exposed farm was just three years old, whereas the other two had operated for 15 years, evidence from overseas studies supports the notion that mussel farming has little or no effect on the benthos under exposed conditions. Benthos densities, diversity and biomass generally decrease beneath mussel farms situated in low energy environments (Mirto et al. 2000; Chamberlain et al. 2001; Stenton-Dozey et al. 2001; Hartstein and Rowden 2003), but increase in higher energy environments (Tenore et al. 1982; Radziejewska 1986; Castel et al. 1989; Hartstein and Rowden 2003). Apparently, this positive effect of mussel (and oyster) farm detritus on benthos occurs where wave action enhances oxygenation of bottom sediments and re-suspends detritus, reducing organic matter accumulating in the sediments (Mirto et al. 2000).

3.2.2. Mitigating factors

- Moderate to high currents resulting in more rapid dispersal.
- Deep water resulting in wider dispersal, even where currents are very weak.

- Low suspended load to reduce pseudofaeces production.
- Appropriate bottom type to limit ecological effects.
- Wave action to aerate upper layers and disperse sediment.
- Abundant deposit-feeders in benthos to recycle organics.
- Periodic farm relocation to allow benthic recovery following high sedimentation.

3.3. Shell drop and habitat change

Even with good farm management practices, large quantities of shell debris and associated material falls to the bottom (shell drop) over time. Live and moribund mussels drop from mussel farm long-lines and may accumulate on the sea floor (Jaramillo et al. 1992; Grant et al. 1995; Cole and Grange, 1996; Grange and Cole 1997) and, under some conditions, may be transported beyond the farm boundaries by currents and/or wave action (shell drift). Shell drop may be substantial. Mattsson and Linden (1983) reported shell drop accumulation of 2,800 ±970 mussels m^{-2} (9.4 ±3.4 kg m^{-2}) beneath a one-year old farm in Sweden. In New Zealand, mussel densities of up to 400 m^{-2} (70 m^{-2} on average) were reported from beneath established farms in Marlborough Sounds, with mussels on the bottom comprising an estimated 7-8 tonnes beneath each farm or 5% of the farmed mussel biomass within Beatrix Bay (Cole and Grange 1996). Mean shell drop densities elsewhere in Marlborough Sounds varied between 1.5 and 113 m^{-2} for three farms in different depths and exposure conditions (Hartstein 2003).

Further losses of mussels occur during harvesting. Long-line cultured mussels are harvested at sea by harvester vessels up to three times for each crop (post-settlement spat harvest, juvenile harvest, production harvest) [11]. During the latter two harvests, the looped dropper rope, to which the mussel crop is attached, is continuously winched through a mechanical stripper to remove mussels and other adhering material. All stripped material, including mussels, falls into a rotating drum, where it is washed with high pressure seawater to separate mussels from each other and from any epibiota. Small mussels, small epibionts and other small debris fall through grills in the drum and, thence, are discharged overboard, along with sediment- and detritus-laden washing water. All washed, retained material is sorted by hand on a conveyer, with unwanted items discarded overboard. Within Marlborough Sounds, at least, blue mussels (*Mytilus galloprovincialis*) appear to be the main component of harvesting

---

[11] This description is drawn from Davidson's (1998) more complete outline of the entire harvesting process.

related discharges (at times it occurs at densities exceeding 800 m^{-1} of culture rope (Pickering 2002), but green-lipped mussels also are common, along with a variety of reef-forming invertebrates (Davidson 1998). Over-sized mussels (>120 mm long) are discarded overboard also.

Floats and mussel farm backbones (heavy lines linking floats and supporting long-lines) usually become heavily fouled with many of the same organisms. Both are cleaned periodically, with the dislodged epibionts contributing to the accumulation of debris on the seafloor below the farm (Davidson 1998). Consequently, most shell drop appears to result from harvesting or other farm-related activities, rather than natural processes between these activities (Gillsepie 1989; Grange and Cole 1997; Davidson 1998).

No data were available on amounts of material discharged during harvesting green-lipped mussels, but volumes are usually substantial. Davidson (1998) reported total suspended solids in seawater beside wash water discharges of 150 g m^{-3} for a re-seeding harvest and 85 g m^{-3} for a production harvest. Tenore et al. (1982) estimated epifaunal and algal production on mussel rafts as about 10% and 33%, respectively, of mussel production. Extrapolating these figures to average long-line culture production in Marlborough Sounds (Hickman 1989; Pickering 2002) indicates that this epibiota is very substantial (2.8-3.7 kg epibionts m^{-1} of culture rope harvested (0.65-0.85 kg of epifauna and 2.2-2.8 kg algae m^{-1} of culture rope harvested)). Applying these estimates to a 3 ha marine farm in Marlborough Sounds with 440 5 m culture ropes per long-line and 3.3 long-lines per hectare (Hickman 1989) indicates that epibiont discharges across the entire farm area may exceed 30 kg m^{-2} y^{-1}, on average.

3.3.1. Ecological effects

Mussels fallen to the seafloor beneath farms attract a variety of scavengers and predators (Kaspar et al. 1985; Grant et al. 1995; Cole and Grange 1996). If conditions allow these displaced mussels to survive and accumulate, mussels (using their byssal threads) and other reef-building invertebrates (e.g., ascidians, bryozoans, hydroids) may bind this material into reef structures with mussel densities up to 400 m^{-2} (Kaspar et al. 1985; Cole and Grange 1996). In time, natural and farm-induced sedimentation fills the numerous interstices between mussels within these reefs, anchoring them in place.

Should such artificial reefs (any hard substrate submerged in the sea) develop on soft bottoms, the benthos in the area changes markedly from a soft bottom, infaunal-epifaunal association to a hard bottom epifaunal and crevice community of fouling and predatory species (Grange and Cole 1997; Svane and Petersen 2001). The original infauna dominated by polychaete worms and smaller crustaceans, along with other soft–sediment dwellers, will disappear. An epifaunal, reef community dominated by suspension feeders (Thiel and Ullrich 2002) will develop in its place (Kaspar et al. 1985). Further, changes to the soft-bottom fauna may extend beyond the edge of the reef structure. Artificial reef formation may have a pronounced effect on the epifauna, infauna and particle size composition of adjacent sediments (Davis et al. 1982) due to changes in the hydrodynamic conditions and fish feeding activities.

Algae may be a significant part of reef communities, along with a rich suite of sessile and mobile reef animals. Reef fish are usually a conspicuous part of these associations and recreational fishing in the immediate area is apparently enhanced (Grange and Cole 1997). In a review, Grossman et al. (1997) concluded that there was little unambiguous evidence that artificial reefs increased regional fish production, rather than concentrating available biomass, especially when located close to natural reef habitats. They considered that artificial structures (e.g., a mussel farm), may concentrate recreational fishing, boosting the potential for over-exploitation of some fish species (Grossman et al. 1997).

Development of mussel reefs, with their associated fish faunas, is often regarded as an enhancement, increasing the environment's biodiversity (e.g., Grange and Cole 1997). Various points are relevant here. Habitat heterogeneity and edge effects are both increased by establishment of clumps of mussel reef over the bottom. However, such patchiness may be an intermediate stage in development of the mussel reefs, which could eventually carpet large areas of sea floor beneath a mussel farm, conceivably spreading well beyond its boundaries by dispersal. As mussel reef cover increases, the habitat heterogeneity inevitably declines.

Research comparing the biodiversity of original sediment bottoms with that of reefs developed over them in New Zealand is very limited. Change in the numbers of species is inextricably related to the scale of modification of habitat, and the relative species richness of original and modified habitats. Although mytilid mussel beds have been observed to increase the diversity of micro-habitats available (Thiel and Ullrich 2002), the biomass and productivity of associated fauna in these mussel beds may not exceed that of fauna in surrounding habitats.

Similar arguments are pertinent to productivity, biomass and effects on ecosystem functioning such as nutrient re-mineralisation. In particular, the abundant deposit-feeding faunas characteristic of these sediment bottoms play vital roles in re-mineralising nutrients and converting organic detritus in sediments into animal tissue and dissolved nutrients that re-enter the system and drive primary production in the overlying water column. In contrast, mussel reef and rocky bottom faunas are overwhelmingly suspension feeding (Thiel and Ullrich 2002), removing plankton and producing their own organic-rich detritus. Reductions in the total area of sediment bottom in an area, therefore, equate to losses of the habitat's capacity to assimilate and re-mineralise nutrients. Thus, we have insufficient information to accurately predict the likely changes to species richness, productivity or effects on ecosystem functioning resulting from mussel reef development in Canterbury waters.

Potentially critical space (e.g., for breeding) and microhabitat for native species inhabiting the general area may be lost when mussel reefs cover significant areas of the seabed. Although the new habitat type present may provide important habitat for other species allowing their populations to increase (e.g., fishes), such changes in species relative abundances may lead to further ecological effects. For example, the meiofauna of a mud bank in Pauatahanui Inlet, dominated by small (<2 mm long) harpacticoid copepods, stimulates microbial activity and increases the rate of organic detritus decomposition (Hicks 1983). Populations of one meiofaunal copepod (*Parastenhelia megarostrum*) attained densities of 263,000 m^{-2}, producing up to 3.6 g organic carbon m^{-2} y^{-1} of copepod tissue through seven generations per year (Hicks 1985). In addition to the significant amount of detrital processing required to achieve such high productivity, this crustacean was practically the sole food for newly settled (8-35 mm long) juvenile flatfish during the first six months of their life on the bottom. This demonstrates the key trophic role of many inconspicuous inhabitants of uniform mud bottoms with the overall ecosystem and the more conspicuous higher-level animals directly or indirectly dependent upon them (Hicks 1983, 1985). Situations akin to that described for Pauatahanui may occur in areas considered suitable for marine farming in the Canterbury region. Juvenile flatfishes abound over parts of central Pegasus Bay (PBAL 2001), but neither their food nor the extent of the bay inhabited is adequately known to permit reliable predictions of likely farming effects.

Wherever mussels drop to the bottom and accumulate, predators, such as the 11-armed starfish *Coscinasterias muricata*, and scavengers are likely to become more abundant (Cole and Grange 1996). Other facultative scavengers likely to increase in abundance wherever mussels accumulate on the seabed include brachyuran crabs (e.g., *Cancer novaezealandiae)*, hermit crabs and whelks, as well as some cumaceans, amphipods and polychaetes that are attracted to carrion. The consequences of elevated predator and scavenger densities beneath farms are uncertain, but potentially include migration to and increased predation pressures on adjacent communities. More important are indications that aggregations of predators, such as the 11-armed starfish, seem likely to result in dramatically increased spawning outputs and recruitment in the general area (Inglis and Gust unpubl. data), with potentially significant ecological consequences from increased predation pressures.

Shell drop, shell drift and accumulation are predicted to vary with the condition of the spat when they are seeded out, and with the wave climate and water depth at the site. There is scant research on either of these issues. A recent investigation in Marlborough Sounds found negligible mussel accumulation (mean density 1.5 m^{-2}) beneath a three year old farm at a relatively exposed site (maximum fetch > 100 km, maximum current velocity >25 cm sec^{-1}) on sand (70%) at 8-14 m depth on the edge of Cook Strait, compared with that beneath 15 year old farms in more sheltered inner Sounds bays (mean density 88-113 m^{-2}, maximum fetch 20 km, maximum current velocity 7-11 cm sec^{-1}) on mud (93-96%) bottoms at 25-42 m depth (Hartstein 2003). Although these results may be attributed to differences in farm age and numbers of harvest cycles, they do indicate that significant mussel drift or transport occurs on shallow bottoms in exposed situations. Shell drift is likely to be less on deeper bottoms at equally exposed situations. Where drift occurs, the effects of shell drop and accumulation may extend beyond the farm boundary. Shell drift could be a significant problem if currents and/or wave action concentrate drift shell into beds elsewhere, possibly modifying important habitat away from the farm (e.g., accumulations on adjacent beaches). However, very little is known about transport of individual and clumps of whole mussels or of shell material, so that predictions of shell drift and accumulation are largely speculative.

3.3.2. Mitigating factors

- Currents and wave action and depth affecting dispersal of shell drop.
- Good farming practice minimising shell drop.

3.4. Fouling communities

Another potential effect of marine farming is the development of fouling communities of algae and various invertebrates on submerged structures where previously there was open water and no settlement surface. An abundant fouling biota usually develops on almost any hard surface within coastal waters. Such fouling is most noticeable in harbour situations. The development and composition of such communities in Lyttelton Harbour[12] provide the best-documented indications of what to expect on farm structures along the Canterbury coast, although quite different fouling communities are likely to develop in more exposed situations. Based on investigations in Lyttelton Harbour (Skerman 1958; Poore 1968; Knox 1980), a diversity of macroalgae and invertebrates, principally sessile forms, are expected to colonise farm

---

[12] Generally, fouling organisms settle on any firm surface, regardless of composition, unless there is some toxic or other adverse factor involved.

structures within a short period. Settlement in Lyttelton peaked during spring-summer, with rapid increases in sizes of individual plants and animals (or colonies) and total surface cover. Additional species colonised the habitat as the community developed, so that after three years, over 130 species of sessile fouling animals, nestlers and free-living mobile animals may be present (Poore 1968; Knox 1980). Established fouling communities in Lyttelton were dominated by algae and suspension feeders, primarily sea squirts, sponges, bryozoans, hydrozoans, bivalves and amphipods (Poore, 1968; Knox 1980). It should be noted however, that epibiotas developing on artificial substrates usually differ from those on natural substrates, probably due to differences in substrate types and community development time (Svane and Petersen 2001).

3.4.1. Ecological effects

Although there has been no detailed investigation of fouling communities on mussel farm structures in New Zealand, casual observation indicates similar fouling communities to those reported from wharf piles at Lyttelton. Algae are abundant and support dense populations of small, suspension-feeding amphipods. Both blue and green-lipped mussels grow on mussel lines and floats, along with sponges, bryozoans, hydroids and sea squirts (ascidians), as well as representatives of most other marine invertebrate groups. Thus, the fouling community appears to be dominated by suspension-feeders that remove plankton and/or detritus from the surrounding water column and release nitrate and ammonium. Thus, fouling communities potentially exacerbating any depletion and enrichment problems.

Despite this dominance by macrofaunal suspension feeders, fouling communities inevitably support abundant populations of small motile invertebrates, notably meiofaunal nematodes, polychaetes and crustaceans. Many of these are likely to become caught in mussel feeding currents as they move over mussel and epibiont surfaces, thus contributing to mussel food. Similarly, many of the epifaunal algae and invertebrates release gametes or larvae into the water column at times, potentially contributing to the pool of organic particles available to mussels as food. This potential food supply and its utilisation by mussels has not been explored, but, conceivably, is important at times in some situations, especially where epibiont biomass is high relative to farmed mussel biomass (e.g., 67% of mussel biomass in overseas raft culture (Tenore et al. 1982).

As well as increasing any phytoplankton depletion, communities fouling mussel farm structures create a reef-type habitat providing food and shelter for small reef fishes, and potentially displacing any open water fishes that might pass through the area.

3.4.2. Mitigating factors

- Good farming practise in maintaining low densities of fouling communities and/or minimising losses of fouling organisms during harvesting.

3.5. Spread of alien species

3.5.1. Ecological effects

Alien species are regarded as undesirable because they may have undesirable effects on ecosystems they invade. These effects include species hybridisations (e.g., the New Zealand grey duck), species extinctions through competition or predation, marked changes in dominant species within some communities (e.g., Grosholz 1999), and changes affecting entire ecosystems (e.g., the zebra mussel in the Great Lakes altering plankton composition (Munawar et al. 1999)). Also, some non-indigenous species may emerge as a major pest of green-lipped mussels in the foreseeable future, completely altering the economic viability of the entire industry. The overall consequences of these effects may be direct or indirect, and involve dramatic changes in the physical structure of habitats, primary productivity, food webs, nutrient cycling and disease outbreaks, leading to adverse economic impacts on fisheries, recreation, commerce and other human activities in both marine and estuarine environments (Grosholz 1999; Mack et al. 2000; Ruiz and Hewitt 2002). There are suggestions that combinations of exotic species may have synergistic effects on their ecosystems, leading to “invasional meltdowns” or ecosystem-wide failures by combinations of species facilitating each other’s invasion (Simberloff and Von Holle 1999).

Fouling communities on mussel structures and cultured mussels are significant in that they provide a refuges for and a means of transporting opportunistic invasive species between sites, whenever such structures are re-located. Also, vessels used in farm activities can serve as vectors for introducing such species and for transporting them elsewhere, increasing the probability and rate of successful alien establishment at multiple sites.

One such species already in New Zealand, the Japanese kelp *Undaria pinnatifida*, almost certainly will be spread inadvertently. Although present on Banks Peninsula in Lyttelton and Akaroa Harbours, the Japanese kelp has not become a major problem species on the Canterbury coast. Several other problem invertebrates (e.g., the Asian mussel) have been introduced via shipping to most countries, including New Zealand, and spread more widely by smaller vessels. About 150 non-indigenous species are known from New Zealand, with some establishing dense beds (e.g., the Asian mussel, *Musculista stenhousia* in Waitemata Harbour) and making conspicuous changes to the physical structure of the seabed (Hayward 1997).

Invasive species also include disease-causing organisms, although it is often difficult to distinguish these from previously unrecognised endemic diseases of wild stock that become problematic as the scale and intensity of aquaculture increases (Bower and Figueras 1989). Even though little is about diseases in mussels generally, and of *Perna canaliculus*, in particular, several pathogenic organisms and potential agents of disease in mussels are known, of which many have been spread widely by aquaculture activities (Bower and Figueras, 1989). These include viruses, bacteria, fungi and Protozoa, as well as metazoans. At the individual level, disease can cause loss of condition (e.g., the microsporidian protozoan *Stenhausia mytilovum*), accumulation of toxic metabolites (e.g., the trematode *Proctoeces maculatus*), muscle weakness and gaping (e.g., *Prosorhynchus squamtaus* (another trematode)), and extensive mortalities (e.g., the trematode *Cercaria tenuans*) (Bower and Figueras 1989). Perhaps most severe is haemocytic neoplasia, a poorly understood, fatal disease reported from Europe, east and west coasts of North America and South Africa (Bower and Figeuras 1989; Stenton-Dozey pers. comm. May 2003). This disease causes >75% mortalities of mussels over 40 mm long in the Puget Sound area (Bower and Figueras 1989). In Saldanha Bay, South Africa, it affects cultured mussels (*Mytilus galloprovincialis*), but, following the start of farming here in 1984, it has also infected and decimated adjacent populations of endemic clams (Stenton-Dozey pers. comm. May 2003). As yet, no major invasive pest species has emerged in Canterbury, but there is a high probability of such pests arriving in the future, notably the Pacific seastar. This voracious predator with a massive reproductive capacity, became established in Tasmania in 1985 (Barker 1994). Occurring at densities of up to 46 m^{-2}, it poses a substantial threat to marine benthic communities and commercial species, notably bivalves (Ross et al. 2002). It has now spread to the Victoria coast (Port Phillip Bay) of Australia where it also occurs in high densities (Ross et al. 2002). Because its larvae spend several months developing in the plankton (Byrne et al. 1997), it seems only a matter of time before this animal arrives in New Zealand waters. Several other invasive species that have become pests for mussel farming in south-eastern Australia (e.g., European fan worms) present a high risk to New Zealand aquaculture in the future, although implementing appropriate protocols can minimise the spread of such pests (Anon. 2002).

Another probable alien is already a pest. In Kaipara Harbour and Marlborough Sounds, four species of flatworm are significant pests, feeding on farmed oysters (Handley 2000). One of these species that lays thousands of eggs may well be an alien imported from Australia (*Imogine mcgrathi*) (Handley 2000). Flatworms also occurred on mussel lines and scallop spat bags during trials in Wellington Harbour (Handley 2000), indicating that such aliens pose significant threats once introduced.

3.5.2. Mitigating factors

- Paucity of known marine aliens in New Zealand suggests lower risk.
- Remoteness from hard substrates resulting in lower probability of settlement.

3.6. Sheltering effects

In addition to moderating water movement within a farm or AMA, the physical presence of a marine farm and of the AMA itself may preclude other human activities (e.g., bottom trawling) that otherwise would have some physical or ecological effect in the area.

3.6.1. Ecological effects

Two ecological effects may follow from the physical presence of a mussel farm. First, it is well known that any matter floating or suspended near the surface in open water tends to attract fishes and other mobile organisms (e.g., Kingsford 1999). Natural and artificial fish aggregating or attracting devices (FADs) have been used by subsistence and commercial fishers on a variety of scales and artificial FADs are now deployed successfully by the international tuna fishery in many parts of the world (Druce and Kingsford 1995; Hampton and Bailey 1999; Le Gall 2000). Although the reason for fish aggregating around such structures on or near the surface is poorly understood, a recent experimental investigation confirmed that fishes are attracted to FADs (Druce and Kingsford 1995). Thus, marine farms using suspended long-lines to culture mussels seem likely to attract fishes, even when located in deeper waters more distant from shore.

Second, the surface or subsurface farm structures preclude many human-induced, mechanical disturbances of the sea floor in the vicinity of the farm, especially from commercial bottom trawling and the associated non-natural, physical disturbance. In this sense, marine farms may provide a partial refuge from physical disturbance by humans. Trawling, especially repeated trawling of the same area, is perhaps the most drastic human disturbance effect over large areas of sea floor. It severely damages many sessile epibenthic dwellers, tubes and burrows in the sediment surface that add habitat-forming heterogeneity to benthic habitats (see reviews by Thrush et al. 1995; Turner et al. 1999). This finer scale habitat heterogeneity may provide critical spawning or nursery habitat, refuges from predation and competition and significant food for many species (Turner et al. 1999). Because they also modify water movements close to the bottom, these structures may create potentially important microhabitats affecting food availability, settlement of larvae and their subsequent growth and recruitment into breeding populations, as well as buffering physical and chemical stresses (Turner et al. 1999). Consequently, by providing refuges from such disturbances, marine farms may protect against some of the main effects of trawling: reduced abundances of many longer-lived sessile species, reduced species diversity through reduced habitat heterogeneity, and increased abundances of mobile scavenging species. However, sedimentation effects (Section 3.2) may completely cancel any beneficial effects of farms as refuges.

Insofar as marine farms provide refuges from human disturbance, they must have beneficial effects for the ecosystem. For example, scallops are abundant under some marine farms in Marlborough Sounds, whereas they are less abundant in equivalent, unfarmed habitat nearby due to heavy dredging pressure from commercial operators (Grange and Cole 1997). Conceivably, these under-farm populations not only are available for recreational harvesting by diving, but also the reservoir of mature adults is a source of spat for habitats throughout the general area (Grange and Cole 1997).

These observations suggest that the refuge from disturbance provided by farm structures and the patches of mussel reef derived from drop-off and accumulation of farmed mussels will enhance benthic diversity (e.g., Grange and Cole 1997; Coen and Luckenbach 2000), at least initially, but this is likely to be reduced with time as organic matter accumulates in bottom sediments. Each of these effects is discussed more fully above (Sections 3.2, 3.3).

3.6.2. Mitigating factors

- High water movement.

3.7. Changes to native populations' gene pools

The genetic diversity inherent in local subpopulations of other marine species has biodiversity value worthy of protection under the New Zealand Biodiversity Strategy. This applies equally to mussels and other potential aquaculture species, as well as to fouling or other species associated with aquaculture. Marine farming has significant potential to reduce natural genetic diversity and disrupt evolution of native species populations via human-induced gene flow associated with translocation of genetic material across natural boundaries (e.g., Hutchings 2000). For example, most mussel farming in New Zealand relies on spat (newly settled mussel juveniles) collected from other regions, traditionally from Kaitaia.

Detailed examination of genetic diversity in green-lipped mussels over 1996-2002 gave conflicting results (Apte and Gardner 2001), despite industry observations that spat from different parts of the country varies in growth behaviour when cultured at the same site (B. Hayden, pers. comm. May 2003; S. Fox, pers. comm. May 2003). More recent further genetic investigation of *Perna canaliculus* confirmed earlier observations of largely discrete northern and southern populations separated at about 42°S (south of Cook Strait), as well as showing greater genetic diversity in the southern population compared with the northern population, and that West Coast populations are genetically more distinct from northern populations than are other southern populations (Star et al. 2003). This study also demonstrated that northern mussels cultured in southern waters were readily distinguished genetically, and modified the genetic diversity of nearby (15 km) wild populations (Star et al. 2003).

Thus, continued translocation of spat, especially if this increases, is likely to substantially reduce the genetic diversity of natural populations of green-lipped mussels. The potential for similar reductions in genetic diversity resulting from translocations for aquaculture demonstrated for this species, are also likely for any other species deliberately or inadvertently translocated within or into New Zealand waters for aquaculture.

3.8. Effects on wildlife

3.8.1. Marine mammals

Direct effects of marine farms on marine mammals appear to be few. Slooten et al's (2000) report on the effects of marine farms on Hector's dolphins around Banks Peninsula identified five effects: habitat competition, physical and chemical changes to the seafloor sediments, entanglements, support vessel and construction noise, and operational losses (lines, buoys and plastics), whereas DuFresne et al. (2000) recognised only the first three effects for Port Levy.

(a). Habitat competition and fragmentation

As yet, no convincing evidence has emerged on habitat competition or exclusion of Hector's dolphins from farmed areas. Slooten et al. (2000) observed Hector's dolphins passing close to a salmon farm and there are confirmed reports of dolphins moving out of and into a 160 ha mussel farm in Golden Bay, apparently independent of human activity (PBAL 2001). Certainly, the farm lines, floats etc. do alter the nature of the water column and partition the subtidal space, at least from a human perspective. Although there is no available evidence of any lessening of the quality or attractiveness of the farmed space for Hector’s dolphins, it is possible that larger farmed areas will be less attractive and provide some form of barrier to these dolphins as medium to longer term habitat. Larger marine mammals, notably whales passing through Pegasus Bay, may well avoid or be excluded from parts of the bay by marine farms (e.g., Mann and Janik cited in Slooten et al. 2000).

Seals seem unlikely to be excluded by the presence of marine farms in the suggested AMAs. These AMAs are not in areas known to be significant seal feeding grounds and seals are likely to pass through mussel farms with ease en route to or from haul out sites. Some seals are attracted to sea-cage salmon farms (see d. below) where they can become a nuisance due to stealing stock from the cages. It is possible that mussel farms will attract seals because of the increased fish communities expected to develop around them.

(b) Changes to bottom sediments

Although identified as having potential direct effects on Hector’s dolphins, Slooten et al. (2000) did not provided a mechanism directly linking the effects of marine farm-induced physical and chemical changes to the seafloor sediments. Indirect effects may occur due to changes in benthic productivity, but, given the relatively high water movement anticipated at most AMAs in the area, these are more likely to be increases in productivity. Any increases in benthic productivity and fish abundance seem likely to benefit Hector’s dolphins and seals. More importantly, the composition of fish faunas living beneath marine farms may change and this could adversely (or beneficially) affect resident or transient marine mammals.

(c) Entanglement

“The risk of entanglements in New Zealand marine farms is likely to be low” (Slooten et al. 2000: 21; see also DuFresne et al. 2000), at least for long-line mussel farms within bays and close to shore (where whales are rare), and for Hector’s and other dolphins. Other types of marine farms that use nets and/or thinner lines conceivably hold the potential to entangle dolphins. Further offshore or wherever whales pass, long-line mussel farms may pose entanglement threats to these large mammals (e.g., a Bryde’s whale entangled in a mussel line off Great Barrier Island; Slooten et al. 2000), especially if continuous, looped culture lines are used instead of separate lines with free ends. Some species may be able to detect mussel farms via their sonar systems, but detection is no guarantee against attempts to move through a farm. Thus, the risk of entanglement for whales seems real for offshore marine farms, but this risk must be weighed against the apparent rarity of whales entering these waters.

Risks of entanglement appear low for seals. Again, the thickness of lines used in mussel farming relative to the size of NZ fur seals suggests that entanglement is improbable. Other types of marine farms, notably caged salmon farms, pose a greater risk. However, seals apparently are adept at stealing fish from such sea pens, indicating that they quickly learn to avoid entanglement.

(d) Noise, human and support vessel activity

Slooten et al. (2000) believed that it is very difficult to predict the likely effects on Hector's dolphins of increased noise from marine farm construction, maintenance and support vessel traffic. In their review, they reported research by others who found that gray, humpback and killer whales appear to avoid areas of higher noise and/or human activity (Gard 1974; Herman 1979; Bryant et al. 1984; Glockner-Ferrari and Ferrari 1990: all cited in Slooten et al. 2000), while noting that bowhead whales seemed very tolerant of considerable noise from oil prospecting and drilling operations (Richardson and Fraker in Slooten et al. 2000). No information of the effects of noise and ship traffic on dolphin distribution and behaviour was available.

Seals also appear to quickly habituate to frequent vessel traffic, as evidenced by their tolerance and the survival of numerous commercial seal watching cruises and swim-with-seals ventures for tourists in New Zealand. There is very little available information on the effects of human activity on NZ fur seals (Lalas and Bradshaw 2001), except for a note on their intolerance of close approaches by humans on shore (Department of Conservation 1995 in Lalas and Bradshaw 2001). South American fur seals tolerate tourists on land, so long as they did not approach within 10 m of the colony (Cassini 2001). Cape fur seals frequent an inner dock section of a busy harbour where loose fish occasionally fall into the water during discharge from trawlers (Shaughnessy and Chapman 1984) showing their tolerance of human activity and vessel movements. Based on this limited information and casual observations, marine farm traffic and other operations appear to pose little threat to seals ashore. Indeed, they are attracted to and become a significant nuisance around sea-cage, salmon farms in Marlborough Sounds (M. Unwin, pers. comm. 19 Mar 2003), but have presented no problems in Akaroa Harbour (D. Bates, Akaroa Salmon, pers. comm. 19 Mar 2003).

(e) Marine debris

Debris from marine farms, notably lines, plastic ties and other items, can pose significant threats to wildlife and marine mammals. The mussel industry Environmental Policy specifically identified debris as a potential source of accidental pollution and, although the industry was not recognised as a significant source of such material, its Environmental Code of Practice (in preparation) includes plans to avoid such accidental losses (NZMIC 1997; see also http://www.greenshell.com/ems.asp).

3.8.2. Birds

Potential direct effects of marine farms on seabirds include physical changes to the seafloor, resulting in changes to the food species available to some seabirds; habitat exclusion; human and support vessel noise; and entanglement.

(a) Changes to bottom sediments

Food available to seabirds within AMAs could be affected if marine farming results in changes to invertebrate and fish communities. Some seabird species preferentially prey on particular invertebrate and fish species, and so any changes in the abundance of prey species could affect their availability to the birds. Also, even if birds take alternative prey, the energetic value of such prey may not be the same those consumed previously. Marine farm induced changes to the benthos via, for example, accumulation of shell debris, are likely to alter the nature of prey items available to diving birds, notably shags and penguins, with unknown consequences, but the extent of such changes will depend on the scale of farming.

White-flippered penguins and spotted shags feed by pursuing their prey underwater. Although no studies of the diet of white-flippered penguins have been reported, the closely related blue penguin forages diurnally, predominantly within 5m of the surface (Heather and Robertson 1996) on a diet consisting of arrow squid and small fish, the latter predominantly small, schooling species such as sprat and Graham's gudgeon (Fraser 1999). The diet of spotted shags is primarily small (<150mm long) fish and marine invertebrates (primarily arrow squid); the main fish species taken are ahuru, red cod, gudgeon, cockabullies and sprats (Lalas 1983; Heather and Robertson 1996). White-fronted terns feed primarily on small, surface-shoaling fish such as smelt and pilchards (Heather and Robertson 1996). A marine farm could well attract pelagic and schooling species of fish, and so increase the abundance of prey available to these three species of seabirds. Equally, the farm structure and changes to the underlying seafloor could decrease the availability of their usual prey.

Of the other seabird species abundant in inshore areas, the three species of gulls feed predominantly on invertebrates and fish obtained near the surface. When ashore, black-backed gulls eat a wide variety of food, but at sea they feed on algae and plunge-dive for small fish and invertebrates (Heather and Robertson 1996). The stomach contents of these gulls collected off Otago Peninsula comprised the decapod Munida gregaria and fish (McClatchie et al. 1989). Likewise, during the breeding season red-billed gulls feed mainly inshore on krill (Nyctiphanes australis) swarms near the surface. Off the Otago Peninsula, the distribution of this gull was correlated with the abundance pattern of this krill (McClatchie et al. 1989). The endemic black-billed gull breeds on braided riverbeds, and so in spring and summer they are mainly inland (Heather and Robertson 1996). However, during winter, they are mainly coastal and forage on krill and small fish. Because these three species of gull feed on surface-dwelling prey over a wide area of the continental shelf, they are unlikely to be affected by the presence of marine farms.

Among the seabirds that occur mainly offshore, shearwaters feed by plunging and swimming underwater (Heather and Robertson 1996). Sooty shearwaters commonly dive to over 40m (Weimerskirch and Sagar 1996) and, off the Otago Peninsula, they fed mainly on Munida gregaria, with some Nyctiphanes australis and fish (McClatchie et al. 1989). Little is known about the prey of fluttering and Hutton's shearwaters, but they probably have similar diets. Consequently, as for the gulls, the presence of marine farms is unlikely to affect the prey of these species.

(b) Habitat exclusion

Feeding opportunities could potentially be lost because some seabirds are unlikely to feed within the area of marine farm structures. This could occur if there are extensive surface structures that birds, such as shearwaters, gulls and terns, avoid. However, if structures are submerged 3-5 m, then this should not be an issue.

On the other hand, marine farms could provide new feeding opportunities for some species. Cole et al. (2000) observed black-backed gulls and red-billed gulls taking advantage of the additional food source at mussel farms during harvesting, preying on broken and discarded bivalves and other invertebrates that are discharged during harvesting.

Another potential benefit of marine farms is that they provide roosting sites (e.g., on buoys) within the foraging areas for several species, such as spotted shags, white-fronted terns and gulls. Roosts close to feeding grounds enable them to feed more efficiently when at sea.

(c) Human and support vessel noise

There is little information available about the effects of human and vessel noise on seabird distribution and behaviour. However, Cole et al. (2000) noted that gulls were attracted to mussel farms during harvesting. Anecdotal information indicates that birds habituate to noise, although the close approach of humans to breeding sites is not tolerated. The latter could be detrimental, particularly if marine farms are constructed close (say, within 100 m) to shore adjacent to traditional nesting sites. This is particularly relevant to AMAs within harbours or semi-enclosed bays. For example, if white-flippered penguins behave similarly to other subspecies of blue penguins, then they will frequent shallow inshore waters and harbours close to their breeding sites (Dann et al. 1992). Within Akaroa Harbour, white-flippered penguins almost exclusively use only the southern, outer half of the harbour, the area suggested as an AMA. This subspecies of penguin is classified as endangered by the International Union for the Conservation of Nature and New Zealand Department of Conservation criteria (Taylor 2000). Therefore, assuming that these penguins breed on the adjacent shore, it would be prudent to exclude marine farming from within 100 m of the shore to avoid any potential disturbance to these birds from farming operations. Likewise, given the lack of information about the effects of noise on breeding birds, AMAs should not sited within 100 m of breeding colonies of spotted shags or white-fronted terns, both species of conservation concern (Taylor 2000).

(d) Entanglement

The risk of seabird entanglements in New Zealand mussel farms is likely to be negligible. Other types of marine farms that use nets and/or thinner lines could conceivably have the potential to entangle seabirds, but generally the thickness of the lines and size of the mesh precludes capture and drowning.

3.8.3. Mitigating factors

- Remoteness from preferred feeding grounds.
- Distance from breeding areas, colonies, roosting, haul out areas and migratory routes.
- Good farming practise following the New Zealand Mussel Industry Council Environmental Code of Practice.
- Size, density and spacing of farms, long-lines and/or cages.

3.9. Scale and cumulative effects

Most of the above ecological effects are associated with individual marine farms, rarely extending any distance beyond the farm boundary (Grange and Cole 1997; Stenton-Dozey et al. 1999). Scale effects operate at the individual farm or AMA level. They are effects that may not be present or apparent when small areas are farmed, but which may arise when larger areas are farmed, or the converse. For example, detectable phytoplankton depletion is unlikely in a small, 3 ha square mussel farm, particularly if it is sited within a moderate current flow. Increasing the size of the farm whilst maintaining the stocking density, especially if extended along the direction of current flow, will increase the likelihood of detectable phytoplankton depletion in water towards the down-current end of the farm due to the new scale. Thus, the size and stocking density of an AMA are key factors in determining scale effects. The AMA's shape and orientation with respect to prevailing flow direction and wave approach may also be important factors.

Cumulative effects operate at the embayment, area or regional levels and refer specifically to the aggregate effects of two or more AMAs. These cumulative effects may be less than, equal to or greater than the sum of individual AMA effects. For example, the individual depletion effects of a series of small AMAs may be minor, but, if arrayed along the direction of predominant current flow, their cumulative depletion effect may be substantial.

3.9.1. Ecological effects

The cumulative effects of several small and/or fewer large marine farms cannot be predicted at present because of the uncertainties of phytoplankton depletion, filtering of meso-zooplankton, benthic habitat changes due to sedimentation and shell-drop. Some of the areas suggested for marine farming are very much larger and the sites much more exposed to wave action than any existing operational marine farm in New Zealand or elsewhere. For these reasons, and because knowledge of mussel farm effects on New Zealand marine benthos is quite limited, it is impossible to extrapolate the ecological effects of existing farms to the likely effects of this proposed farm with any certainty. However, given the large scale of some of the suggested AMAs and their almost square shape, any existing ecological consequences are likely to be magnified, unless alternative farming practices (e.g., lower overall stocking densities) are employed. Even with more conservative practices, however, neither the individual effects of such large farmed areas, nor the cumulative effect of all farmed areas combined, can be predicted with any certainty based on present knowledge.

Shell-drop appears to pose the greatest threat to benthic habitats and faunas, even assuming good farm husbandry. Shell drop is certain to occur as losses of individuals, clumps of mussels and, infrequently, as whole lines. Thus, because no or minimal shell-drop cannot be guaranteed and the full ecological consequences of larger scale habitat modification by shell-drop and sedimentation are unknown, it seems prudent to develop each of the large AMAs suggested for Pegasus Bay in stages over a period of several production cycles. Provisional cumulative ecological effects criteria could be established for shell drop before development of each AMA. These criteria would be monitored repeatedly during development, with end-of-stage or annual reviews of the effects.

Plankton depletion associated with individual farm and cumulative effects have been dealt with in resource consent hearings or Environment Court appeals on many occasions in recent years (e.g., Ross 2001, James 2002). Cumulative effects are difficult to deal with in relation to small, near-shore mussel farms in embayments due to the high degree of natural variability that usually confounds attempts to identify sources of low phytoplankton abundance (e.g., Ross and Image 2002). Even when there are extensive long-term data sets, it is very difficult to identify any long-term effects of depletion (e.g., changes to plankton community composition) because any such changes take place against a background of significant natural variability driven by climate patterns (Ross 2002).

Cumulative effects of plankton depletion have the potential to become significant ecological issues in large AMAs. In addition, smaller AMAs in close proximity to each other (e.g., along both sides of a narrow bay) could reduce the phytoplankton available for natural suspension-feeding populations and communities, including surf clams on soft bottoms. Further, mussel feeding may consume zooplankton, including the eggs and larvae of some benthic species, including fishes (e.g., flatfish) and invertebrates. For example, Pegasus Bay has dense, highly productive surf clam populations inshore of the suggested AMAs (Cranfield and Michael 1992; Cranfield et al. 1994; Fenwick and Ogilvie 2001; Cranfield et al. 2002). Planktonic eggs and larvae of these species are possibly retained within or entrained towards shore by the gyre of the Southland current. Placement of substantial suspension-feeding aquaculture species within this system could result in lower larval recruitment to these populations and consequent reductions in population size. Aquaculture structures could further influence larval settlement by altering the hydrodynamic, thus influencing larval transport and, ultimately, successful recruitment. These factors, coupled with increased harvesting pressures on these populations, could have consequences for some species populations, such as tuatuas, both locally and regionally.

Potential effects on plankton abundance are not confined to large AMAs, but could be equally or more severe in embayments. Some suggested AMAs comprise a significant proportion of the embayments that they occupy. In others, the AMAs span much of the entrance to the embayment or of a shore. In such situations, the chances of planktonic eggs reaching open waters and of larvae reaching inner reaches of these bays or their shores may be appreciably reduced. Thus, depletion may reduce recruits to some naturally-occurring populations and result in lower population sizes, at least locally.

A further cumulative effect is the reduction in area of particular habitat types through preferential placement of farms or AMAs in specific situations. For example, mussel farms have typically been located over muddy bottoms, which are considered to be less valuable habitats, and close to shore in order to avoid navigational issues. Conceivably, some species or community may be specifically tied to this type of habitat for some or all of its life history, or it may be important for some ecological function. Therefore, it seems prudent to avoid modifying much or all of any one habitat or sub-habitat type, by restricting marine farming within a proportion of any single habitat type within a region or major embayment.

3.9.2. Mitigating factors

Apart from the configuration, size and location of AMAs, policy and consent conditions affecting farm factors (spacing, size, layout and farm stocking densities), a few mitigating factors reduce the above scale effects.

Locating AMAs or marine farms over mud or sediment bottoms seems most appropriate because their faunas are predominantly deposit feeders, assimilating and re-mineralising organic matter and nutrients deposited from the overlying water column back into the water column to promote primary production. Reef and rocky bottom faunas are mostly suspension feeders, abrogating the role of decomposition and re-mineralisation to sediment biotas elsewhere. It must be reiterated that locating marine farms over sediment bottoms may not completely mitigate the effects of organic sedimentation. Aerobic processes on sediment bottoms can be overloaded by excessive amounts or rates of organic matter accumulation, resulting in dramatic changes in the benthic fauna and functioning of the ecosystem. Consequently, although sediment bottoms are adapted to cope with organic and inorganic sedimentation and are, thus, the obvious bottom type for placement of AMAs, other factors become increasingly important as farm-induced sedimentation increases with farm size, especially where there is little dispersion of farm-derived sediment.

High water movement and mixing by currents and wave action are significant mitigating forces through rapidly mixing any phytoplankton-depleted water and bringing un-depleted water into the area, as well as widely dispersing faeces and pseudofaeces. Indeed, high water movement seems essential for any AMA presenting a long downstream distance to prevailing water movement.

4. Ecological monitoring, AMA development and management

The ecological effects of intensive marine farming are poorly understood, even in a world-wide context. In New Zealand, this problem is exacerbated by a lack of base-line data on the marine environment. There has been very little significant marine research activity in Canterbury, and only occasional investigations to support developments, usually for the RMA process. Given this small knowledge base and the RMA's requirement for sustainable management, a conservative strategy for developing aquaculture within the region seems prudent to minimise adverse environmental effects. This can be achieved by staged development of aquaculture operations, accompanied by close monitoring of potential ecological effects. Development beyond each stage would be subject to a review of actual measured ecological effects determined from monitoring results, with scope for altering AMA management, including the scale and intensity of farming, to address any significant environmental effects that emerge. This is a form of adaptive management in which the initial conservative development is extended only when its environmental effects have been assessed as being within acceptable limits, or is retrenched if unacceptable environmental effects are detected.

4.1. Adaptive management of aquaculture and the role of monitoring

An FAO working group on the ecological effects of coastal aquaculture defined ecological monitoring as: "the regular collection, generally under regulatory mandate, of biological, chemical or physical data from pre-determined locations such that ecological changes attributable to aquaculture wastes can be quantified and evaluated" (GESAMP 1996: 2).

In practical terms, ecological monitoring is broader, given that effects other than wastes may have appreciable environmental consequences. Thus, monitoring the effects of aquaculture ideally involves statistically robust, quantitative sampling[13] to measure specific phenomena at set intervals in time, with the specific intention of identifying meaningful changes in those phenomena that can be unequivocally attributed to particular aquaculture events or activities at identified locations. More importantly, monitoring is not an end in itself, but must be followed by decisions and actions based on the results of monitoring if it is to be effective. This is best achieved by incorporating monitoring into an appropriate environmental management system, such as that recommended by GESAMP (1996).

More recently, management systems for aquaculture and natural resources have recognised the importance of stakeholder involvement, the uncertain utility of specific

---

[13] Such monitoring involves repeated sampling at several affected and control sites.

factors or species as indicators in a monitoring programme, and the paucity of scientific knowledge on the outcome of any given management action on the ecosystem being managed. Consequently, adaptive management approaches that evolve over time by incorporating learning and revision from trial and monitoring within limits of acceptable environmental change are widely advocated (e.g., Holling 1978; Walters 1986; GESAMP 1996; Golden Bay Marine Farmers et al. vs Tasman District Council 2003), but these are not entirely without problems (Walters 1997; Gray 2000). The Limits of Acceptable Change (LAC) (Fig. 8) approach is one adaptive management model that has received considerable attention (e.g., Oliver 1995; Stankey et al. 1995; Shafer and Inglis 2000; Inglis et al. 2000). Central to this model is stakeholder participation in establishing desired social, biophysical and managerial resource quality levels and setting limits of acceptable change.

A variation of the LAC model seems promising. Rogers and Biggs (1999) proposed closer integration of science and management by involving tests of scientific assumptions and predictions, and investigations of the consequences of managerial actions. Their model, based on practices at the Kruger National Park, thus seeks to use monitoring as an auditing process to check that specific actions do achieve their intended outcomes and to explicitly test the accuracy of predictions based on science (Rogers and Biggs 1999). Their consultative, adaptive management process, summarised in Fig. 9, seems entirely appropriate to the management of AMAs in Canterbury because of the wide interest in aquaculture from diverse stakeholders and because of the inadequate scientific knowledge of the effects of marine farming and various management actions.

4.2. Monitoring: factors and critical values

Effective monitoring must detect any ecologically meaningful changes in relevant indicators and reliably distinguish human-induced changes from natural variations in these attributes. Further, to be effective, a monitoring programme must also be part of a larger management strategy that ensures that decisions and actions follow. Ideally three key issues must be resolved before any monitoring can occur: what should be measured, how can human-induced change in each of these factors be detected reliably, and what level of change is acceptable.

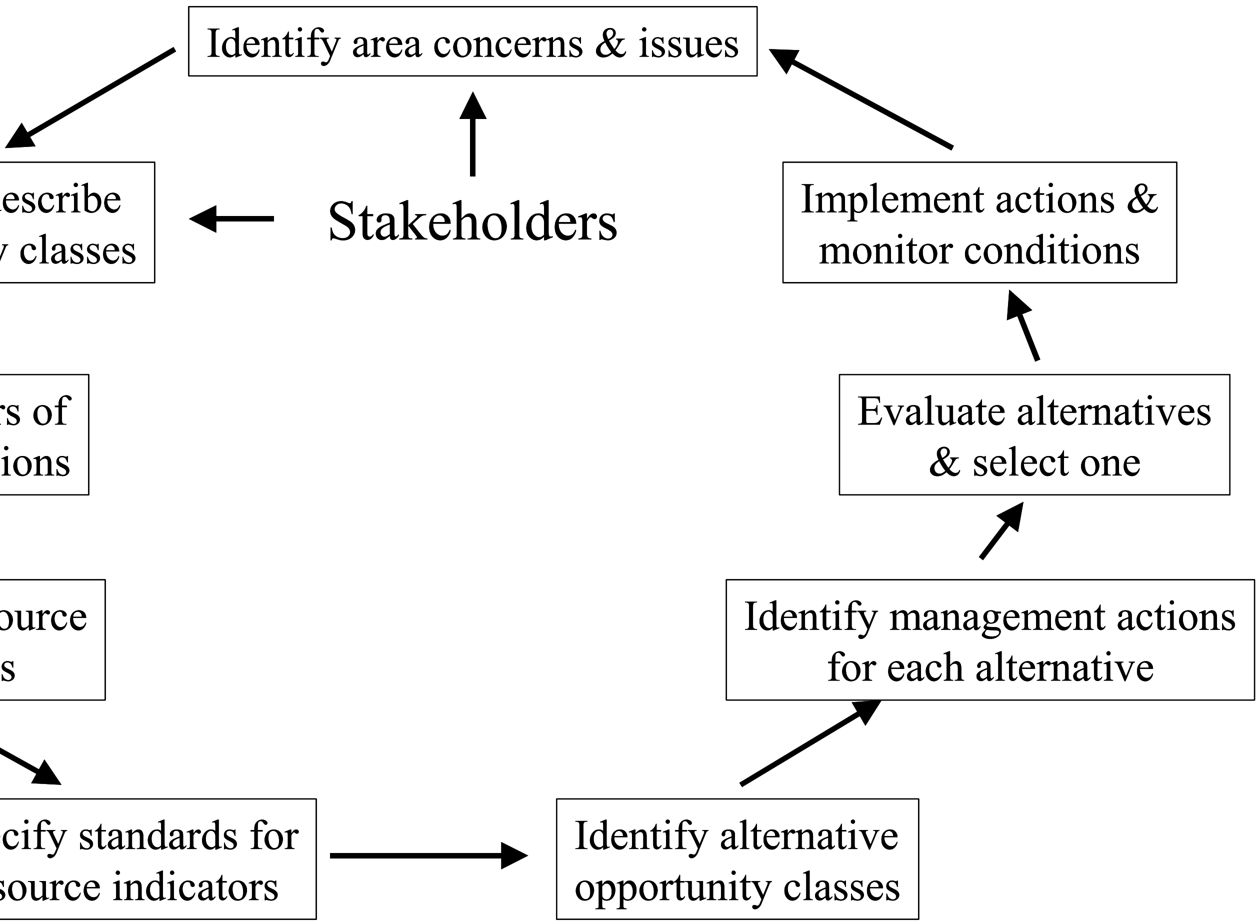

Figure 8: **Limits of acceptable change planning model (after Stankey** et al**. 1995)..**

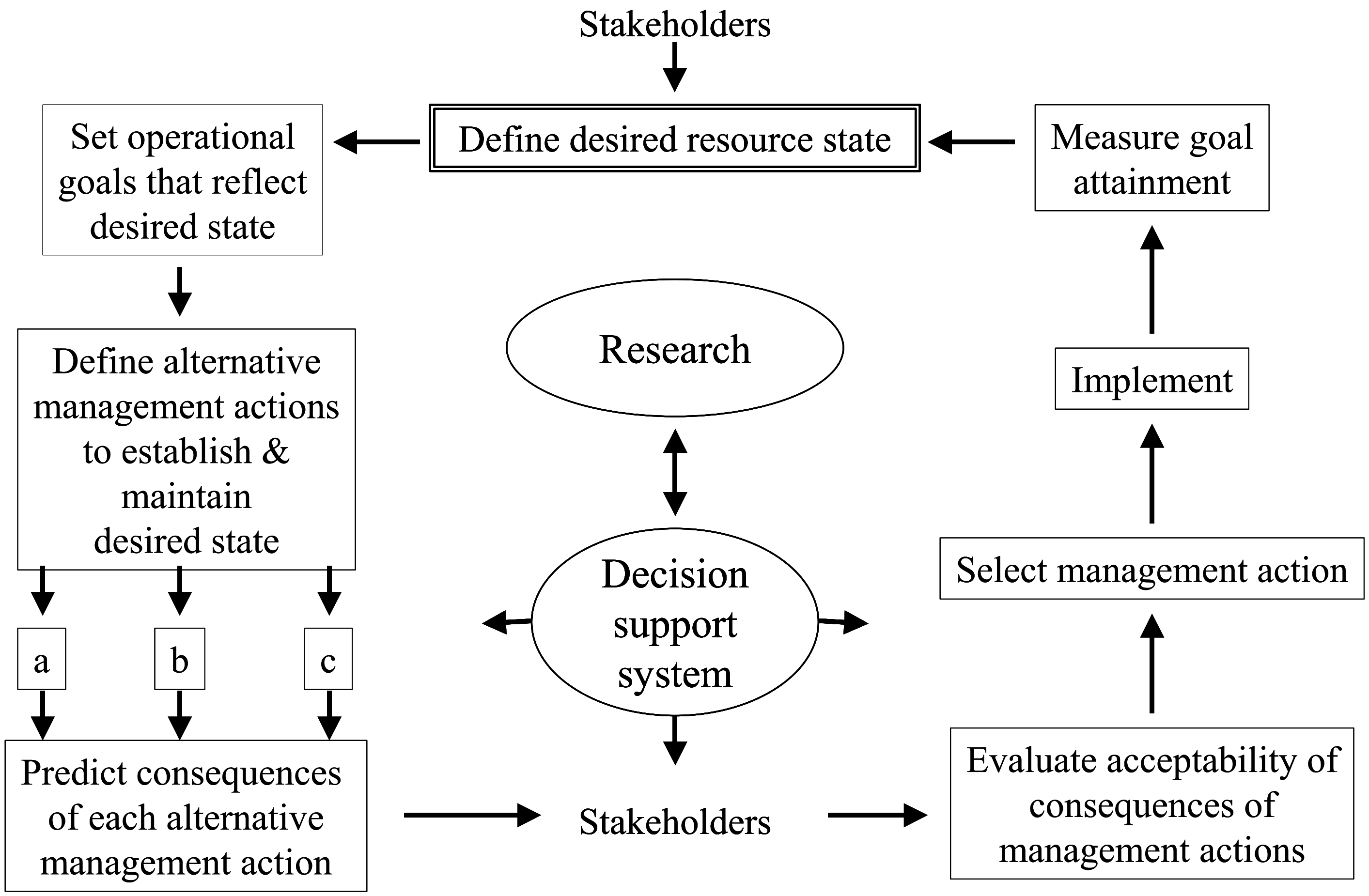

Figure 9: **The consultative, adaptive management process (after Rogers and Biggs, 1999: 442).**

4.2.1. What should be monitored?

Following the management models outlined above, the factors to be monitored will depend upon the operational goals set in consultation with stakeholders (Rogers and Biggs 1999), and the issues of greatest concern in the situation to be monitored. Monitoring for ecological purposes can focus on physicochemical factors that are known to drive ecological changes, on species populations, community composition, and/or ecological processes. Some mix of these tends to be monitored in practice, often for practical reasons.

Some important populations (e.g., Hector's dolphins, white-flippered penguins) may make application of appropriate monitoring difficult because their populations are small and range over large areas (Marsh 1995). Long-lived species may also make monitoring difficult because any changes in their populations may take several years to become detectable (Marsh 1995). In facing these issues, Marsh (1995) noted that species chosen for monitoring should have shorter life spans (i.e., years, rather than decades), have well known life histories, be abundant so that their populations can be sampled reliably at low cost, be relatively sedentary so that they are always available, and be amenable to experimentation to confirm causes of change.

4.2.2. How will natural variation be distinguished from human-induced change?

Natural populations, communities and ecological processes are very variable in time and space (e.g., Thrush 1991). This makes the task of demonstrating that a given change is due to a specific human activity demanding (e.g., Downes et al. 2002). Generally, sampling designs involving repeated before and after measurements at multiple control locations and with replication at each time and location are required to assemble sufficient quantitative data for the appropriate analytical tools. The BACI (before/after, control/impact) design and its successor Beyond BACI (Underwood 1992, 1995) are widely advocated.

The scale of sampling and associated work required by these approaches is probably beyond the means of smaller marine farm operators, so a range of alternative designs and analytical tools will be necessary. Regardless of the approach taken, however, it is imperative that sampling and analysis is statistically sound and capable of detecting change within the acceptable or threshold limits required to manage the ecological impacts of a marine farm.

4.2.3. What level of ecological change is acceptable?

Scientifically-derived Limits of Acceptable Change (Stankey et al. 1995) or Thresholds of Probable Concern (TPCs) (Rogers and Biggs 1999) of specific relevant indicators are integral to most adaptive management approaches. These pre-determined TPCs for each indicator signal that some definite effect has occurred and is likely to increase, but that the magnitude of change at the TPC is insufficient to have any significant adverse environmental effect. Thus, TPCs are values of specific indicators that detect the probable emergence of undesirable levels of human-induced, environmental change and signal that some management action is required to ensure that significant adverse environmental effects do not ensue.

Ideally, TPCs (or LACs) would be determined through a detailed understanding of the ecosystem's functioning and the effects of an aquaculture activity on important species, the community as a whole and the ecological processes inherent in that community. In the real world, however, and especially in Canterbury, we have very limited empirically-derived knowledge of the effects of aquaculture on local communities and ecosystems, so that science-based predictive capabilities are limited. Predictions of the likely magnitudes of effects of mussel farming at specific sites must be developed by scientific inference from research conducted elsewhere, even though most of that research was conducted in very different situations. Consequently, TPCs should be developed judgementally by a panel of scientists working within a hierarchy of environmental management objectives (Rogers and Biggs 1999). TPCs incorporating an appropriate conservative bias, seems the most pragmatic approach. As monitoring proceeds, the usefulness of each indicator and its TPC should be re-evaluated and, if appropriate, revised, or the indicator abandoned in favour of a more meaningful one.

4.2.4. Existing approaches

The development of a specific ecological management process is currently underway for the management of the large mussel farm off Wilson's Bay in the Firth of Thames (Hauraki Gulf). This involves the setting of LACs for a few key parameters. Preliminary LACs based on expert opinion are being developed. These are likely to be subject to review as more becomes known about the actual effects of the mussel farm (J. Zeldis pers. comm.). A simpler approach has been proposed elsewhere based on a performance criterion relating to phytoplankton depletion (e.g., James 2000, Hayden 2000, Ross 2001). This aspect has been used both because phytoplankton are at the base of the food chain and, hence, ecologically significant, and because rapid and extensive measurement of phytoplankton abundance is possible (Ross 2001).

4.3. Generic issues for all AMAs

4.3.1. Farm location and configuration

The above discussion of ecological constraints indicates that the ecological effects of a marine farm are likely to differ with the farm's specific location within an AMA. In particular, retaining an unfarmed avenue (e.g., >50 m) between the landward margin of any farm and the seaward extent of rocky bottoms will protect both the transitional (ecotonal) habitat and the rocky bottom itself from farming-related impacts. Such avenues will also give wildlife better access to adjacent shores (often used for roosting/resting, feeding, breeding), and buffers their on-shore habitats from farm-related activity. For these reasons, coastal marine farms may be better located further from shore, rather than as close to them as possible.

Similarly, the shape and/or orientation of a farm relative to shore, currents, winds, etc may ameliorate the biophysical effects of a farm. Farm size and stocking density (intensity) are additional factors that have received limited scientific scrutiny in the past, yet may have appreciable influence on the nature and magnitude of ecological effects.

4.3.2. Incremental development and monitoring

Farming within each proposed AMA, and within each farming operation within an AMA would occur incrementally through a series of stages. Successive stages would involve, either increments in the total area farmed, or increases in stocking density of the area already farmed. In addition, it may be preferable to develop only some AMAs initially until a better understanding of effects is achieved.

Monitoring and re-evaluation of environmental effects would follow each development stage to determine what changes have occurred since the latest increment, whether the predicted changes were realised, and that the observed changes can be unequivocally attributed to the most recent development action. Ideally, monitoring would occur over at least two production cycles between successive increments, because some biophysical effects are unlikely to become apparent over shorter times.

Any existing aquaculture development, as in Akaroa Harbour and Pigeon Bay, should be considered in planning and monitoring development of nearby AMAs. Baseline data are needed before any further aquaculture development occurs in these areas to ensure that any ecological effects of existing aquaculture activities can be reliably distinguished from those of new developments by monitoring.

4.3.3. Farming practice

Some potential biophysical effects, such as the high rates of sedimentation and debris discharge during harvest and re-seeding that may comprise much of the total mussel drop from a farm (Davidson 1998), may be controlled by better farming practice. It would be desirable if consent conditions required better farming practice.

Further, where sediment accumulation and enrichment occurs beneath farms, rotational re-location of the farm is recommended to allow benthic recovery, especially for farming that involves the addition of food (e.g., salmon farming), but also for mussel farming in less exposed situations. The frequency of re-location should be determined by the rate of sediment change by farming activities and its natural recovery times. It is important to retain rotation as a viable management option by allocating no more than 50% of each AMA's area to farming, at least over its first several (4-6) production cycles.

4.4. Management plans

Because so little is known about the biophysical effects of marine farming in the Canterbury region, especially in environments so exposed to wave action, a cautious approach to development within each AMA is advised. This could involve limiting the number of AMAs that are developed, either in close proximity, or in similar habitats.

Each AMA will require a specific management plan for its incremental development through iterative steps involving development, production, monitoring and evaluation according to specified environmental criteria. The first task is to set the management priorities for each AMA so that planning can proceed. Two options might be:

- Develop the AMA **solely** for aquaculture use, but require that no significant adverse effects, including ecological effects, occur outside the AMA boundaries.

- Develop the AMA with a **combined** management objective of promoting aquaculture and maintaining ecological value (e.g., spawning areas) inside the AMA, as well as requiring no significant adverse effects, including ecological, to occur outside the AMA.

Section 5 identifies issues specific to groups of AMAs. The AMA management plan will involve design of the initial stage of development, the geographical extent of the area to be developed, and the farming intensity (or long-line density). We suggest that the development beyond Stage 1 (i.e., increments in area farmed and/or farming intensity) be dependent on the outcome of a review of monitoring during Stage 1. Stage 1 development would be governed by several issues, including that:

1. Development should be sufficient in scale to have some measurable, but not adverse effects. Very small initial stages are unlikely to be useful, unless the AMA is within a restricted water body (i.e., an embayment or harbour), or the initial stage is designed to test some specific environmental effect.

2. The initial stage of development should not be significantly greater in size or intensity than that which has been developed elsewhere in a comparable environment. For example, existing mussel farm developments cover an area of 160 ha. near Collingwood (Golden Bay) in moderate–strong current flows, and another at Wilson's Bay (Firth of Thames), located in strong current flows, will be approximately 400 ha when fully developed. By comparison, current flows in the vicinity of the suggested Canterbury AMAs are likely to be moderate off shore, and moderate-weak in the inner bays of the northern Peninsula. There could be a trade-off between intensity and size (e.g., the existing farm in Golden Bay is much more intensively farmed than many of the recent proposals). There have also been many smaller developments in the Marlborough Sounds and other regions.

Further development beyond Stage 1 would be dependent on a review of monitoring when Stage 1 was fully developed. A monitoring programme and performance criteria, including judgementally-derived TPCs or LACs (see Section 4.2.3), would need to be devised for the Management Plan to cover the following types of issues:

1. Direct, local, and measurable biophysical effects, such as shell drop, sediment deposition, plankton depletion, wildlife disturbance etc. These would be monitored for each AMA or set of AMAs where they are closely grouped, relative to their size. This would be done for all AMAs.

2. Indirect local ecological effects (e.g., benthic community changes) that may arise from sedimentation and shell drop. These would be monitored for all AMAs.

3. Indirect ecosystem changes that take place over areas larger than the individual AMA (e.g., changes to water column nutrients, plankton species, shell accumulation away from the farms). These would be monitored for each large AMA, or for groups of smaller AMAs, wherever there is the potential for cumulative effects. Appropriate control sites would need to be identified away from individual AMAs.

Monitoring should include repeating the same measurements at two or more control sites so that farming effects can be distinguished from natural variability in the factors being measured. Ideally, control sites would be located in similar situations to the AMAs against which data will be compared, but away from any AMAs or other local anthropogenic influence. One set of control sites should be required for AMAs in each of the three environment types: sheltered embayments, exposed coasts and offshore environments.

Some issues will also require appropriately designed baseline surveys to be conducted prior to Stage 1 development.

5. Specific ecological constraints on suggested AMAs

Any adverse effects of marine farms that are not adequately ameliorated by location-specific mitigating factors may be regarded as ecological constraints (see p. 3 for definition) on that location. This section of the report identifies ecological constraints for AMAs, any natural mitigating factors (potential management policies or actions are not included), and potential scale and cumulative effects. Next, the suitability of each area for marine farming from an ecological management perspective[14] is outlined based on limited available scientific information. This section also identifies environmental information gaps and farming effects information gaps that limit critical evaluation of each location's suitability for marine farming. These information gaps should be filled for each AMA before establishment of marine farming within that AMA.

Many of these evaluations are based on very limited local scientific investigation, having been drawn from limited research elsewhere in New Zealand or internationally. The management plan developed for each AMA, as discussed in Section 4, should account for this uncertainty, in the pre-consent investigation required, the intensiveness of farming during each development stage, and the scope of the monitoring programme.

Detailed management plans and recommendations are beyond the scope of this report. Some consultative process should be formulated to contribute to development of these plans, ideally involving industry, resource managers, scientists and conservation and other interest groups.

---

[14] Note, issues of financial viability of marine farming within these areas are beyond the scope of this report.

5.1. AMA 1N and 1S (Motunau North and South)

Motunau North (AMA 1N) (Fig. 1) is approx. 0.5 km square (27.5 ha) located 1.2 km off the Motunau coast in c. 11 m of water (Davidson 2001). The bottom of the proposed area is rippled sand with an apparently sparse fauna. **Motunau South (AMA 1S)** (Fig. 1) is orientated almost parallel to shore, some 0.7-1.2 km off shore, located about 3 km south-west of Motunau. It is 0.5 km wide and 3 km long (along shore), covers 150 ha, and spans 9-12 m depth over a rippled sand bottom (Davidson 2001). Ecologically, it is similar to the adjacent Motunau North (AMA 1N).

5.1.1. Principal ecological constraints

Constraints at this exposed area would appear to be few, although significant information gaps limit evaluation.

- Amount, survival and dispersal of shell drop. Location of the AMA south-west of Motunau beach raises the possibility of storm waves carrying ashore mussels and other debris from beneath the suggested AMAs. However, high exposure to wave action is likely to break up and disperse any accumulating sediment, shell or organic material. Further, mobile substrates likely to bury and smother live mussels free on the bottom, and to fragment shell material.

- Rocky reefs nearby (see Davidson 2001) could be smothered by any increased sediments. However, the biota living on these reefs appears to have a low biodiversity value.

5.1.2. Scale and cumulative effects

- There is no information on the hydrodynamics of this area, so it is difficult to predict any cumulative effects that may be associated with these two AMAs. However, their close proximity creates the potential for cumulative effects. Indeed, both of the identified effects are possibly cumulative. It is suggested, therefore, that ecological effects from these AMAs be managed together.

- The scale of the combined AMAs at 177.5 ha is large relative to existing developed farms. At least four incremental development stages of increased area and/or stocking density would be prudent.

5.1.3. Preliminary evaluation of suitability

From an environmental perspective, the environment of this AMA seems compatible with mussel farming, although there are significant information gaps.

5.1.4. Critical information gaps

(a) Information gaps on the environment at this AMA

- Plankton abundance and species composition.
- Hydrodynamics (currents, waves).
- Bottom sediment composition (including particle size composition, reducing layer depth, organic and nitrogen content).
- Knowledge of the benthic infauna and epifauna is poor.
- Seabird and marine mammal use of these areas.

(b) Information gaps on aquaculture effects for this AMA

- Dispersion and accumulation of shell drop, other debris and sedimentation (natural suspended matter, faeces and pseudofaeces).
- Plankton depletion.

These information gaps should be filled before management plans are developed for these proposed AMAs. This will require field-based research for some gaps, whereas others may be adequately filled by expert opinion.

5.2. AMAs 2-5 (Pegasus North, Pegasus Central, Kowai, Spencerville)

Four large AMAs were suggested for central Pegasus Bay (Fig. 1):

Pegasus North (AMA 3) in the north consisting of an area of 3500 ha is situated some 11 km offshore in 30-40 m of water. The 5 km by 7 km block is oriented parallel to shore (roughly NNE-SSE). No information on any other aspect of its general environment or ecology was available for this report.

Pegasus Central (AMA 5) is located approximately in the centre of Pegasus Bay. It is 8.5 x 13.5 km, covering over 10,600 ha. It is rectangular, except the SE corner was removed for navigational purposes. It lies in water 24-34 m deep, and is oriented N-S, parallel to shore, some 10 km directly east of the Waimakariri River mouth. Considerable information relevant to this site is available from PBAL (2001), but several significant information gaps remain.

The **Kowai AMA (2)** is located c. 5 km off the Kowai River mouth and 2.5 km inside AMA 3 in northern Pegasus Bay, this suggested AMA is 2 km wide by 7 km long and oriented parallel to shore (NNE-SSE). It is 1400 ha, and lies over sediment bottoms in 17-24 m of water. Very little information on the biophysical characteristics specifically of this suggested AMA was available for this report.

The **Spencerville AMA (AMA 4)** is situated 5 km from shore and inside the southern half of Pegasus Central (AMA 5). This suggested AMA extends 7 km NNW-SSE parallel to shore and is 2 km wide. Its total area of c. 1400 ha covers sediment bottoms in about 17-22 m depth. Very little information specific to the biophysical characteristics of this suggested AMA was available for this report.

5.2.1. Principal ecological constraints

- Potential wave attenuation by an estimated 5-30 % (C. Stevens pers. comm., May 2003) and disruption to the hydrodynamics having potential for widespread ecosystem consequences.

- Potential for plankton depletion, including depletion of phytoplankton food for surf clam populations. High exposure to wave action and probable currents reduces the likely effects of depletion.

- Reduce recruitment to benthic communities by depletion of planktonic eggs and larvae of fishes, surf clams and other benthic invertebrates resident in the area, especially shallow-water surf clam populations. Distance from shore of some of the suggested AMAs reduces the likely impact on some sensitive near-shore areas.

- Possible accumulation of faeces and pseudofaeces underneath farms, changing benthic habitat, benthic communities and nutrient cycling. Exposure to wave action is likely to rapidly disperse faecal and pseudofaecal matter from the bottom.

- Amount, survival and dispersal of shell drop and associated debris resulting in reef formation. Shell drop from beneath the farms may be transported shoreward and deposited intertidally on beaches to the west and north-west. Exposure to wave action is also likely to break up and disperse any mussel drop, but may also transport some of this material onto beaches.

- May overlie habitat that is important for some fish or invertebrate populations and may disrupt breeding through changes to the sediments and benthos, especially breeding/nursery areas for some fish (e.g., flatfishes) species.

- Disturbance to wildlife feeding.

5.2.2. Scale and cumulative effects

- The large size of each of these AMAs potentially amplifies all of the above ecological constraints, depending on both the intensity of development and scale of developments within each AMA.

- The four AMAs total about 159 km^2, which equates to 33.3% of the c. 487 km^2 area of the rectangle that encloses them. While each AMA is washed by water from much further afield, the combination of their large sizes and close proximities to each other, suggest the potential for strong cumulative effects, especially changes to the hydrodynamic conditions and consequent ecological effects. In addition, this scale of development (individually and cumulatively) increases the risk of unknown factors affecting ecosystem processes. The potential for cumulative effects will require some issues to be managed across all AMAs.

5.2.3. Preliminary evaluation of suitability

The general environment of these AMAs seems suitable for marine farming, although shell accumulation is likely, given the depth of water here. However, at least one of these suggested AMAs overlies important nursery habitat for some fishes, whilst others are close to dense surf clam populations. Thus, their individual and combined large areas pose several environmental risks, so that additional information is essential before management plans can be finalised.

5.2.4. Critical information gaps

(a) Information gaps on the environment at this AMA

- There is poor knowledge of the hydrodynamics of Pegasus Bay, particularly variability in the bay's circulation patterns.

- For some of the AMAs (Pegasus North, Kowai, Spencerville (2, 3, 4)), there is no current or wave climate data.

- Data on phytoplankton concentrations and dynamics within Pegasus Bay are short-term, don't include any understanding of community composition and, therefore, are general not adequate for this scale of development.

- There are no zooplankton data available for any area in Pegasus Bay.

- There is no information on the benthos for the Kowai and Pegasus North AMAs (2 and 3) and limited information for Spencerville and Pegasus Central (AMAs 4 and 6).

- The importance of each AMA relative to other parts of Pegasus Bay for fish recruitment, especially flatfish, is largely unknown.

- The fate of organically-rich biodeposits and shell drop is unknown.

- There is limited information on seabird and marine mammal use.

- Likely scale and cumulative effects are completely unknown.

(b) Information gaps on aquaculture effects for this AMA

- Effects of physical farm structures over such large areas on currents and wave are poorly understood.

- Phytoplankton depletion has been estimated for Pegasus Central (AMA 5) at one time of year only (PBA2001), but not at all for the other AMAs.

- No evaluation of effects on zooplankton and benthic recruitment.

- The fate of shell material reaching the bottom is unknown. In particular, the likelihood of shell drift reaching the shore and exacerbating accumulation and/or drift.

- Likely extent of shell drop, mussel survival, reef formation and benthos change are all significant gaps in knowledge of these AMAs' ecological effects.

- Knowledge of the likelihood of organically-rich sediment accumulation beneath such large farmed areas is lacking.

The above information gaps should be addressed before specific management plans are drawn up, and, where necessary, fieldwork instigated. Some of these issues may be addressed through a consensus approach of expert opinion. Others will require field investigations. It is particularly important to understand the seasonal variability of the hydrodynamics of the bay, and to establish the main spawning and juvenile rearing areas, particularly for flatfish. Equally important is an investigation of how farming on such large scales might alter the hydrodynamics and modify planktonic processes and benthic recruitment.

5.3. AMAs 6 and 7 (Port Levy West, Port Levy East)

The 135 ha **Port Levy West (AMA 6)** lies against the western shore of Port Levy, just inside Adderley Head. It is about 675 m wide and its landward boundary is within 50 m of the steep rocky shore in places. Sediments in the general area range from silty muds in deeper (11-13.5 m) waters to seaward, to medium sand in shallower depths (7.5 m) at the southern end of the area. The organic content of these sediments was uniformly low. The fauna inhabiting these sediments changes further into the bay, but is similar to the faunas on similar bottoms elsewhere around Banks Peninsula.

The **Port Levy East AMA (7)** lies against the eastern shore of Port Levy, just inside Baleine Point. At some 77 ha in area, it varies between 320 and 500 m wide and its landward boundary is within c. 50 m of the steep rocky shore in places. Sediments in the general area are very fine clay muds in waters 6-12 m deep. The organic content of these sediments was uniformly low. The fauna inhabiting these sediments was very similar to that towards the inshore end of the Port Levy West AMA and to those faunas in equivalent situations elsewhere around Banks Peninsula.

5.3.1. Principal ecological constraints

- Potential for plankton depletion during long calm periods, especially depletion of phytoplankton for populations inhabiting adjacent rocky shores. Moderate exposure to wave action may reduce the likely effects of phytoplankton depletion.

- Amount, survival and dispersal of shell drop and associated debris, particularly potential for drift of shell onto inshore bottoms and/or towards mid-line of the bay. Exposure to wave action is likely to break up and disperse any mussel drop, but may carry it onto shore.

- Potential for accumulation of faeces and pseudofaeces given the water depth at the seaward end of these AMA. However, exposure to wave action, at least in the outer half of Port Levy East, is likely to rapidly disperse faecal and pseudofaecal matter from the bottom, as well as to break up and disperse mussel drop. Exposure to wave action is also likely to rapidly disperse faecal and pseudofaecal matter.

- Potential for cumulative effects between these AMAs, particularly phytoplankton depletion and possible shell drop accumulation in the middle of the bay.

5.3.2. Scale and cumulative effects

- Scale effects are a concern for these AMAs given the length of shoreline against which they are located.

- Cumulative effects between the two AMAs in this narrow embayment. The principal concern is that, together, these two AMAs span c. 55% of the entrance of the bay, potentially constricting exchanges between open water and the bay head. This may alter current flows, sediment regimes and the ecology (sedimentation, food availability, recruitment of planktonic larvae) of the inner portion of the port. Each of these effects could be worsened if mussel drop, from Port Levy East, in particular, results in mussel reef across much of the seaward width of the embayment. A further cumulative effect may result from marine farms occupying almost the entire rock bottom-sediment interface habitat within outer Port Levy, potentially modifying this habitat, as well as intertidal environments. These habitats may be important for some species, so that it seems prudent to restrict occupation to less of the shoreline, at least in the first stage until more is known of actual effects.

- The potential for cumulative effects with all the other AMAs on the northern Banks Peninsula coast merits a precautionary approach to development. We recommend that management plans, including staging and monitoring, for all northern Banks Peninsula AMAs be linked, so that they are consistent, enable sharing of learning between development experiences of individual AMAs and take account of any potential cumulative effects.

5.3.3. Preliminary evaluation of suitability

There are potentially important cumulative effects from these AMAs in that marine farming will influence much of the shoreline and the rock-sediment bottom interface. There is also the potential for marine farming in these AMAs to reduce exchanges between the open coastal environment and inner bay, with possibly whole ecosystem implications. We recommend, therefore, that a precautionary approach be adopted, with low density farming (e.g., backbones and/or droppers widely spaced) restricted to small areas, until potential effects are better understood.

5.3.4. Critical information gaps

(a) Information gaps on the environment at this AMA

- No information on zooplankton and use of these parts of the habour by fishes, particularly at sensitive stages in their life histories.

- Phytoplankton and nutrient dynamics in the northern bays is poorly known (previous research was short-term and investigated neither community composition nor seasonality). The narrow nature of Port Levy limits exchanges of the inner bay with open coastal waters, so that eutrophication and phytoplankton blooms are a potential risk during protracted calm periods, as reported for Akaroa Harbour. It is conceivable that mussel farms may reduce this risk by filtering phytoplankton, but could potentially enhance it by accelerating nitrogen cycling through digestion of non-labile particulate material and subsequent excretion.

(b) Information gaps on aquaculture effects for this AMA

- Effects of physical farm structures over such a large proportion of an inlet's entrance on wave, current, sediment climate are unknown. This is a developing area of knowledge and one that should be a key part of staged development, including the design of Stage 1, in order to limit the risk of significant reductions in embayment flushing.

- The likelihood of organically-rich sediment accumulating beneath such an exposed farmed area cannot be assessed from present knowledge.

- The fate of shell material reaching the bottom is unknown. In particular, the likelihood of shell drift reaching adjacent bottoms or of forming reefs across the entrance of the embayment (with contributions from both Port Levy AMAs) is unknown.

The above information gaps should be addressed and, where necessary, research initiated, before specific management plans are drawn up. Some of the issues may be addressed through expert opinion and consensus. Other issues may require field investigations. It is particularly important to understand how these AMAs modify the near-shore environment. Studies on the existing farm in Pigeon Bay may help elucidate some of these issues.

We recommend that a joint management plan is established for developing these two AMAs in concert.

5.4. AMAs 8-9, 12-15 (exposed and semi-sheltered sites on northern Banks Peninsula)

The c. 26 ha **Beacon Rock East AMA (8)** fills the outer portion of a triangular bay immediately north-west of Double Bay. Its unequal, five-sided shape varies between c. 320 and 500 m wide and is c. 750 m long. The landward boundaries are within c. 40-50 m of the steep rocky shore in places, so that the suggested AMA fills c. 70% of the bay's width. The almost level bottom at c. 13-15 m depth consists of silty mud sediments containing little organic matter. The fauna inhabiting these sediments was found to similar to that towards the seaward end of the Port Levy West AMA and to those faunas on similar bottoms elsewhere around Banks Peninsula.

The **Big Bay AMA (9)** occupies c. 30 ha of outer Big Bay and Double Bay. It is almost 400 m wide and c. 1 km long. The landward (eastern) boundaries are within c. 40-50 m of the steep rocky shore in places. Its location close to one shore and tapered shape to landward seems likely to lessen any biophysical effects. The gently sloping bottom varies from very fine sand in deeper (15 m) waters to seaward to silty muds in shallower water (11 m) further into Big Bay. The fauna inhabiting these sediments was similar to that on similar bottoms elsewhere around Banks Peninsula.

Situated in 16 m of water over an almost level, poorly sorted silt bottom between Pigeon and Menzies Bays, the **Scrubby Bay AMA (12)** is the largest AMA in this group at approximately 166 ha. Its 2 km length spans 90% of the seaward openings of three bays (Whitehead, Scrubby and Manuka Bays). The landward boundary is within c. 100 m of three steep rocky headlands, but up to c. 1 km to seaward of these bays' beaches. The fauna inhabiting bottom sediments in the vicinity of this AMA is characteristic of that on similarly exposed bottoms elsewhere around Banks Peninsula.

Menzies Bay (AMA 13) is approximately 17 ha, extending some 1.3 km along the eastern shore of Menzies Bay, from c. 300 m off the beach to about 500 m inside Otohuao Head, spanning over half of the bay's eastern shore. It is about 130 m wide and much of its eastern boundary lies within 100 m of the rocky shore. No information on bathymetry, bottom types or bottom fauna was available for this AMA.

The **Squally Bay AMA (14)** occupies c. 96 ha. It is situated over an almost level silty mud bottom in 15-16 m of water between Menzies and Decanter Bays. Its 1.2 km length (and 800 m width) screens Squally Bay and adjacent rocky shores and reefs from open water. The landward boundary is mostly >100 m from shore, but within c. 20 m of one rocky promontory and some reefs. The fauna inhabiting sediments immediately beneath this suggested AMA appears similar to that inhabiting similar bottoms elsewhere around Banks Peninsula.

Situated in **Little Akaloa, AMA 15** extends along 40% (c. 1.5 km) of the western shore of the bay, from just inside the head to about its midpoint, and covers approximately 42 ha. It is about 280 m wide, filling about half of the bay's width at its inshore end. The AMA is located very close (<50 m) to the steep rocky shore along most of its length. To seaward (north-east), the water is c. 13 m deep, shoaling to 9 m at this AMA's inshore end. Sediments are silty mud, with abundant horse mussels near the rock-sediment transition and in dense patches to seaward. The fauna living in these sediments otherwise appears broadly similar to that of equivalent situations elsewhere around Banks Peninsula.

5.4.1. Principal ecological constraints

- Potential for plankton depletion, as a food source and for recruitment to species populations inhabiting adjacent subtidal and intertidal shores. Exposure of these AMAs to moderate wave action reduces the likely effects of plankton depletion, but there is some scope for depletion by farmed mussels during long, calm periods, given the large farmed area protecting these shores from open waters.

- Amount, survival and dispersal of shell drop and associated debris, particularly potential for drift of shell onto horse mussel beds and inshore bottoms, and to form reefs over sediment bottoms.

- Possible accumulation of faeces and pseudofaeces, especially towards the landward ends of these AMAs, although wave action is likely to disperse this material at times.

- The effects of some constriction of current and wave action by marine farm structures and mussel accumulation on the ecology of the bay as a whole.

- Scale effects due to locating relatively large AMAs close to coastal features.

5.4.2. Scale and cumulative effects

- Scale effects are a potential concern for these AMAs, given their size relative to coastal features, including currents, and the length of specific shoreline types they cover. There is potential for accumulation of mussels on the bottom, especially inshore, and for depletion of plankton.

- Cumulative effects of AMAs on the northern Banks Peninsula coast may become important. The main concern is that, together, these AMAs occupy much of the moderately exposed, outer harbour, near-shore habitat around the northern Peninsula, potentially modifying this habitat, as well as intertidal environments.

5.4.3. Preliminary evaluation of suitability

Although the area appears generally suitable for marine farming, adjustments to the location and scale of the suggested AMAs may reduce the risk of inshore ecological effects. We recommend that consideration could be given to modifying the developed areas, at least during Stage 1. Reducing the size of the AMAs and relocating them further to seaward (>100 m from shore or >50 m seaward of the rock-sediment interface) to lessen the risk of ecological effects could achieve this. These AMAs are large relative to their adjacent coast/bay areas and may restrict exchange between open and inshore waters, although the exposure to current and wave action does ameliorate these concerns, except during long calm periods. Retaining unfarmed areas at the centre of some of these AMAs would effectively reduce the density of mussel long-lines, reducing the risk of adverse effects, especially from phytoplankton depletion.

5.4.4. Critical information gaps

(a) Information gaps on the environment at this AMA

- Phytoplankton and nutrient dynamics in these bays is poorly known (previous research was short-term and investigated neither community composition nor seasonality). Many of these bays are small and largely screened from open waters by the suggested AMAs, thus limiting exchanges between near-shore and open coastal waters. Depletion could become a problem, especially for supply of planktonic larvae to shore communities.

- There is very little information on the hydrodynamics of the region, which are complex (e.g., see Fig. 7).

- No information on zooplankton and use by fishes, particularly at sensitive stages in their life histories.

(b) Information gaps on aquaculture effects for this AMA

- We lack sufficient information to be able to predict the nature and magnitude of any changes in hydrodynamics induced by farm structures and their effects on plankton supply, sedimentation and benthic communities of inshore waters.

- Knowledge of the likelihood of organically-rich sediment accumulation beneath such an exposed farmed area within some of these small bays is lacking.

- Scale and cumulative effects in relation to hydrodynamics, sedimentation, plankton depletion and shell accumulation and drift are poorly understood. They are likely to be of greatest ecological significance in the near-shore environment of all bays.

The above information gaps should be addressed and, where necessary, research initiated, before specific management plans are drawn up. Some of the issues may be addressed through expert opinion and consensus. Other issues may require field investigations. It is particularly important to understand how these AMAs modify the near-shore environment. Studies on the existing farm in Pigeon Bay may help elucidate some of these issues.

5.5. AMAs 10 and 11 (Pigeon Bay West and Pigeon Bay East)

The approximately 130 ha **Pigeon Bay West (AMA 10)** (Fig. 3) extends over 4 km along the western shore of Pigeon Bay, from just inside Pigeon Point to over half way along this long, narrow harbour. It is about 300 m wide and much of its western boundary lies within 50 m of the steep rocky shore. Because of its length, this AMA traverses different bottom types. At the northern seaward end, sediments are silty muds in deeper (14 m depth), whereas poorly sorted, mixed silt-sand-pebble sediments occur in shallower (6 m) depths at the area's southern end. The organic content of these sediments was uniformly low. The fauna inhabiting these sediments changes with depth and wave exposure into the embayment, but is broadly similar to the faunas on similar bottoms elsewhere around Banks Peninsula.

Pigeon Bay East (AMA 11) (Fig. 3) is located near the middle of the bay's eastern shore, and is approximately 30 ha. It is opposite the southern portion of the larger Pigeon Bay West AMA, and is about 300 m wide, 1 km long and mostly more than 75 m off the steep rocky eastern shore. The silty mud bottom is low in organic content and is about 6-7 m deep. The fauna inhabiting these sediments changes with depth and wave exposure into the embayment, but is broadly similar to the faunas on similar bottoms elsewhere around Banks Peninsula.

5.5.1. Principal ecological constraints

- Potential for plankton depletion, including larvae of species inhabiting adjacent rocky shores. Moderate exposure to wave action, especially over the seaward half of Pigeon Bay West, reduces the likely effects of phytoplankton depletion.

- Possible accumulation of faeces and pseudofaeces, especially towards the landward end of this AMA. Periodic penetration of wave action well into this harbour is may disperse faecal and pseudofaecal matter, particularly from the seaward ends of these AMAs.

- Amount, survival and dispersal of shell drop and associated debris, notably reef formation. Wave action is unlikely to break up or disperse any mussel drop from beneath the inner half of these AMAs.

- The effects of some constriction of current and wave action by marine farm structures and mussel accumulation at the mid-reaches of the bay are unknown.

- Potential for cumulative effects and unforeseen ecosystem effects, particularly on the western shore communities due to length of Pigeon Bay West (AMA 10).

5.5.2. Scale and cumulative effects

- Scale effects are a concern for Pigeon Bay West given the length of shoreline it covers and its closeness to this shore.

- Cumulative effects of the two AMAs in this long, narrow embayment may be significant. The main concern is that, together, these two AMAs span c. 50% of the mid-bay's width, potentially constricting exchanges between open water and the bay head. This may alter current flows, sediment regimes and the ecology (sedimentation, food availability, recruitment of planktonic larvae) of the inner portion. Each of these effects could be worsened if mussel drop results in mussel reef across much of the seaward width of the embayment. A further cumulative effect may result from farms occupying almost the entire rock bottom-sediment interface habitat along outer Pigeon Bay's western shore, potentially modifying this habitat, as well as intertidal and rocky bottom habitats.

- Cumulative effects with the other AMAs (Port Levy West, Port Levy East, Menzies Bay, Little Akaloa (AMAs 6, 7, 13, 15)). The main concern is that, together, these AMAs occupy much of the moderately exposed, outer harbour, near-shore habitat around northern Banks Peninsula, potentially modifying this habitat, as well as nearby intertidal environments. It is prudent to reduce the percentage of the total habitat susceptible to modification, even though the ecological importance of this habitat to permanent or ephemeral inhabitants is poorly known.

5.5.3. Preliminary evaluation of suitability

Although the area is generally suitable for marine farming, we recommend that the location and size be adjusted. First, increasing the distance between the shore and the AMA's shoreward boundary would reduce the risk of any adverse ecological effects on these diverse rocky habitats. Second, reducing the width of both AMAs, at least during Stage 1, is recommended as a precaution against any plankton depletion effects on food and recruitment for rocky communities from this scale of marine farming. Finally leaving one of more undeveloped gaps in the Pigeon Bay West AMA would further reduce the risks to the near-shore ecosystem.

5.5.4. Critical information gaps

(a) Information gaps on the environment at this AMA

- Phytoplankton and nutrient dynamics in this bay are poorly known (previous research was short-term and investigated neither community composition nor seasonality). Much of this bay would become partially screened from open waters by the suggested AMAs, thus limiting exchanges between inner Pigeon Bay and open coastal waters. Depletion could become a problem, especially for supply of planktonic larvae to inshore communities. Similarly, eutrophication may become a problem during lengthy calm periods as land use intensifies and water temperatures increase.

- There is only limited, short-term, information on the hydrodynamics of the bay.

- No information on zooplankton and use by fishes, particularly at sensitive stages in their life histories, is available or this bay.

(b) Information gaps on aquaculture effects for this AMA

- The fate of shell material reaching the bottom is unknown. In particular, the likelihood of shell drift reaching adjacent bottoms or forming reefs across the embayment is unknown.

- Phytoplankton and nutrient dynamics in the northern bays is largely unknown. There is relatively weak exchange between inner Pigeon Bay and open coastal waters, so that eutrophication and phytoplankton blooms are a potential risk during protracted calm periods, as reported for Akaroa Harbour. It is conceivable that mussel farms may reduce this risk by filtering phytoplankton, but could potentially enhance it by accelerating nitrogen cycling through digestion of non-labile particulate material and subsequent excretion.

- We lack sufficient information to be able to predict the nature and magnitude of any changes in hydrodynamics and their effects on inshore waters.

- Scale, intensity and cumulative issues in relation to hydrodynamics, sedimentation, and plankton depletion are poorly understood, even though the existing farm achieves good growth rates. Any such scale or cumulative effects are likely to be of greatest ecological significance in the near-shore environment.

The above information gaps should be addressed and, where necessary, field work instigated, before specific management plans are drawn up. Some of the issues may be addressed through a consensus approach of expert opinion. Others may require field investigations. It is particularly important to understand how these AMAs modify the near shore environment. The existing farms in Pigeon Bay provide an excellent opportunity to investigate some of these information gaps, because two mussel farms of different ages and wave exposures already operate here.

5.6. AMA 16 (Akaroa Harbour)

Forming a 200-400 m wide ribbon along more than 6 km of Akaroa Harbour's rocky outer western shore, the c. 150 ha Akaroa Harbour AMA (Fig. 6) traverses a range of environmental conditions. It includes moderately sheltered to moderately exposed habitats with bottom sediments ranging from silty muds to sand along the depth (13-21 m) and exposure gradient from inner to outer harbour. The benthic fauna appears to change in response to sediment and exposure conditions, but is similar to that on similar bottoms elsewhere around Banks Peninsula.

There are three operational marine (salmon and abalone) farms within this AMA. These are widely spaced along the AMA from Ohinepaka Bay in the inner harbour to Mat White and Lucas Bays further seaward.

5.6.1. Principal ecological constraints

- There is considerable potential for plankton depletion as a food source and recruitment of species inhabiting adjacent subtidal and intertidal shores. Moderate exposure to wave action reduces the likely effects of plankton depletion over the seaward half of this AMA. However, long periods of calm conditions do occur at times along the entire hrbour, indicating significant potential for depletion.

- Amount, survival and dispersal of shell drop and associated debris, particularly potential for drift of shell onto inshore bottoms/reef formation. Wave action is unlikely to break up or disperse any mussel drop beneath the AMA, except perhaps over the outer portion.

- Possible accumulation of faeces and pseudofaeces, especially towards the landward end of this AMA. Periodic penetration of wave action to at least the midpoint of this AMA is also likely to disperse faecal and pseudofaecal matter from the bottom, but less likely over the inner half of the AMA.

- The effects of some constriction on current and wave action by marine farm structures and mussel accumulation on the ecology of the bay as a whole.

- Potential for unforeseen scale effects on the communities along this stretch of coast.

- Potentially problematic phytoplankton blooms do occur in Akaroa Harbour, especially during protracted calm periods, and may involve toxic species (Fenwick and Image 2002) that can limit harvesting and shellfish gathering. As a precaution, farm-related nitrogen enrichment of this area should be limited (although at present there is no research indicating that eutrophication from marine farming in the harbour may be a contributing factor to bloom formation).

- Akaroa Harbour is used intensively by endangered Hector's dolphins and marine farming structures and farm-related activities may affect them.

- Endangered white-flippered penguins roost and breed along this coast. Farm structures and farming operations may interfere with their use of this habitat or their breeding success. Also, yellow-eyed penguins, classified as vulnerable, breed in bays just outside Akaroa Harbour and conceivably use this area at times.

- Possible scale effects arising from the length of coastline that will be influenced by marine farming and potential change to a large area of near-shore habitat.

5.6.2. Scale and cumulative effects

- Scale effects are a significant concern for this AMA given the length of shoreline it covers, its unbroken length, its closeness to this shore and the occurrence of both phytoplankton blooms and long calm spells within Akaroa Harbour.

- Cumulative effects will probably be negligible given that there are no other proposed AMAs in the general area.

5.6.3. Preliminary evaluation of suitability

Key ecological management issues for Akaroa Harbour include the risk from nitrogen enrichment (eutrophication), the existence of extensive wildlife populations (including two endangered species: Hector's dolphins and white-flippered penguins), and the rocky shore ecosystem. The human importance of Akaroa Harbour suggests that management aims for the suggested AMA, if it goes ahead, will need to encompass more than aquaculture, both within and outside of the AMA. In practice, that means precautionary, staged development and monitoring to ensure ecologically sustainable use, measured against criteria relating to all of the management objectives. It also means that potential conflicts between different types of aquaculture practised within this AMA must be addressed. For example, increased eutrophication from and therapeutic chemicals used in fin-fish farming within this AMA may adversely affect any neighbouring shellfish farms.

The costs of developing an AMA like Akaroa Harbour where there are complex issues, are likely to be higher because multiple management objectives must be addressed for the space occupied by the AMA, as well as for the surrounding ecosystem. An alternative approach is to modify the AMA to reduce the risk of adverse ecological effects. For example, the distance between the shore and the AMA's shoreward boundary could be increased to at least 50 m (preferably >80 m) to minimise the risk to adjacent rocky habitats. Reducing the AMA's width, at least during an initial development, is recommended as a further precaution against any plankton depletion effects on food and recruitment for rocky communities. Maintaining one or more unfarmed gaps within the AMA would further reduce risk. Such breaks in farm structures would also serve to enhance water circulation during calm spells and provide shore-access regions for wildlife.

5.6.4. Critical information gaps

(a) Information gaps on the environment at this AMA

- There is no information on zooplankton, fishes and the extent to which the harbour is used as a breeding and nursery area.

- Information on the hydrodynamics of the harbour is limited. The University of Canterbury has developed a 2-dimensional, hydrodynamic model of the harbour, which could be used for further investigations, including plankton depletion and sediment dispersal, and for investigating nutrient and phytoplankton dyanmics.

- Nutrient and phytoplankton dynamics within Akaroa Harbour are largely unkown.

(b) Information gaps on aquaculture effects for this AMA

- There is limited evidence for and industry claims of high nutrient loadings and phytoplankton blooms during long calm periods in Akaroa Harbour (Fenwick and Image 2002). The extent and sources of nutrient enrichment, including potential inputs from the AMA, need to be identified and the risk to bloom development determined, either by seasonal experimentation or modelling.

- Effects of physical farm structures over such a large proportion of an inlet's shore on wave, current, sediment climate is unknown. We lack sufficient information to be able to predict the nature and magnitude of any changes in hydrodynamics and consequent effects on adjacent rocky bottom and intertidal communities.

- Current, wave climate and plankton data are inadequate to properly assess the likelihood of depleting phytoplankton and zooplankton, especially planktonic larvae of benthic invertebrates.

- The fate of shell material reaching the bottom is unknown.

- The effect of marine farm structures and farm-related activities on wildlife, especially Hector's dolphins and white-flippered penguins, are not known.

- The effects of farming scale and intensity on all of the above factors are a significant gap in knowledge of marine farm effects.

The above information gaps should be addressed and, where necessary, fieldwork instigated, before specific management plans are drawn up. Some of the issues may be addressed through expert opinion and consensus. Others may require field investigations. Existing farms in Akaroa may help to fill some of these information gaps, although hey are not mussel farms. Studies on the farms in Pigeon Bay may also help.

6. Conclusions

It must be reiterated that much of the assessment in this report is constrained by the lack of rigorous scientific information on the Canterbury coastal environment and on the effects of marine farming on the environments and ecosystems in which these suggested AMAs are located. Most of the investigations of marine farm effects have been conducted in sheltered waters in the northern hemisphere. The few New Zealand investigations are mostly centred on the Marlborough Sounds, with only 1-2 in exposed situations. More intensive studies are underway elsewhere in New Zealand, such as associated with large mussel farm development in the Firth of Thames (Hauraki Gulf), but these have just started and the applicability of their findings to Canterbury remains uncertain.

The main gaps in knowledge required to make more reliable evaluations of the suitability of most AMAs include better understandings of local hydrodynamics to assess potential plankton depletion issues and how changes in farm size, shape, location and rotation of locations may lessen these. We strongly recommend that a comprehensive 3-dimensional hydrodynamic model of Pegasus Bay be developed as a long-term investment to support ecological prediction and management of this complex system. Such knowledge would also assist predictions of sediment (faeces and pseudofaeces) dispersion or accumulation, and the likelihood of mussel drop accumulating and binding into semi-permanent reef structures beneath farms.

There also are significant gaps in knowledge of the biota within the vicinity of the suggested AMAs that are pertinent to their evaluation. Just as important are the substantial gaps in knowledge of fishes' and birds' use of the suggested AMAs, especially the very large ones in less accessible situations. Thus, assessments of the likely ecological effects of farming the suggested AMAs on these populations are inadequate, especially for the endangered and at risk species.

As a consequence of these major information gaps (many of which are unavoidable at present), we recommend a precautionary approach to establishment of AMAs in the region (Section 4). In the absence of such locally-relevant, scientific evidence of marine farming effects and ecologically acceptable levels of change, adaptive management approaches (e.g., see Section 4) are preferred, because they provide greater opportunity to apply knowledge and learning more effectively to all facets of the industry's development, not only to minimise adverse ecological effects, but also to maximise the longer term sustainability and profitability of marine farming in the region.

7. Acknowledgments

We wish to acknowledge and thank the several people contributed in many ways to the preparation of this report. Megan Gee (NIWA) for her patience, efficiency and good humour with our endless requests for obscure articles and reports. Barbara Hayden and Jeffrey Ren (NIWA) assisted by locating useful references and passing these on to us. Hamish Barrell (ECan) for providing access to, assembling and copying the huge files of AEEs for marine farms in the region and for his patience, understanding and good humour in helping to clarifying a number of key issues. Hamish also provided several very useful comments that improved the final report. ECan generously allowed us to use their maps of the suggested AMAs (Figs 1-6). Carol Whaitiri (NIWA) skilfully formatted the report, improving its readability and overall presentation.

8. Literature cited

Allen, J.C.; Kirk, R.M.; Hemmingsen, M.; Hart, D. (1999). Coastal processes in southern Pegasus Bay: a review. Unpublished report to Woodward-Clyde New Zealand Ltd and the Christchurch City Council by Land and Water Studies (International) Ltd. 90 pp.

Annala, J.H.; Sullivan, K.J.; O'Brien, C.J.; Smith, N.W.M. (2002). Report from the Fishery Assessment Plenary, May 2002: stock assessments and yield estimates. Parts 1 and 2. *Unpublished report held in NIWA library.* 640 pp.

Anonymous. (2002). Flexing our mussels to keep out exotic pests. *Natural Heritage 14*: 27.

Apte, S.; Gardner, J.P.A. (2001). Absence of population genetic differentiation in the New Zealand greenshell mussel *Perna canaliculis* (Gmelin 1791) as assessed by allozyme variation. *Journal of Experimental Marine Biology and Ecology 258(2)*: 173-194.

Barker, M. (1994). Unwelcome visitors!! Japanese starfish invades Tasmania, could it happen in New Zealand? *Seafood New Zealand 2(4)*: 6-9.

Blake, G.J. (1968). The rivers and the foreshore sediments of Pegasus Bay, South Island, New Zealand. *New Zealand Journal of Geology and Geophysics 11*: 225-235.

Bolton, L.A.; Ritchie, A.D. (1997). Ecological assessment of a site in Pigeon Bay, Banks Peninsula: a report for Pigeon bay Aquaculture Ltd. 23 pp.

Bower, S.M.; Figueras, A.J. (1989). Infectious diseases of mussels, especially pertaining to mussel transplantation. *World Aquaculture 20(4)*: 89-93.

Bower, S.M.; McGladdery, S.E.; Price, I.M. (1994). Synopsis of infectious diseases and parasites of commercially exploited shellfish. *Annual Review of Fish Diseases 4*: 1-199.

Brager, S.; Stanley, S. (1999). Near-shore distribution and seasonal abundance of white-flippered penguins (*Eudyptula minor albosignata*) at Banks Peninsula, New Zealand. *Notornis 46*: 365-372.

Brodie, J.W. (1960). Coastal surface currents around New Zealand. *New Zealand Journal of Geology and Geophysics 3*: 235-252.

Brown, A.F. (1976). Beach and near-shore dynamics, Pegasus Bay. Unpublished M.A. thesis, University of Canterbury, New Zealand.

Byrne, M.; Morrice, M.G.; Wolf, B. (1997). Introduction of the northern Pacific asteroid *Asteria amurensis* to Tasmania: reproduction and current distribution. *Marine Biology 127(4)*: 673-685.

Campbell, J.R. (1974). Processes of littoral and nearshore sedimentation in Pegasus Bay. Unpublished M.A. thesis, University of Canterbury, New Zealand.

Cassini, M.H. (2001). Behavioural responses of South American fur seals to approach by tourists: a brief report. *Applied Animal Behaviour Science 71(4)*: 341-346.

Castel, J. Labourg, P.J.; Escaravage, V.; Auby, I.; Garcia, M.E. (1989). Influence of seagrass beds and oyster parks on the abundance and biomass patterns of meio-and macrobenthos in tidal flats. *Estuarine, Coastal and Shelf Science 28*: 71-85.

Challies, C.N. (1998). *Eudyptula minor albosignata* In: Penguin conservation assessment plan (Report from workshop held 8-9 September 1996, Cape Town, South Africa). Ellis, S.; Croxall, J.P.; Cooper, J. (eds). IUCN/SSC Conservation Breeding Specialist Group, USA. pp. 86-88.

Chamberlain, J.; Fernandes, T.F.; Read, P.; Nickell, T. D.; Davies, I.M. (2001). Impacts of biodeposits from suspended mussel (*Mytilus edulis* L.) culture on the surrounding surficial sediments. *ICES Journal of Marine Science 58(2)*: 411-416.

Coakley, A. (1971). The biological and commercial aspects of the elephant fish. 1. The commercial fishery. *Fisheries Technical Report 76*. 29 pp.

Coen, L.D.; Luckenbach, M.W. (2000). Developing success criteria and goals for evaluating oyster reef restoration: Ecological function or resource exploitation?. *Ecological Engineering 15(3-4)*: 323-343.

Cole, R. (2001). Impacts of marine farming on wild fish populations. Draft Final Research Report for Ministry of Fisheries Project ENV2000/08. 55 pp.

Cole, R.; Grange, K. (1996). Under the mussel farm. *Seafood New Zealand November '96*: 25-26.

Cole, R; Handley, S.; Alcock, N. (2000). Ecological survey of benthic environmental at three proposed marine farm sites in Little Akaloa Bay, Banks Peninsula. NIWA Client Report MUS01407. 15 pp.

Colman, J.A. (1979). Spawning of the sprat, *Sprattus antipodum* (Hector), round the South Island of New Zealand. *New Zealand Journal of Marine and Freshwater Research 13*: 263-272.

Cranfield, J.; Michael, K. (1992). Surf clams – a fishery in waiting? *New Zealand Professional Fisherman October '92*: 57-62.

Cranfield, H.J.; Michael, K.P.; Stotter, D.; Doonan, I.J. (1994). Distribution, biomass and yield estimates of surf clams off New Zealand beaches. *New Zealand Fisheries Assessment Research Document 94/1*. 17 pp., 6 tables, 6 figs.

Cranfield, H.J.; Michael, K.P.; Dunn, A. (2002). The distribution, abundance and size of tuatua (*Paphies donacina*) on New Brighton Beach, Christchurch, in 2001. *New Zealand Fisheries Assessment Report 2002/5*. 24 pp.

Dahlbäck, B; Gunnarsson, L.Å.H. (1981). Sedimentation and sulfate reduction under a mussel farm. *Marine Biology 63*: 269-275.

Dann, P.; Cullen, J.M.; Thoday, R.; Jessop, R. (1992). Movements and patterns of mortality at sea of little blue penguins *Eudyptula minor* from Phillip Island, Victoria. *Emu 91*: 278-286.

Davenport, J.; Smith, RJ.J.W.; Packer, M. (2000). Mussels *Mytilus edulis*: significant consumers and destroyers of mesozooplankton. *Marine Ecology Progress Series 198*: 131-137.

Davidson, R.J. (1989). The bottom fauna of three subtidal locations around Banks Peninsula, Canterbury, New Zealand. *New Zealand Natural Sciences 16*: 87-95.

Davidson, R.J. (1998). Preliminary report on ecological issues related to mussel harvesting activities. Davidson Environmental Ltd Research, Survey and Monitoring Report 158. 18 pp.

Davidson, R.J. (1999a). Biological report on a proposed marine farm located in Titoki Bay, Akaroa Harbour. Davidson Environmental Ltd Research Survey and Monitoring Report No. 301. 9 pp.

Davidson, R.J. (1999b). Biological report on a proposed marine farm located south of Titoki Bay, Akaroa Harbour Permit E. Davidson Environmental Ltd Research Survey and Monitoring Report No. 302. 9 pp.

Davidson, R.J. (1999c). Biological report on a proposed marine farm located in south western Akaroa Harbour Permit G. Davidson Environmental Ltd Research Survey and Monitoring Report No. 303. 9 pp.

Davidson, R.J. (1999d). Biological report on a proposed marine farm located south of Lucas Bay, Akaroa Harbour Permit F. Davidson Environmental Ltd Research Survey and Monitoring Report No. 304. 9 pp.

Davidson, R.J. (2000a). Biological report on a proposed marine farm located south of Ohinepaka Bay, Akaroa Harbour Permit A. Davidson Environmental Ltd Research Survey and Monitoring Report No. 322. 8 pp.

Davidson, R.J. (2000b). Biological report on a proposed marine farm located south of Ohinepaka Bay, Akaroa Harbour Permit B. Davidson Environmental Ltd Research Survey and Monitoring Report No. 323. 9 pp.

Davidson, R.J. (2000c). Biological report on a proposed marine farm located north of Mat White Bay, Akaroa Harbour Permit C. Davidson Environmental Ltd Research Survey and Monitoring Report No. 324. 9 pp.

Davidson, R.J. (2000d). Biological report on a proposed marine farm located in south western Akaroa Harbour Permit H. Davidson Environmental Ltd Research Survey and Monitoring Report No. 325. 9 pp.

Davidson, R.J. (2000e). Biological report on a proposed marine farm located north of Jacobs Ladder, south western Akaroa Harbour Permit I. Davidson Environmental Ltd Research Survey and Monitoring Report No. 325. 9 pp.

Davidson, R.J. (2001). Biological report on a proposed marine farm located south of Motunau, North Canterbury. Davidson Environmental Ltd Research Survey and Monitoring Report No. 387. 11 pp.

Davies, I.M. (2002). Waste production by farmed Atlantic salmon (*Salmo salar*) in Scotland. Pp. 24-36. In Gillibrand, P.A.; Gubbins, M.J.; Greathead, C.; Davies, I.M. Scottish executive locational guidelines for fish farming: predicted levels of nutrient enhancement and benthic impact. *Scottish Fisheries Research Report Number 63*. 53 pp.

Davis, N.; Vanblaricom, G.R.; Dayton, P.K. (1982). Man-made structures on marine sediments: effects on adjacent benthic communities. *Marine Biology 70*: 295-304.

Dingwall, P.R. (1974). Bay-head sand beaches of Banks Peninsula, New Zealand. *New Zealand Oceanographic Institute Memoir No. 15*. 63 pp.

Doherty, J.L.; Brager, S. (1997). The breeding population of spotted shags (*Stictocarbo punctatus punctatus*) on Banks Peninsula: 36 years later. *Notornis 44*: 49-56.

Downes, B.J.; Barmuta, L.A.; Fairweather, P.G.; Faith, D.P.; Keough, M.J.; Lake, P.S.; Mapstone, B.D.; Quinn, G.P. (2002). Monitoring ecological impacts. Cambridge, Cambridge University Press. 434 pp.

Druce, B.E.; Kingsford, M.J. (1995). An experimental investigation on the fishes associated with drifting objects on coastal waters of temperate Australia. *Bulletin of Marine Science 57(2)*: 378-392.

DuFresne, S.; Slooten, L.; Rayment, W.; Clement, D.; Jones, G. (2000). Report on the potential effects on Hector’s dolphins of a proposed marine farm in Port Levy. Report to Southern Seas Marine Farm Ltd. 14 pp.

ECan. (2002). Sharing our sea: management of Canterbury's coastal marine area. Environment Canterbury Report Number R02/21. 26 pp, 7 figs.

Eckman, J.E.; Duggins, D.O.; Sewell, A.T. (1989). Ecology of understorey kelp environments. I. Effects of kelps on flow and particle transport near the bottom. *Journal of Experimental Marine Biology and Ecology 129*: 173-187.

Fenwick, G.D. (1999). Marine benthos off South Brighton, Pegasus Bay: a preliminary assessment. NIWA Client Report CHC99/53. 27 pp.

Fenwick, G. (2002a). Assessment of ecological effects of the proposed marine farm off Scrubby Bay, Banks Peninsula. NIWA Client Report CHC02/47. 25 pp.

Fenwick, G. (2002b). Marine benthic infauna of three bays around Banks Peninsula. NIWA Client Report CHC02/51. 26 pp.

Fenwick, G.; Cole, R. (2001). Assessments of the benthic ecology of proposed marine farm sites at Banks Peninsula. NIWA Client Report CHC01/17. 41 pp.

Fenwick, G.D.; Image, K. (2002). Effect of Lakes Ellesmere and Forsyth openings on the Banks Peninsula coastal environment. NIWA Client Report CHC2002/036. 33 pp.

Fenwick, G.D.; Ogilvie, S. (2001). Long-term changes in tuatua populations in Brighton Beach: an investigation of traditional ecological knowledge. *Final Fisheries Report for Ministry f Fisheries Project BBI2000/01*. 12 pp., 2 figs.

Fenwick, G.D.; Ross, A. (2002). Supplementary assessment of ecological effects of the proposed marine farm extension in Pigeon Bay, Banks Peninsula. NIWA Client Report CHC01/24. 47 pp.

Fenwick, G.D.; Ross, A.; Mason, C; Cole, R. (2001). Ecological and physical assessments in relation to the proposed marine farm site in Big Bay, Banks Peninsula. NIWA Client Report CHC01/10. 19 pp.

Forrest, B. (1995). Overview of ecological effects from shellfish farms in Marlborough sounds: background information for marine farm applications. *Cawthron Report No. 282*. 18 pp.

Fraser, M.M. (1999). Seasonal variation in the diet of blue penguins (*Eudyptula minor*) at Oamaru. Unpublished M.Sc. thesis, University of Otago, Dunedin.

Frechette, M; Grant, J. (1991). An *in situ* estimation of the effect of wind-driven resuspension on the growth of the mussel *Mytilus edulis* L. *Journal of Experimental Marine Biology and Ecology, 148*: 201-213.

Gales, R.; Williams, C.; Ritz, D. (1990). Foraging behaviour of the little blue penguin *Eudyptula minor*: initial results and assessment of instrument effect. *Journal of Zoology (London) 220*: 61-85.

Gardner, J.P.A. (2000). Where are the mussels in Cook Strait (New Zealand) shores? Low Stetson quality as a possible factor limiting multi-species distributions. *Marine Ecology Progress Series 194*: 123-132.

GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). (1996). Monitoring the ecological effects of coastal aquaculture wastes. Rome, Food and Agriculture Organisation of the United Nations.

Gibbs, M. (2002). Seabed survey of two proposed marine farming sites in Pegasus Bay. Cawthron Report No. 710. 3 pp.

Gibbs, M.M.; Vant, W.N. (1997). Seasonal changes in factors controlling phytoplankton growth in Beatrix Bay, New Zealand. *New Zealand Journal of Marine and Freshwater Research 31(2)*: 237-248Gillespie, P.A. (1989). The impact of long-line mussel culture on benthic habitat. Report to Department of Conservation. 18 pp.

Gillibrand, P.A.; Gubbins, M.J.; Greathead, C.; Davies, I.M. (2002). Scottish executive locational guidelines for fish farming: predicted levels of nutrient enhancement and benthic impact. *Scottish Fisheries Research Report Number 63*. 53 pp.

Golden Bay Marine Farmers, William J Wallace, Challengers Scallop Enhancement Company, First Wave Limited, New Zealand Marine Farming Association, Ngati Tama Manawhenua Ki Te Tau Ihu Trust vs Tasman District Council. Environment Court New Zealand Decision No. W 19/2003.

Goring, D.G.; Macky, G. (1997). Estimation of wave run-up height resulting from extreme sea level for the Christchurch coastal area. Part B. Extreme waves and sea levels in the Christchurch shoreline. NIWA Client Report No. CHC97/16. 35 pp.

Gorman, T.B.S. (1963). Biological and economic aspects of the elephant fish *Callorhynchus milii* Bory in Pegasus Bay and the Canterbury Bight. *Fisheries Technical Report 8*. 54 pp.

Grange, K. (2001). An analysis of benthic communities under a proposed marine farm, Pegasus Bay. NIWA Client Report PMF02401. 8 pp.

Grange, K.; Cole, R. (1997). Mussel farming impacts. *Aquaculture Update 19*: 1-3.

Grant, J.; Hatcher, A.; Scott, D.B.; Pocklington, P.; Schafer, C.T.; Winters, G.V. (1995). A multidisciplinary approach to evaluating impacts of shellfish aquaculture on benthic communities. *Estuaries 18*: 124-144.

Gray, A.N. (2000). Adaptive ecosystem management in the Pacific northwest: a case study from coastal Oregon. *Conservation Ecology [online] 4(2)*: 6.

Grenz, C.; Hermin, M.-N.; Baudinet, D.; Daumas, R. (1990). *In situ* biochemical and bacterial variation of sediments enriched with mussel biodeposits. *Hydrobiologia 207*: 153-160.

Grossman, G.D.; Jones, G.P.; Seaman, W.J. (1997). Do artificial reefs increase regional fish production? A review of existing data. *Fisheries 22(4)*: 17-27.

Grozholz, E. (1999). Ecological and evolutionary consequences f invasions: addenda to the agenda. Pp. 147-153. In Pedersen, M. (ed). Marine bioinvasions, proceedings of the first national conference, January 24-27, 1999. Cambridge, MA.

Hampton, J.; Bailey, K. (1999). Fishing for tunas associated with floating objects: review of the western pacific fishery. *Inter-American Tropical Tuna Commission Special Report No. 11*: 222-284.

Handley, S. (2000). Flatworms – oyster predators or mere scavengers? *Aquaculture Update 24*: 4-5.

Hartstein, N.D. (2003). Acoustical characterisation of substrates in and around sheltered and open-ocean mussel aquaculture sites and its bearing on the dispersal of mussel debris. Unpubl. ms. 33 pp.

Hartstein, N.D.; Rowden, A.A. (2003). Effects of biodeposits from mussel culture on macrobenthic assemblages at sires of different hydrological regime. Unpubl. ms. 26 pp.

Hatcher, A.; Grant, J.; Schofield, B. (1994). The effects of suspended mussel culture (*Mytilus* spp.) on sedimentation, benthic respiration, and sediment nutrient dynamics in a coastal bay. *Marine Ecology Progress Series 115*: 219-235.

Hawke, D.J. (1998). Seabirds around Banks Peninsula (New Zealand) from aerial surveys. *Notornis 45*: 113-125.

Hayden, B. (2000). Statement of evidence before the Marlborough District Council in the matter of application by Maclab (New Zealand) Ltd for coastal permits to farm greenshell mussels in Rerekarua, Kokowhai and Pukatea Bays in Admiralty Bay. November 2000. 17pp.

Hayward, B.W. (1997). Introduced marine organisms in New Zealand and their impact in the Waitemata Harbour, Auckland. *Tane 36*: 197-223.

Heather, B.D.; Robertson, H.A. (1996). The field guide to the birds of New Zealand. Viking, Auckland.

Hickman, R.W. (1989). Farming the green mussel in New Zealand. *World Aquaculture 20(4)*: 20-28.

Hicks, G.R.F. (1983). Numerical status and functional role of estuarine meiobenthos. *In*: Gillespie, P.A. (ed.) Nutrient processing and biomass production in New Zealand estuaries. Pp 20-22. *Water and Soil Miscellaneous Publication No. 60.*

Hicks, G.R.F. (1985). Biomass and production estimates for an estuarine meiobenthic copepod, with an instantaneous assessment of exploitation by flatfish predators. *New Zealand Journal of Ecology 8*: 125-127.

Holling, C.S. (1978). Adaptive environmental assessment and management. London, John Wiley and Sons.

Horsted, S.J.; Nielsen, T.G.; Riemann, B.; Pock-Steen, J.; Bjoernsen, P.K. (1988). Regulation of zooplankton by suspension-feeding bivalves and fish in estuarine enclosures. *Marine Ecology Progress Series 48 (3)*: 217-224.

Hutchings, J.A. (2000). Numerical assessment in the front seat, ecology and evolution in the back seat; time to change drivers in fisheries and aquaculture sciences? *Marine Ecology Progress Series 208*: 299-303.

Hydrographer, Royal New Zealand Navy. (2000). Banks Peninsula. Chart 632.

Inglis, G.J.; Hayden, B.J.; Ross, A.H. (2000). An overview of factors affecting the carrying capacity of coastal embayments for mussel culture. NIWA Client Report CHC00/69. 31 pp.

James, G.D.; Unwin, M.J. (1996). Diet of chinook salmon (*Oncorhynchus tshawytscha*) in Canterbury coastal waters, New Zealand. *New Zealand Journal of Marine and Freshwater Research 30*: 69-78.

James, M.R. (2000). Statement of evidence before the Environment Court in the matter of an appeal by Kuku Mara Partnership (Forsyth Bay) (RMA 391/00). 26pp.

James, M.R. (2002). Statement of evidence before the Environment Court in the matter of an appeal by Kuku Mara Partnership (Beatrix Bay East) (RMA 491/00). November 2002. 26pp.

James, M.R.; Weatherhead, M.A.; Ross, A.H. (2001). Size-specific clearance, excretion, and respiration rates, and phytoplankton selectivity for the mussel *Perna canaliculus* at low levels of natural food. *New Zealand Journal of Marine and Freshwater Research 35*: 73-86.

Jaramillo, E.; Bertran, C.; Bravo, A. (1992). Mussel biodeposition in an estuary in southern Chile. *Marine Ecology Progress Series 82(1)*: 85-94.

Kaspar, H.; Hall, G.H.; Holland, J. (1988). Effects of sea cage salmon farming on sediment nitrification and dissimilatory nitrate reduction. *Aquaculture 70*:333-344.

Kaspar, H.; Gillespie, P.A.; Boyer, I.C.; MacKenzie, A.L. (1985). Effects of mussel aquaculture on the nitrogen cycle and benthic communities in Kenepuru Sound, Marlborough Sounds, New Zealand. *Marine Biology 85*: 127-136.

Kingsford, M.J. (1999). Fish attraction devices (FADs) and experimental designs. *Scientia Marina 63(3-4)*: 181-190.

Knight, G.S. (1974). Benthic community structure in Lyttelton Harbour. *New Zealand Journal of Marine and Freshwater Research 8(2)*: 291-306.

Knox, G.A.; Fenwick, G.D.; Bolton, L.A. (1978). A preliminary quantitative study of the benthic fauna off Spencerville, Pegasus Bay. Estuarine Research Unit Report No. 17. 42 pp.

Knox, G.A. (1980). A study of the fouling organisms on an experimental floating tyre breakwater in Lyttelton Harbour. *Estuarine Research Report No. 23*: 1-42.

Lalas, C. (1983). Comparative feeding ecology of New Zealand marine shags (Phalacrocoracidae). Unpublished PhD thesis, University of Otago, Dunedin.

Lalas, C.; Bradshaw, C.J.A. (2001). Folklore and chimerical numbers: review of a millennium of interaction between fur seals and humans on the New Zealand region. *New Zealand Journal of Marine and Freshwater Research 35(3)*: 477-497.

Le Gall, J.Y. (2000). Tuna fishing and fish aggregating devices. Peche thoniere et dispositifs de concentration de poisons (Colloque Caraibe-Martinique, 15-19 Octobre 1999), no. 28 Actes de colloques. (Abstract).

Lehane, C.; Davenport, J. (2002). Ingestionof mesozooplanktin by three species of bivalve; *Mytilus edulis*, *Cerastoderma edule* and *Aequipecten opercularis*. *Journal of the Marine Biological Association of the United Kingdom 82(4)*: 615-619.

Mack, R.N.; Simberloff, D.; Lonsdale, W.M.; Evans, H.; Clout, M.; Bazzaz, F.A. (2000). Biotic invasions: causes, epidemiology, global consequences, and control. *Ecological Applications 10(3)*: 689-710.

Marsh, H. (1995). Pp. 122-130. The limits of detectable change. In Grigg, G.C.; Hale, P.T.; Lunney, D.C (eds) Conservation through sustainable use of wildlife. Centre for Conservation Biology, University of Queensland, Brisbane, Australia.

Mattsson, J.; Linden, O. (1983). Benthic macrofauna succession under mussels, *Mytilus edulis* L. (Bivalvia), cultured on hanging long-lines. *Sarsia 68*: 97-102.

McClatchie, S.; Hutchinson, D.; Nordin, K. (1989). Aggregation of avian predators and zooplankton prey in Otago shelf waters, New Zealand. *Journal of Plankton Research 11*: 361-374.

McShane, P.E. (1997). Environmental effects of sea-based farming of paua (*Haliotis* spp.) and kina (*Evechinus chloroticus*). *Conservation Advisory Science Notes 143*: 1-13.

Mirto, S.; La Rosa, T.; Danovaro, R.; Mazzola, A. (2000). Microbial and meiofaunal response to intensive mussel-farm biodeposition on coastal sediments of the western Mediterranean. *Marine Pollution Bulletin 40(3)*: 244-252.

Morrisey, D.J.; Gibbs, M.M.; Pickmere S.E.; Cole, R.G. (2000). Predicting impacts and recovery of marine-farm sites in Stewart Island, New Zealand, from the Findlay-Watling model. *Aquaculture 185*: 257-271.

Munawar, M.; Munawar, I.F.; Van Stam, H.; Wengehofer, C.; Fitzpatrick, M.; Lorimer J. (1999). The changing size structure of plankton as a potential indicator of food-web dynamics and ecosystem health. Conference of the International Association of Great Lakes Research: Great lakes, great science, great cities. Program and abstracts, p. A-83.

Mundy, A.R. (1968). A study of the biology of the sand flounder *Rhombosolea plebeia* Richardson off the Canterbury coast. Unpubl. PhD thesis. University of Canterbury. 151 pp.

Nairn, H. (1999). Ecological assessment of a site in Port Levy, Banks Peninsula. Report to Southern Seas Marine Farm Ltd. 30 pp.

Nairn, H. (2000). A benthic survey of a proposed long-line mussel farm Scrubby Bay, Banks Peninsula. Report to Ocean Marine Farm Ltd. 6 pp.

Nairn, H. (2001a). Benthic survey of a proposed long-line mussel farm extension, Pigeon Bay, Banks Peninsula. Report to Pigeon Bay Aquaculture Ltd. 8 pp.

Nairn, H. (2001b). Benthic survey of a proposed long-line mussel farm, Squally Bay, Banks Peninsula. Report to Pegasus Bay Marine Farm Ltd. 11 pp.

Nairn, H. (2001c). Benthic survey of a proposed long-line mussel farm, Big Bay, Banks Peninsula. Report to Pigeon Bay Aquaculture Ltd. 11 pp.

Newell, C.R. (1994). Grazing of natural particulates by the mussel, *Mytilus edulis*: a spatial and temporal perspective. *Journal of Shellfisheries Research 13(1)*: 301.

Newell, C.R.; Richardson, J.E. (2000). Grazing of natural particulates by blue mussels on rafts: simulations using FLOW-3D. *Journal of Shellfisheries Research 19(1)*: 610.

New Zealand Mussel Industry Council. (1997). Mussel industry environmental policy. Lincoln Environmental. 12 pp.

Ogilvie, S.; Ross, A.H.; Schiel, D.R. (2000). Phytoplankton biomass associated with mussel farms in Beatrix Bay, New Zealand. *Aquaculture 181*: 71-80.

Ogilvie, S.C. (2000a). Phytoplankton depletion in cultures of the mussel *Perna canaliculus*. Unpubl. Ph.D. thesis, University of Canterbury.

Ogilvie, S.C.; Mason, C.; Hatton S. (2000b). Assessment of mussel food concentration associated with a large mussel farm in Golden Bay. NIWA Client Report CHC00/83 [submitted in evidence of James (2002)].

Oliver, J. (1995). Is the “limits of acceptable change” concept useful for environmental managers? A case study from the Great Barrier Reef Marine Park. Pp. 131-139. In Grigg, G.C.; Hale, P.T.; Lunney, D.C (eds). Conservation through sustainable use of wildlife. Centre for Conservation Biology, University of Queensland, Brisbane, Australia.

Pegasus Bay Aquaculture Limited (2001). Pegasus Bay marine farm resource consent application and assessment of environmental effects. Consent application document to Environment Canterbury. 212 pp.

Pickering, J.C. (2002). Statement of evidence in the matter of RMA 505/00, RMA 522/00, RMA 523/00. 10 pp. Figures 1-2.

Poore, G.C.B. (1968). Succession of a wharf pile fauna at Lyttelton, New Zealand. *New Zealand Journal of Marine and Freshwater Research 2*: 577-590.

Radziejewska, T. (1986). On the role of *Mytilus edulis* aggregations in enhancing meiofauna communities off the southern Baltic coast. *Ophelia Supplement 4*: 211-218.

Rhodes, L.L.; Mackenzie, A.L.; Kaspar H.F.; Todd K.E. (2001). Harmful algae and mariculture in New Zealand. *ICES Journal of Marine Science 58(2)*: 398-403.

Robinson, K.; Zeldis, J.; Ross, A. (2002). Do mussels eat zooplankton? *Water and Atmosphere 10(3)*: 9.

Rogers, K.; Biggs, H. (1999). Integrating indicators, endpoints and value systems in strategic management of the rivers of the Kruger National Park. *Freshwater Biology 41(2)*: 439-451.

Ross, A.H. (2001). Statement of evidence. Submission to the Hawke Bay Regional Council by Napier Mussels Ltd, March 2001. Pp166-182.

Ross, A.H. (2002). Statement of evidence before the Environment Court in the matter of an appeal by Kuku Mara Partnership (Beatrix Bay West) RMA 505/00. November 2002. 17pp.

Ross, A.; Image, K. (2001a). Assessment of sustainable production issues related to marine farm proposals by Southern Seas Aquaculture Ltd in Port Levy, Banks Peninsula. NIWA Client Report CHC01/51. 27 pp.

Ross, A.; Image, K. (2001b). Assessment of sustainable production issues related to marine farm proposals by Ocean Marine Ltd on the northern coast of Banks Peninsula. NIWA Client Report CHC01/61. 28 pp.

Ross, A.; Image K. (2002). Assessment of sustainability issues relating to proposed marine farm extensions: a case study in Clova Bay. NIWA Client Report Ch02/48. 43 pp.

Ross, D.J.; Johnson, C.R.; Hewitt, C.L. (2002). Impact of introduced seastars *Asterias amurensis* on survivorship of juvenile commercial bivalves *Fulvia tenuicostata*. *Marine Ecology Progress Series 241*: 99-112.

Ruiz, G.M.; Hewitt, C.L. (2002). Toward understanding patterns of coastal marine invasions: a prospectus. Pp. 529-547. In Leppäkoski, E.; Gollasch, S. Olenin, S. (eds). Invasive aquatic species in Europe: distribution, impacts and management. The Netherlands, Kulwer.

Schiel, D.R. (1993). Impact assessment of proposed marine farm site at Wainui, Banks Peninsula. Unpublished report to R.D. Beattie Ltd. 10 pp.

Shafer, C.S.; Inglis, G.J. (2000). Influence of social, biophysical, and managerial conditions on tourism experiences within the Great Barrier Reef World Heritage Area. *Environmental Management 26(1)*: 73-87.

Shaughnessy, P.D.; Chapman, P. (1984). Commensal Cape fur seals in Cape Town docks. *South African Journal of Marine Science 2*: 81-91.

Simberloff, D.; Von Holle, B. (1999). Positive interactions of nonindigenous species: invasion meltdown? *Biological Invasions 1*: 21-32.

Single, M.; Fitzgerald, A. (2001). A summary of coastal processes in Pegasus Bay. Unpublished report to Sealord Shellfish Ltd. 31 pp.

Skerman, T.M. (1958). Marine fouling at the Port of Lyttelton. *New Zealand Journal of Science 1(2):* 224-257.

Slooten, E.; DuFresne, S.; Clement, D. (2000). Potential effects of mussel farming on Hector's dolphin in the Banks Peninsula region. Unpublished report to Environment Canterbury. 41 pp.

Slooten, E; Dawson, S.M.; DuFresne, S.; Clement, D. (2001). Line-transect survey of Hector's dolphin abundance between Farewell Spit and Motunau. *DOC Science Internal Series 22.* 15 pp.

Smaal, A.C. (1991). The ecology and cultivation of mussels: new advances. *Aquaculture 94*: 245-261.

Stankey, G.H.; Cole, D.N.; Lucas, R.C.; Petersen, M.E.; Frissel, S.S. (1995). The limits of acceptable change (LAC) system for wilderness planning. USADA Forest Research Paper INT-176.

Star, B.; Apte, S.; Gardner, J.P.A. (2003). Genetic structuring among populations of the greenshell mussel *Perna canaliculus* revealed by analysis of randomly amplified polymorphic DNA. *Marine Ecology Progress Series 249*: 171-182.

Stenton-Dozey, J.M.E.; Jackson, L.F.; Busby, A.J.; (1999). Impact of mussel culture on macrobenthic community structure in Saldanha Bay, South Africa. *Marine Pollution Bulletin 39*: 357-366.

Stenton-Dozey, J.; Probyn, T.; Busby, A. (2001). Impact of mussel (*Mytilus galloprovincialis*) raft-culture on benthic macrofauna, *in situ* oxygen uptake, and nutrient fluxes in Saldanha Bay, South Africa. *Canadian Journal of Fisheries and Aquatic Sciences 58*: 1021-1031.

Suggate, R.P. (1978). The geology of New Zealand. Government Printer, Wellington. 820 pp.

Svane, I.; Petersen, J.K. (2001). On the problems of epibioses, fouling and artificial reefs, a review. *Marine Ecology 22(3)*: 169-188.

Taylor, G.A. (2000). Action plan for seabird conservation in New Zealand. Parts A and B. *Threatened Species Occasional Publication no. 17*. Department of Conservation, Wellington.

Tenore, K.R.; Boyer, L.F.; Cal, R.M.; Corral, J.; Garcia-Fernandez, C.; Gonzalez, N.; Gonzalez-Gurriaran, E.; Hanson, R.B.; Iglesias, J.; *et al.* (1982). Coastal upwelling in the Rias Bajas, NW Spain: Contrasting the benthic regimes of the Rias de Arosa and de Muros. *Journal of Marine Research 40(3)*: 701-772.

Thiel, M.; Ullrich, N. (2002). Hard rock versus soft bottom: the fauna associated with intertidal mussel beds on hard bottoms along the coast of Chile, and considerations on the functional roles of mussel beds. *Helgolander Marine Research 56*: 21-30.

Thrush, S.F. (1991). Spatial patterns in soft-bottom communities. *TREE 6(3)*: 75-79.

Thrush, S.F; Hewitt, J.E.; Cummings, V.J.; Dayton, P.K. (1995). The impact of habitat disturbance by scallop dredging on marine benthic communities: what can be predicted from the results of experiments? *Marine Ecology Progress Series 129*: 141-150.

Turbott, E.G.; Bell, B.D. (1995). A census of spotted shags (*Stictocarbo punctatus punctatus*) breeding on Banks Peninsula in 1960. *Notornis 42*: 197-202.

Turner, S.J.; Thrush, S.F.; Hewitt, J.E.; Cummings, V.J.; Funnell, G. (1999). Fishing impacts and the degradation or loss of habitat structure. *Fisheries Management and Ecology 6*: 401-420.

Underwood, A.J. (1992). Beyond BACI: the detection of environmental impacts in populations in the real, but variable, world. *Journal of Experimental Marine Biology and Ecology 161*: 145-178.

Underwood, A.J. (1995). Detection and measurement of environmental impacts. Pp. 311-324. In Underwood, A.J.; Chapman, M.G. (eds). Coastal marine ecology of temperate Australia. Sydney, UNSW Press. 341 pp.

URS New Zealand Ltd. (2001). Technical reports Volume 1, assessment of environmental effects for Christchurch wastewater discharge, prepared for Christchurch City Council, 29 March 2001.

Waite, R.P. (1984). Farmed mussels feeding study. *Catch ’84 11*: 16-17.

Walters, C.J. (1986). Adaptive management of renewable resources. New York, Macmillan. 374 pp.

Walters, C.J. (1997). Challenges in adaptive management of riparian and coastal ecosystems. *Conservation Ecology [online] 1(2)*: 1.

Weimerskirch, H.; Sagar, P.M. (1996). Diving depths of sooty shearwaters *Puffinus griseus*. *Ibis 138*: 786-788.

Whitehead, P.J.P.; J, S.P.; Robertson, D.A. (1985). The two species of sprat in New Zealand waters (*Sprattus antipodum* and *S. muelleri*). *New Zealand Journal of Marine and Freshwater Research 19*: 261-271.