Beach-cast seaweed: a review

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EXECUTIVE SUMMARY

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The current status of beach-cast seaweed harvesting in New Zealand and the environmental effects of its collection have been reviewed. There are four main sectors currently using beach-cast seaweeds in New Zealand: mussel farmers for spat collection, paua farmers for food, production of agricultural fertilisers, and agar extraction. In addition to commercial uses, beach-cast seaweed is removed for cosmetic purposes as part of beach cleaning operations by territorial authorities.

The size (biomass) of the annual beach-cast seaweed harvest in New Zealand is poorly understood, with estimates ranging from 14 to 2000 kg/m/yr. Species collected include phaeophytes (*Ecklonia radiata, Macrocystis pyrifera, Lessonia* spp, *Durvillea* spp) and rhodophytes (*Pterocladia* spp, *Gracilaria chilensis, Gigartina* spp). The harvest of these species is related to algal distribution, abundance, and events including storms, and seasonal senescence.

Reported collections have occurred mostly on the east coast of New Zealand with FMA 2 (Central East) having the highest recorded take, followed by FMA 3, 5, and 4 respectively. Recorded landings from FMA 9 (Auckland West) are conspicuously low considering the large volume of seaweed known to be harvested each year for mussel spat collection from this region. A survey of regional and district councils identified nine councils that undertake beach cleaning operations resulting in the removal of beach-cast seaweeds from the coastal environment. These collections were mostly restricted to summer periods, after storm events, or in response to nuisance booms of particular species.

Kelp forests are very productive communities, turning over their biomass many times per year. Much of this productivity can become unattached and end up cast along the shore line in response to storm events, seasonal mortality, or senescence. It has been estimated that up to 25% of annual kelp production may end up in the surf zone of the beach environment and, when not removed from the beach environment, this beach-cast seaweed can play a significant role in coastal ecosystems.

Once cast ashore, the seaweeds can either be washed back into the ocean over subsequent tidal cycles or stay in the beach environment, where it is either incorporated into physical beach processes like dune formation or incorporated into terrestrial or marine food webs through consumption and decomposition. The seaweeds can support a diverse ecology of organisms through its nutrient cycling and decomposition including bacteria, yeasts, and fungi in the microflora, nematodes, invertebrate larvae and mites in the meiofauna, and numerous species of macrofaunal invertebrates of marine and terrestrial origin. If washed up high enough on the beach, the seaweed can also provide habitat for pioneering dune forming vegetation. When washed back into the sea these seaweeds become available as a food source for a variety of organisms including sea urchins and abalone. The floating component of the drift algae may also play a significant role in the dispersal of beach invertebrate species and also appears to play a role in the dispersal of juvenile fish. Seaweed decomposition has also been identified as an important nitrogen source for coastal waters due to the relatively rapid release of nutrients during breakdown, with flow on effects to primary productivity (phytoplankton) and on up the food chain.

There are few published studies that investigate the impacts of harvesting beach-cast seaweeds on the coastal environment. Most studies completed to date indicate an immediate short-term decrease in densities of strandline species extending to fish species in estuaries. While recovery of these species occurred relatively rapidly after single events, long-term harvesting created a beach fauna and flora very similar to beaches that had no input of beach-cast seaweeds. Differences in beach topography and habitat values have also been noted between raked and unraked beaches. Where in use, vehicles in the coastal environment have also been identified as a source of negative impacts on coastal ecosystems.

This review has identified a number of key research gaps related to the removal of beach-cast seaweeds from the coastal environment. Knowledge gaps include quantitative data on distribution of beach-cast seaweeds, the relationship between beach-cast seaweed and offshore algal stands, residence time of the seaweed on the beach, the fate of seaweeds when not collected and the communities they support, the role of floating seaweeds, and the effects of removals on the coastal ecosystem and fisheries resources.

1. INTRODUCTION

Seaweeds are a valuable resource that are used in many countries. In New Zealand there has been limited use of seaweeds, either wild growing or seaweeds cast up on the beach. Before this resource can be placed under the Quota Management System it must determined what environmental impacts might be caused by this harvest.

1.1 Objectives

Overall objective

To assess the nature and extent of the effects of harvesting beach-cast seaweed on the marine environment. MFish Project code: ZBS 2002/03-KMA.

Specific objectives

1. To collate existing information on the role of beach-cast seaweed in coastal ecosystems to describe the nature and extent of the effects that commercial removals of beach cast seaweed may have on the marine environment.
2. To collate existing information on the role of beach-cast seaweed in coastal ecosystems to describe the nature and extent of the effects that other deliberate removals of beach-cast seaweed may have on the marine environment.
3. On the basis of the reviews in specific objectives 1 & 2, to identify key research gaps related to any marine environment effects that the removal of beach-cast seaweed might have.

2. METHODS

Specific objective 1

We collated existing information on the role of beach-cast seaweed in coastal ecosystems to describe the nature and extent of the effects that commercial removals of beach cast seaweed may have on the marine environment. This was accomplished primarily by:

1. reviews of existing literature, and
2. telephone interviews with selected and interested parties, including harvesters and regional and local government.

1) Literature review – a review of current literature, databases, websites, and bibliographies. The review focussed on three main subject areas:

a) Ecological information:

- the species and quantities of beach-cast seaweeds potentially available for harvest in New Zealand
- the fate of seaweed when not collected
- a characterisation and quantification of beach-cast inhabitants (e.g., microflora, meiofauna, macrofauna)

- the importance of beach-cast seaweeds and inhabitants on:

  feeding and nesting shorebirds

  recycling nutrients for primary productivity in nearshore coastal ecosystems

  detrital food webs and associated organisms in nearshore coastal ecosystems

  nutritional contribution of seaweed inhabitants to nearshore coastal ecosystems when seaweed is washed back into the sea

b) Harvesting methods, both in New Zealand and overseas, were examined in an effort to determine relative effects upon the environment.

c) Legislation –New Zealand legislation on beach-cast harvesting was reviewed. This includes regulation under the Resource Management Act (Regional Coastal Plans) and the Fisheries Act (Permits).

In addition to peer reviewed articles, there exists a considerable amount of "grey" literature (e.g., local and national government reports) on the ecology and harvest of beach-cast seaweeds, particularly in Australia and South Africa. Use of extensive contacts in the seaweed industry and government in these and other countries was made to access and assess this data.

2) Telephone interviews: Much of the information required for this review was not available in published form; anecdotal evidence from the individuals involved in harvest was therefore required, particularly on information on harvest methods currently used in New Zealand and the quantities being harvested. To gather this information, people involved in harvesting were interviewed by telephone. Methods used to harvest seaweed in other countries were discovered through contacts in governing agencies in those countries, and information or literature on the effects of those collection methods as relevant to New Zealand was reviewed. Information collected from the telephone interviews included the following (see also Appendix 1):

- harvest methods used
- targeted/collected species
- seasonality/timing of harvest
- frequency of harvest
- quantities harvested
- areas/locations of harvest
- environmental variables

An important part of this review was the determination of the current structure of the seaweed harvesting industry in New Zealand. As such, part of this work focussed on characterisation of the structure of the seaweed harvest industry in New Zealand.

Specific objective 2

Non-commercial harvesting of seaweed is generally undertaken for cosmetic purposes. Beach grooming can include extensive sand conditioning processes using large purpose-built machinery, or may entail hand-removal of offensive rotting seaweed. In addition private or recreational harvest (e.g., for use in composting and garden fertiliser) also occurs. Private gatherers have been seen removing all of the obvious beach-cast seaweed from pocket beaches in the Nelson-Marlborough area.

To review information in this topic we:

- outlined the extent and nature of current sand cleaning operations in New Zealand (by sourcing literature from relevant regional councils and territorial authorities);
- reviewed the methods and effects of beach cleaning worldwide.

To carry out the latter reviews, information gathered from three main areas was collated and evaluated:

- published literature – databases, websites, and bibliographies;
- local government authorities that currently undertake beach cleaning – these bodies may have undertaken surveys and/or produced impact reports before and/or after beach cleaning;
- contractors and manufacturers of equipment – companies may have information on operational practices and equipment and may also have produced impact reports to assist in marketing their services and equipment.

Specific objective 3

Information from Objectives 1 and 2 was used to identify key information gaps on the effects that removal of beach-cast seaweed could have on coastal marine environments. The outcome of this objective provided a synthesis of the state of knowledge of this topic in New Zealand, to provide for reliable and sustainable management of this important resource.

3. RESULTS

The results of the desktop review and harvester-survey are given in Section 4. Various databases, both national and international, were used in the search for literature regarding beach-cast seaweed, including Index NZ, Newztext Plus, Current Contents, Aquatic Sciences and Fisheries Abstracts, Scirus, and Google.

In addition, a number of industry representatives within New Zealand were interviewed by telephone to provide greater detail on the use of beach-cast seaweed by industry in New Zealand. Information on non-commercial removals of beach-cast seaweed was obtained by letter survey sent to 12 regional and 51 city councils (Table 1) asking for information on beach cleaning operations within their districts (Appendix 2).

4. THE ROLE OF BEACH-CAST SEAWEEDS IN COASTAL ECOSYSTEMS AND THE ENVIRONMENTAL EFFECTS OF COMMERCIAL, NON-COMMERCIAL, AND COSMETIC REMOVALS

4.1 General introduction

Seaweeds are used in a variety of ways: for food, medicines, and agricultural products (Chapman & Chapman 1980), paper (Cecere 1998), production of biogases (Beavis & Charlier 1987), as biofilters (Buschmann 1996, Jimenez del Rio et al. 1996), in polyculture with other species (Petrell & Alie 1996, Troell et al. 1997), and for the phycocolloids (agar, carrageenan, and alginates) found in their cell walls.

Two million tonnes dry weight (about 13 million tonnes fresh weight) of seaweed is collected annually with a value in excess of NZ$12 billion worldwide (Zemke-White & Ohno 1999). Almost all of the seaweed that is used worldwide is either harvested live or is cultured. Of this, 50% (by volume) is cultured, with 90% of the cultured seaweed being produced in China, Korea, and Japan. In the decade preceding 1995 the use of seaweeds worldwide more than doubled.

In some areas, however, the seaweed that is cast up on beaches and reefs is commercially collected. Beach-cast seaweed may also be removed from beaches in urban or heavily populated areas for cosmetic reasons.

4.2 Uses and users of beach-cast seaweeds

Open sandy beaches adjacent to productive rocky reefs or kelp forests often receive high levels of organic input from beach-cast seaweeds. Seaweed that has been detached may be left stranded on the beach after high tides and has been gathered by people for numerous uses since prehistoric times. These seaweeds, along with seagrasses and other plant and animal remains and other miscellaneous debris including litter are termed "wrack" (Ochieng & Erftemeijer 1999).

Commercial use of beach-cast seaweeds is mainly restricted to temperate regions, with most collected in Australia (McHugh & King 1998) and South Africa (Share et al. 1996, Critchley et al. 1998); small industries based on beach-cast seaweeds also exist in Canada (Chopin 1998), Namibia (Molloy 1998) and New Zealand (Luxton & Courtney 1987, Schiel & Nelson 1990, Brown 1998, Zemke-White et al. 1999, Zemke-White & Ohno 1999).

In Australia, the industry is based on King Island between Victoria and Tasmania in Bass Strait. *Durvillaea potatorum* is the key species harvested, with large quantities of detached beach-cast seaweed collected, air dried, and used in alginate production. Harvests are between 15000 and 23000 t wet weight per year (Kirkman & Kendrick 1997). The industry in South Africa uses two genera of brown algae, *Ecklonia* and *Laminaria*, and four genera of red algae, *Gracilaria*, *Gelidium*, *Gigartina*, and *Porphyra*, and is centred on the coast from Transkei to Namibia (Anderson et al. 1989).

The commercial use of beach-cast seaweeds in New Zealand dates from the Second World War when New Zealand was isolated from its historical Asian suppliers of agar. Because agar was an essential material, the government encouraged the development of a domestic industry, and part-time collectors in small rural coastal communities undertook seaweed collection, primarily of *Pterocladia lucida*. This collection arrangement has survived to the present day.

Due to the number of individuals involved in collecting the seaweed and the small amount taken by each, fishing permits were considered impractical. This is reflected in the Fisheries Act (1996) which prohibits the collection of any beach-cast seaweed except rhodophytes without a permit. In 1999 the Fisheries Act (1996) was amended to allow the Ministry to issue permits for the collection of any beach-cast seaweeds, although rhodophytes are still exempt from permit requirements.

There are four main sectors currently using beach-cast seaweeds in New Zealand:

- Mussel farmers – most mussel spat used in the marine farming industry comes from seaweed collected from Ninety Mile Beach, North Island.
- Paua farmers – Paua farmers use beach-cast seaweeds as food for their paua stocks.
- Fertilisers – a number of small operations currently use beach-cast seaweeds to produce agricultural fertilisers.
- Agar extraction – this industry is small, but well established.

In addition to commercial purposes, beach-cast seaweed may be removed for cosmetic reasons (beach 'grooming'). This is common on many resort and public beaches throughout the world, and has recently become more common in New Zealand.

Seaweeds are also known to be harvested live and on-grown as a food supplement: this practice is common overseas, it is not in New Zealand. An example of a New Zealand based operation is the on-growth of *Macrocystis pyrifera* in Lyttelton Harbour, Christchurch. Here the seaweed is dried and marketed as a food condiment called "Kelp Pepper" (NZ Kelp Pepper Ltd).

Beach-cast seaweeds may thus be seen as a resource by some and a nuisance by other parts of the community. When not removed from the beach, this material can play a role in the energetics and food webs of sandy beaches and adjacent coastal areas. To assess the effects of removing this material, it is necessary to understand the role of beach-cast seaweeds in coastal ecosystems.

4.3 Ecology

4.3.1 Introduction

Kelp forests are very productive communities, turning over their biomass many times per year (Mann 1972a, 1972b). Much of this produced biomass breaks off and ends up on the shore in response to storm events, seasonal mortality, or senescence (Polis & Hurd 1996). Up to 25% of the annual production of kelp forests may end up in the surf zone and on the beach (Robertson & Hansen 1982); both the surf zone and sandy beaches are therefore considered major sites for processing and breakdown of offshore primary production

The inputs of beach-cast seaweeds can be very large; up to 2000 kg wet weight per metre (of beach) per year has been reported from both South Africa (Koop et al. 1982a) and Western Australia (Robertson & Hansen 1982) and up to 473 kg wet weight per metre per year has been recorded in California (Hayes 1974). On small islands the on-shore drift of detached seaweed can deliver a large amount of allochthonous biomass, exceeding that produced by autochthonous terrestrial productivity (Polis & Hurd 1996).

Sandy beaches can be sites of high bacterial production and considerable amounts of nitrogen can be stored by interstitial micro-organisms, meiofauna, and supralittoral fauna. These organisms are often found in zones that correlate with the deposition of beach-cast seaweeds (McLachlan 1985). Meiofauna (typically dominated by nematodes and oligochaetes) are usually concentrated on the mid to upper beach region at the higher tidal levels near wrack banks, with protozoans located near the beach/air/water surface interface. Bacteria show the reverse distribution to meiofauna with highest concentrations towards the mid to lower beach. Supralittoral macrofauna are generally concentrated on the high tidal zone close to the wrack line (Griffiths et al. 1983, Inglis 1989). As many of these organisms form the base of coastal food chains, their abundance and the amount of nutrients available to support their biomass are important factors in the abundance and diversity of coastal ecosystems.

Whether beaches retain nutrients derived from beach-cast seaweeds (i.e., act as sinks) depends on their physical environment. As most of the world's coastlines are eroding, and prograding (accumulative) beaches are rare (Bird 1983), it is likely that most sandy beaches do not act as nitrogen sinks, but cycle the nitrogen inputs back into the sea, with some loss to the atmosphere via denitrification (McLachlan & McGwynne 1986). Some beaches undergo seasonal changes in the pattern of sand deposition, with sand being deposited over summer and swept away in winter. These seasonal changes in depositional environments, combined with changes in groundwater flushing, may lead to cyclical changes in the rate of nitrogen flushing and nutrient availability to coastal ecosystems.

The discharge of groundwater into the inter- or sub-tidal zones is a feature of most sandy beaches and can have a significant effect on beach nutrient cycling (Johannes 1980). This groundwater cycling can either be additive or subtractive, dependent on the nutrient status of the groundwater itself and discharge rate in relation to nutrient accumulation. The cycling of nutrients derived from beach-cast seaweed is discussed in greater detail in the sections that follow.

4.3.2 Inhabitants of beach-cast seaweeds

Beach-cast seaweeds form an important part of complex coastal food chains (Kirkman & Kendrick 1997, Rodríguez, 2003). The lack of significant in situ primary productivity in beach environments means that organisms living there must rely on organic inputs, including beach-cast seaweeds, that arrive via the surf zone (Inglis 1989).

Beach-cast seaweeds arriving throughout the surf zone are colonised very quickly by both micro-organisms and invertebrates and are subsequently consumed and/or decomposed. In New Zealand, for instance, 40–60% of the dry weight of beach-cast seaweed was lost within 18 days of stranding (Inglis 1989). This rate may be much higher in South Africa, where one study indicated that beachcast seaweeds lost at least half their dry weight within 7 days (Griffiths & Stenton-Dozey 1981). Although the means of breakdown can vary, there is a distinct successional sequence to the colonisation and subsequent breakdown of the beach-cast seaweeds (Moore & Legner 1973, Koop et al. 1982a, 1982b, Inglis 1989, Marsden 1991b, Colombini et al. 2000, Pennings et al. 2000)(Table 2).

Koop et al. (1982a) described the successional sequence of micro-organisms beginning with coccoid bacteria on the exterior of the algae aligning along superficial cell borders of beach-cast *Ecklonia maxima* in South Africa. This occurs within a day of deposition. After three days the epidermal layer of the algae begins to separate revealing the honeycomb-like cellular structure beneath. The exudates formed from the cellular contents are colonised by rod-like micro-organisms, yeasts, and fungi. Invertebrate colonisation also begins within the first day of deposition, with amphipods and isopods amongst the clumps of beach-cast seaweed. These crustaceans soon give way to insects; first dipterans and then coleopterans, some of which feed on the dipteran larvae (Moore & Legner 1973). Both the adult amphipods and dipteran larvae feed in the rotting kelp, while adult flies apparently use mucus on the surface of the algae (Griffiths & Stenton-Dozey 1981). Other arthropod species also colonise the seaweed if left unwetted for several days with amphipods giving way to insects, while following rewetting, insects leave the wrack and are replaced by amphipods (Moore and Legner 1973). After the first three days the macrofauna begins to be replaced by meiofauna, including dipteran larvae, nematodes, oligochaetes, mites, and springtails (Inglis 1989, Marsden 1991a, 1991b).

The successional change in species composition, with predatory species following grazers, is related in part to food sources, moisture content, and other progressive microclimate changes of the deposits as the seaweed is decomposed (Moore & Legner 1973). Pennings et al. (2000), for instance, found that the isopod *Ligia pallasia* and the amphipods *Traskorchestia traskiana* and *Megalorchestia californiana* preferred aged stranded seaweed to fresh algae, suggesting that they are later successional species. They suggested that increases in the organic and mineral contents during the decomposition process were important in mediating successional sequence between individual species. Nematodes, oligochaetes, and collembola tend to colonise wrack that has been on the beach longer (Colombini et al. 2000). Thus while there is a general pattern in the successional sequence to communities associated with beach-cast seaweeds (refer Table 2), there remains some variability in the timing of colonisation by particular community members.

The initial agents of gross breakdown are macrofauna. The actions of these species produce smaller algal particles as well as faeces which are colonised by bacteria. Aside from directly eating the material, the macrofauna can increase the rate of breakdown by spreading micro-organisms and maintaining the surface microbial community in a state of increased metabolic community flux (Inglis 1989) through constant turnover of microbial cells from grazing activity. Meiofauna have a similar role within the sediments.

Empirical investigations of beach productivity suggest that the macrofauna contribute little to the overall beach productivity (estimated at 87% attributed to bacteria, 10% to meiofauna (dominated by nematodes in New Zealand (Inglis 1989)) and 3% to macrofauna (Koop & Griffiths 1982). However, this importance may be underestimated if the role that macrofauna play in making the organic material available to interstitial bacteria is not considered.

A variety of factors can affect the nature of the communities present in stands of beach-cast seaweed. For instance, whether the seaweed is mainly colonised and eaten by grazers or decomposed by micro-organisms may be site dependent. Griffiths & Stenton-Dozey (1981) reported that 60–80% of the beach-cast seaweed material was consumed by amphipods and dipteran larvae within 14 days of deposition. Conversely, other studies (Koop & Lucas 1983, Inglis 1989) reported that less than 9% of kelp tissue was consumed by grazers and most of the weight loss was due to microbial digestion and abiotic trituration.

Competitive interactions between micro-organisms and invertebrates can also be important, as feeding by the amphipod *Gammarus locusta* can inhibit algal decomposition by selectively removing rotting weed (Bedford & Moore 1985). Macrofaunal populations are thus influenced by trophic interactions from within the wrack as well as by kelp supply and predation by birds and reptiles from outside (Stenton-Dozey & Griffiths 1983). Conversely the infauna are free from external influences; the major influence of this semi-isolated infaunal community is in its consumption of organic carbon, production of waste products (e.g., faeces and CO_2) and the remineralisation of nitrogen and phosphorus (Stenton-Dozey & Griffiths 1983).

Macrofaunal abundance is strongly correlated with abundance of kelp on a beach. Densities of up to 1000 animals per kg of beach-cast seaweed are common and can be much higher (Butlin et al. 1984, Pank 1997). There is evidence that some macroinvertebrate species may time reproductive output to coincide with times of a high biomass of kelp strandings (Koop & Field 1980). For example, in South Africa juvenile cohorts of the isopod *Ligia dilatata* were at highest abundance over the winter months (Koop & Field 1980). Growth rates for this species were also observed to be slower during summer and faster during winter when food (beach-cast seaweed) was more plentiful (Koop & Field 1980).

In terms of biomass the most important elements of beach-cast seaweed fauna are herbivorous coleopterans (Griffiths & Stenton-Dozey 1981). Predatory Coleoptera formed the second largest component, with populations following fluctuations in herbivorous species abundance. These flies make up a significant proportion of the invertebrates feeding on the seaweed (Nelson 1998), with up to 49% of the macrofaunal wrack community in New Zealand composed of dipterans (Inglis 1989). On Australian coasts, 13 species of flies from the family Coleopidae (seaweed flies) were found on beach wrack with their overall abundance observed to fluctuate with the position of the seaweed on the shoreline and the tidal cycle (Blanche 1992). The principal source of energy for seaweed flies are the microbial cells involved in the breakdown of the algae (Cullen et al. 1987).

Macroinvertebrate colonisation of seaweeds cast onto New Zealand beaches peaks in density within three days of stranding (Inglis 1989). Twenty-two macroinvertebrate species were observed in this study, with six species making up over 90 % of the total abundance (Table 3). The talitrid amphipod *Talorchestia quoyana* was considered the most important of the macrofaunal consumers on New Zealand beaches; other abundant species were the dipteran fly *Leptocera aucklandica*, the centipede *Nesogeophilus xylophagus*, and the beetles *Lagrioida brouni*, *Sitonia humeralis*, and *Bledius* sp. Nematodes dominated the meiofauna, making up 85% of this community.

It is possible that the population characteristics and breeding biology of the New Zealand amphipod *Talorchestia quoyana* allow it to exploit the sandy beaches that receive seaweeds on a regular, but low level, basis (Marsden 1991b). This species is capable of producing multiple broods (up to 4–5) of young throughout the course of the year. Some zonation of life history characteristics was also observed with *T. quoyana*, with juveniles released at the most recent drift algal line on the beach where they are provided with refuge and suitable food source (Marsden 1991b). Adults being more tolerant of desiccation have a much wider distribution range. The drift algal line was the preferred habitat type for this species, with the beach-cast algae providing food, moisture, and protection from temperature extremes.

4.3.3 Fate of seaweed

The length of time beach-cast seaweed spends on a beach is variable and dependent on the tidal cycle and sea conditions at the time of being cast onto the shore (Ochieng & Erftemeijer 1999) and also on human interaction (e.g., beach grooming, other harvest). Seaweeds that are deposited following neap tides may be washed back into the sea as the tides increase in height towards the spring tide. This may not always be the case as one patch of seaweed on South New Brighton Beach, near Christchurch ,persisted on the beach for three months (Marsden 1991a).

The length of time that wrack remains on a beach obviously has implications for local nutrient cycling with the beach ecosystem as well as the physical nature of the beach itself. Taking beach residence time into consideration, beach-cast seaweeds have three possible fates;

- they can remain on the beach,
- they can be incorporated into terrestrial food webs, or
- they can be incorporated into beach and near-shore food webs including nutrient cycling in these systems.

Remaining on the beach: physical processes

Beach-cast seaweeds may play a role in sand dune formation and coastline stability. Seagrass wrack in both Australia (Hesp 1984) and Mauritania (Hemminga & Nieuwenhuize 1990) has been found in various stages of decay extending under dune formations. The latter authors described a mechanism of dune formation involving the interacting processes of beaching of seagrass litter and wind-blown transport of sand from the seaward direction. This may also apply to seaweeds deposited very high on the beach (possibly on a spring tide combined with a strong onshore wind) so that the seaweed did not merely wash back into the sea.

Beach-cast seaweeds amongst the strand line were identified as being of particular importance on exposed shores where they play a role as precursors to sand dunes. Llewellyn & Shackley (1996) outline how strandline material acts to trap sand and stabilise the foreshore and enhancing conditions for growth of other coastal vegetation through provision of organic material, nutrients, and moisture. In Wales, these strandline deposits provide an environment in which pioneering plants, including sea sandwort (*Honkenya peploides*), sea rocket (*Cakile maritime*), and saltwort (*Salsola kali*) become established and entrap more sand, thus enabling the formation of embryo dunes subsequently leading to foredune environments.

The importance of beach-cast seaweeds and other wrack in dune formation was also highlighted in North America (Nordstrom et al. 2000), where strand-line debris act as a sand trap, seed trap, and source of nutrients for dune flora and foredune formation. The establishment of successional species in these newly developed dune areas was dependent on the richness of soil micorrhyzal fungi and other soil nutrients and on the physical soil structure resulting from healthy growth of pioneer plants.

Both of the above information sources highlight the importance of beach wrack in the early formation of dune habitat and beach stability. They also outline concerns regarding stability and growth of these habitats when wrack is removed mainly by beach grooming activities.

The role of beach-cast seaweeds in dune formation in New Zealand has not been quantitatively assessed, but similar physical processes to those described previously would be expected to occur. Here, strandline vegetation including the native sand sedge (*Carex pumila*) and introduced sea rocket (*Cakile edentula, C. maritime*) and saltwort would be expected to become established amongst the beach-cast wrack and accumulating sand (Partridge 1992). These species would be replaced by sand binders including sedge pingao (*Desmoschoenus spiralis*), spinifex (*Spinifex sericeus*), and the introduced marram (*Ammophila arenaria*) (Partridge 1992; figure 1).

Incorporation into terrestrial food webs

The primary route for the nutrients released by beach-cast seaweeds to enter terrestrial food webs is through consumption of the seaweed inhabitants by birds or reptiles. Anecdotal evidence, however, suggests that some large vertebrates also occasionally feed on beach-cast seaweeds, for example deer in the northwestern United States, cattle in eastern Canada, kangaroos in Australia, and pigs on the Chatham Islands. Seaweed-eating goats and pigs have also been observed on the Auckland Islands (Chimera et al. 1995). However this is apparently a relatively rare occurrence and is only very rarely reported on mainland New Zealand.

There have been no quantitative studies of the energetic input of birds feeding on beach-cast seaweed inhabitants in New Zealand. Griffiths et al. (1983) modelled the energy cycling of beach-cast seaweeds (Figure 2) and estimated that about 0.4% of the energy from the kelp wrack went to birds and 25% of this was either returned to the sea or made available to interstitial fauna through faeces. While it might be concluded from this that the seaweed has little significance for birdlife, this may not be the case.

More convincing evidence of the importance of wrack for birds is derived from a natural experiment in California which suggests that beach-cast seaweeds have had a significant effect on density and abundance of some shorebirds. In the early 1970s, populations of giant kelp (*Macrocystis pyrifera*) declined significantly due to an El Niño event and were subsequently not found in large quantities on the shore. The kelp beds and beach-cast wrack returned by the early 1980s. The numbers of birds that exclusively foraged in the kelp wrack increased significantly with the recovery of *M. pyrifera* derived beach-cast seaweed (Bradley & Bradley 1993). Conversely, birds that did not feed on beach-cast seaweeds did not increase in numbers. Winter shorebird densities were considered to be primarily determined by resource abundance which, in this case was the supply of beach-cast giant kelp (Bradley & Bradley 1993).

Birds may nest on the wrack (Shields & Parnell 1990), and although this has not been observed in New Zealand, many local bird species have been reported to feed among beach-cast seaweeds (Table 4). Laughing gulls (*Larus atricilla*) have been shown to orient strongly towards elevated piles of debris and nest on them preferentially (Bongiorno 1970). Herring gull (*L. argentatus*) nesting numbers and breeding success are adversely affected by removal of beach wrack, with the amount of wrack present directly related to nest densities along shorelines in New York Harbour (Maccarone et al. 1993).

In addition to the nutritional value of the beach-cast seaweed and its associated fauna and its importance for nesting, the way that beach-cast seaweeds are collected may negatively effect birds that nest on the foreshore of sandy beaches. In a study of nesting hooded plovers (*Charadrius rubricollis*) in South Australia, Buick & Paton (1989) found that just a few vehicles per day resulted in an 81% probability of net loss (5–7% per day), either through interfering with breeding behaviour or by physical disturbance of the nests. This study was related to recreational off-road vehicle use and may not be an issue with the collection of beach-cast seaweeds. When harvesting beach-cast seaweeds, vehicles are likely to be driving at mid-low tide on the hard sand below the high tide line, rather than amongst the dunes where shore birds are known to nest. This may not be the case on all beaches and the method of collection may need to be controlled on a case-by-case basis to ensure that nesting birds are not detrimentally disturbed by such vehicles.

Human presence is known to adversely affect the success of certain native New Zealand birds: for example, the New Zealand dotterel (*Charadrius obscurus*) has demonstrated decreased fledgling (Lord et al. 1997) and nesting success (Lord et al. 2001) in the presence of humans.

As well as birds, several species of skinks and geckos may also feed on the inhabitants of beach-cast seaweeds. In the North Island, as far south as Auckland on the west coast and Gisborne on the east coast, the shore skink (*Oligosoma smithi*) is found among low vegetation on coastal dunes. In the southern North Island, South Island, and Stewart Island this species is replaced in these habitats by the common skink (*Oligosoma nigriplantare*). Both the widespread common gecko (*Hoplodactylus maculatus*) and, in Nelson and eastern areas from Hawke's Bay to Southland and Stewart Island, the spotted skink (*Oligosoma lineoocellatum*) can also be found on coastal dunes (Gill & Whitaker 1996). There are no published data on the dietary uptake of seaweeds and/or seaweed inhabitants by these reptiles.

As with birds, off-road vehicle use has been proven to have an adverse effect on lizard populations in sand dunes. Luckenbach & Bury (1983) demonstrated in California, USA, that vehicle use of dunes can depress lizard population densities and lead to a decline in the number of species. As with birds, it is difficult to extrapolate these findings to New Zealand.

Incorporation into beach food web

Nutrients from the seaweeds are available to interstitial beach organisms, and beach-cast seaweeds may provide more than 90% of the energy to consumers in sandy beach systems adjoining kelp beds (Griffiths et al. 1983). High concentrations of organic leachates are found underneath piles of seaweed (Koop et al. 1982a), and while up to 90% of the carbon from these leachates is used by bacteria during drainage through the sand, the remainder is available to interstitial meiofauna (McGwynne et al. 1988).

On beaches with heavy loadings of wrack, an anoxic layer forms underneath the seaweed which can have an adverse effect on meiofauna (McGwynne et al. 1988). On beaches with smaller amounts of seaweed, however, nutrients from the algal leachates and faeces from seaweed inhabitants percolate down to interstitial micro-organisms and meiofauna. Removing beach-cast seaweeds interferes with recycling of nutrients via faecal matter and deprives interstitial beach organisms of the dissolved organic material leaching from the seaweeds (Anderson et al. 1989).

Nutrients seldom accumulate on beaches once an equilibrium is reached between food supply and animal density (Hennig et al. 1983). As most beaches undergo flushing from ground water and therefore do not act as nutrients sinks, the dissolved and particulate organic matter from the seaweed will generally be flushed back in to near-shore waters and become available for incorporation into near-shore marine food webs.

Incorporation into marine food webs

The sources of energy and nutrients that may wash back into the sea include whole seaweed, inhabitants of the wrack, and dissolved and particulate organic matter. When whole seaweed washes back into the sea it can form an important habitat for juvenile fishes, can be eaten by herbivores, or can be further decomposed and used by detritivores and filter feeders, or the dissolved nutrients be taken up by primary producers (Lenanton et al. 1982, Robertson & Lucas 1983, Kingsford 1992, Druce & Kingsford 1995, Ingolfsson 1995, Ingolfsson & Olafsson 1997, Ingolfsson 1998, Norkko 1998, Ingolfsson 2000, Norkko et al. 2000, Brooks & Bell 2001, Mora et al. 2001, Rodríguez, 2003).

While there is little empirical evidence regarding the residence time of beach-cast seaweeds, it seems that, if not harvested, a large proportion of this seaweed must become resuspended, either floating in the water column or on the surface or near the sea floor. This is because a significant portion of beach-cast seaweed must be cast up during neap tidal cycles. Spring tides or wave action would provide a medium through which this material could be resuspended, thus removing it from the beach environment.

Bottom drifting seaweeds play a role in coastal ecosystems and benthic species differ in their ability to use this resource. Sea urchins and abalone both target drifting algae as a food source (Rodríguez 2003). Mobile opportunistic species are often positively affected by drifting algae as a food source, while some sessile species can be negatively affected by smothering and anoxia in underlying sediments (Norkko 1998). These different responses of organisms to detached algae demonstrate that drift seaweeds can act as both stressors and an alternative food source and habitat for benthic organisms (Norkko et al. 2000).

Potentially one of the most significant roles of beach-cast seaweed that is resuspended following stranding is as a habitat for juvenile fishes, providing both shelter and food sources for these important life stages (Kingsford 1992), and also as a long-distance dispersal mechanism of invertebrate species (Brooks & Bell 2001). Much research has focused on the role of drifting algae as a habitat for invertebrates (Robertson & Lucas 1983, Ingolfsson 1995, 1998, 2000, Ingolfsson & Olafsson 1997, Norkko 1998, Norkko et al. 2000, Olafsson et al. 2001) and juvenile fish (Lenanton et al. 1982, Kingsford 1992, Druce & Kingsford 1995, Mora et al. 2001).

Bluenose (*Hyperoglyphe antarctica*) is an economically important midwater fish in New Zealand waters. There are only three records of pre-settlement juveniles of this species, and they have all been found amongst floating debris and/or seaweeds (Duffy et al. 2000). In northeastern New Zealand, floating algae can become quickly colonised by juvenile fishes, leading to high concentrations of small fish around the drift algae (Kingsford 1992). A number of species were found around the algae that are not commonly found in open waters, suggesting that the seaweed may have an important influence on the distribution of presettlement fish (Table 5). It was concluded that floating objects may enhance conditions for feeding, provide shelter, provide pelagic substrate, and may act as cleaning stations for larger fish (Kingsford 1992).

Intertidal animals, including midge larvae, mussels, and harpacticoid crustaceans, that have colonised beach-cast seaweeds can survive for up to 20 days when resuspended, while the seaweed is quickly colonised by subtidal organisms including benthic amphipods, calanoid copepods, and fish fry (Ingolfsson 1998). These patches of floating seaweed thus support special communities composed of a mixture of intertidal, benthic, and pelagic colonising species, and show a much higher species richness than the surrounding waters (Ingolfsson 1998). This has important implications for the harvesting of beach-cast seaweeds as the presence of intertidal species indicates that much floating seaweed may have spent some time on the beach and been subsequently resuspended.

It has been demonstrated that drift algae play an important role in the life of four species of economically important fish in Western Australia: the yellow-eyed mullet (*Aldrichetta forsteri*), the cobbler (*Cnidoglanis macrocephalus*), school whiting (*Sillago bassensis*) and Australian herring *Arripis georgianus*) (Lenanton et al. 1982). The arrival of juveniles of these species on the open coast was correlated with large amounts of detached seaweed and the main food items of these fish species were invertebrates that occurred on the detached seaweed. The association between floating plants and juvenile fish appears to be quite widespread along the southwest coast of Western Australia (Lenanton et al. 1982).

Nutrients

When washed back into the sea, seaweed may have an important role in the remineralisation of nutrients in nearshore ecosystems. The bacteria that have grown on these seaweeds are also a food source for nearshore food webs (Kirkman & Kendrick 1997). The amphipod *Allochestes compressa* consumes considerable amounts of detached *Ecklonia radiata* in the surf-zone, and can potentially turn over the entire *E. radiata* biomass twice per month in summer and once every 1–2 months in autumn and spring (Robertson & Lucas 1983). In addition, some species of invertebrates are found associated almost exclusively with detached seaweed, (e.g., the polychaete *Platynereis dumerilii* associated with detached *Laminaria saccharina*) while some others prefer partially decomposed seaweed (e.g. the sea urchin *Psammenchinus milaris*) (Bedford & Moore 1985).

Through microbial regeneration of nutrients from beach-cast seaweeds, 95% of the nitrogen from beach-cast seaweeds may be returned to the sea (Koop et al. 1982b); phosphate and nitrate concentration are higher in coastal waters adjacent to beaches with wrack accumulations (Robertson & Hansen 1982).

Decomposing seaweeds are important to coastal ecosystems (Mann 1973, Smith & Foreman 1984, Thresher et al. 1992), with growth rates of benthic suspension feeders two to five times as high at kelp-dominated islands than at those without kelp beds (Duggins et al. 1989). Seaweeds are particularly important as a nitrogen source in coastal waters because of their ability to rapidly release nutrients during decomposition (Hanisak 1992). The role of kelp may be greatest in winter when phytoplankton production is at a minimum and kelp standing stock is either senescing or being physically degraded during storms (Duggins et al. 1989). This degraded or detached seaweed then enters detrital food webs, which are important in near-shore systems (Talbot & Bate 1988). Carbon isotope analysis shows that kelp-derived carbon is found throughout nearshore food webs and particulate carbon supports benthic filter feeders (Duggins et al. 1989). Detrital biomass in the surf zone may be four times that offshore (Talbot & Bate 1988). However, detrital pathways in marine systems are still not well understood, and many organisms thought to be herbivores may be detritovores, making this an important route for energy from primary production to enter marine food webs.

The seaweed source-sink relationship should be taken into account in nutrient budget models wherever there are significant standing stocks of seaweeds, either subtidally or intertidally. This may be more important in tropical and subtropical systems where macrophyte production is more likely to be nutrient limited as these waters are usually oligotrophic (Hanisak 1992).

4.4 Species and quantities of beach-cast seaweeds available for harvest in New Zealand

The species available for harvesting from the beaches of New Zealand are related to algal distribution and abundance (Moore 1961, Nelson 1994). As most of the beach-cast seaweeds collected are storm generated, quantities available for harvest are often variable and weather dependent.

The main species that have attracted commercial attention in New Zealand to date have been the brown algae *Ecklonia radiata, Macrocystis pyrifera, Lessonia* spp., and *Durvillaea* spp. and the red algae *Pterocladia* spp., *Gracilaria chilensis*, and *Gigartina* spp. (Table 6).

The only study available on the quantities and seasonality of beach-cast seaweeds in New Zealand was carried out on South New Brighton Beach, near Christchurch (Marsden 1991a). Material stranded on the beach was weighed and identified along 5 m wide transects stretching from low water to high water. Organic input to Brighton Beach throughout the year was dominated by driftwood, grass, and two kelp species, *Macrocystis pyrifera* and *Durvillaea antarctica. Hormosira banksii, Carpophyllum maschalocarpum, Lessonia variegata, Cystophora scalaris, Scytosiphon lomentaria, Sargassum sinclairii*, and *Marginariella boryana* were also found, but combined they made up less than 16% of the algal biomass. The average monthly input (± standard error) of seaweeds was 5.8 ± 2.2 kg for each transect. This equates to about 14 kg per metre per year, a relatively low total input when compared with those reported from both South Africa (Koop et al. 1982a), Australia (Robertson & Hansen 1982), and California (Hayes 1974) (Table 7). The greatest quantities of seaweed were beach-cast in the winter but there were irregular large strandings, dominated by *Macrocystis pyrifera*, over the summer as well. This pattern correlates with the predominantly easterly winds that Canterbury experiences in summer (Inglis 1989).

There is unpublished data from the Wairarapa coast where a number of reasonably accessible bays were surveyed over two years (Ian Miller, pers. comm.). The estimated volumes of beach-cast seaweed over a single 12 month period were 18 500 m^3 and 20 000 m^3 in the following year (this equates to about 2000 kg per linear metre of beach, Table 7). On one day this land-based surveillance effort was checked through an aerial search of the same areas. It was considered that the above values were almost certainly underestimates, as the voluntary surveyors missed significant deposits on that day. The volumes are estimated because, while lengths, breadths, and heights could be measured accurately, the beach topography at the centre of large beach-cast seaweed heaps remained unknown (Ian Miller, pers. comm.).

Another indirect source of information on beach-cast seaweeds comes from Ninety Mile Beach where seaweed is collected for the mussel spat that are attached to the algae. Spat from beach-cast seaweed supplies most of the spat for New Zealand's mussel industry (Alfaro et al. 2001). A single wash-up event at Ninety Mile Beach can comprise up to 70 t of algae, for an estimated 70000 t of combined spat and seaweed harvested per year from along the beach (Alfaro & Jeffs 2002). The spat covered seaweed is gathered by hand using vehicles and trailers to transport the material back to a depot where it is sorted and packed, typically into approximately 10 kg plastic bags. These bags containing the spat still attached to the seaweed are then sent around the country to the various mussel growing areas. The spat covered seaweed is packed into a biodegradable stocking along with a growing rope, which is then hung out in the sea for on-growth of mussels. Both the stocking and seaweed disintegrate over time, leaving behind the mussels attached to the growing rope.

The species collected from Ninety Mile Beach were identified by Alfaro & Jeffs (2002) and broadly grouped into three classes based on the level and degree of branching of the washed-up material (Table 8). This classification system was chosen as the degree of branching is correlated with the number of mussel spat settling on the seaweed strands, with densities greater on fine-branching material.

All the algal species identified were red algae, except *Carpophyllum angustifolium* (Phaeophyta), which contributed less than 5% of the total weight of the samples collected (Alfaro & Jeffs 2002). This algal class differentiation was consistent throughout the three beach-castings sampled (October and December 1998, May 1999) and is considered to be representative of the total take of beach-cast seaweed for mussel spat from Ninety Mile Beach.

Seasonality of the algal species also plays a role in the abundance as a component of the beach-cast wrack (Hay & Villouta 1993, Gillanders & Brown 1994, Kingsford 1992). Biomass of *Xiphophora gladiata* in Otago, for instance, peaks in autumn, just before the winter storm season (Gillanders & Brown 1994). Sporophytes of *Undaria pinnatifida*, on the other hand, grow rapidly from winter to spring and degenerate from summer to autumn (Hay & Villouta 1993), potentially making them a more common component of the wrack in these seasons. This is likely to vary latitudinally because degradation occurs earlier in more northern regions in response to changing water temperatures.

Weather plays a primary role in determining the abundance of beach-cast seaweeds. Winter storms may be responsible for tearing loose a large biomass of seaweed (there are no data available from New Zealand, but in South Africa an estimated 10–15 % standing biomass may be detached) (Anderson et al. 1989), and northeasterly winds may also result in a significant deposit of beach-cast seaweeds along the Pacific coast of northern New Zealand over the summer.

4.5 Customary use of beach-cast seaweed

Seaweeds (rimu, rimurimu, rimupara) were a valuable resource for Maori, and were used as storage containers, medicine, food, and in trade (Ngai Tahu 1992; Riley 1994) and as a fertiliser for crops (Cooper 2002; Vause 2001). Examples of its use include rimurapa (bull kelp *Durvillaea*) as a material to make poha, small containers used for storage of titi (mutton birds) and other foods (Ngai Tahu 1992) and also as a medicinal treatment for skin disorders, burns, worms and goitre, as a laxative (Riley 1994 Brooker et al. 1987 Williams 1996). Its medicinal and food value made it a valuable tradable commodity(Ngai Tahu 1992, Muriwhenua 1988). Baskets of dried seaweed were transported inland, where they were traded for forest products (Muriwhenua 1988).

Karengo or parengo (*Porphyra* spp) was of particular note as an edible food source in the South Island that is still popular today (Ngai Tahu 1992, Hurd et al. 2004). Karengo was dried and traded with forest people and was also used as a medicinal laxative and a treatment for goitre (Brooker et al. 1987, Riley 1988, 1994, Crowe 1997). *Porphyra* was also noted as being of cultural significance to Maori (Hurd et al. 2004). *Gigartina* (rehia) was known to be consumed by Maori and used as dried product (Riley 1988) and as a medicine to treat sore throats and coughs (Riley 1994). A total of 15 New Zealand seaweed species were described by Crowe (1997) as being edible, and all of these species may have been available for consumption by Maori after stranding on beaches.

Currently, the harvest of beach-cast seaweeds provides a valuable commercial crop for iwi, in particular the harvest of *Pterocladia lucida* which is gathered, dried, and sold to purchasing agents for on-selling to agar manufacturers (Muriwhenua 1988). Other species, including *Ecklonia radiata* and *Durvillaea*, have also been collected and processed into fertilisers (Muriwhenua 1988).

4.6 Current commercial take

The Ministry of Fisheries database was used to extract data on reported landings of beach-cast seaweeds. As there is no reporting requirement for the collection of beach-cast rhodophytes, individual operators from the seaweed industry were also interviewed.

Based on reports to the Ministry of Fisheries, the total collection of beach-cast seaweeds over the last 10 years has fluctuated widely (e.g., 0.78 t in 1999–2000 to 21.17 t in 1997–98) (Figure 3). The catch also varies in species composition, with *Macrocystis pyrifera* making up the largest proportion of the catch in most years (Figure 4). Part of the fluctuation in catch return information is due to the issuing of fishing permits for the collection of beach-cast seaweeds in 1998. Collections under these permits do not appear to have been included in the Ministry of Fisheries database. There are extant permits for bladder kelp (2), bull kelp (1), *Gracilaria* (2), *Lessonia* (1), *Porphyra* (1), and *Pterocladia* (5). Mean annual reported landings of beach-cast seaweeds by Fisheries Management Area is shown in Figures 5 and 6.

Four business sectors currently commercially use beach-cast seaweeds in New Zealand: phycocolloid (agar) production, fertiliser production, paua farming, and mussel farming. The potential of New Zealand seaweeds for the commercial application of other pharmaceutical products, including small organic molecules, carrageenans, alginates, and other novel structures has been examined (Hurd et al. 2004). The quality of these chemicals, including agar, is generally higher from attached plants than from those cast up on beaches (Hurd et al. 2004). Research has mostly focussed on the harvest of attached forms. The novel pharmaceutical sector is therefore not a major consumer of beach-cast seaweed.

Agar production

The only company currently using seaweed for the commercial production of agar buys dried, beach-cast seaweed (mainly *Pterocladia* spp.) from part-time rural collectors. It produces various grades of agar, primarily for export, but also fertilisers, animal drenches, and animal food supplements for the local market. The company has been increasingly relying on imported seaweed, and their requirement for New Zealand beach-cast *Pterocladia* has declined to about 10 t dry weight per year.

Agar produced from attached plants is generally considered to be of higher and more uniform quality than that from beach-cast material (Luxton & Courtney 1987).

Fertiliser production

One company currently uses about 3–4 t (dried weight) per year of beach-cast *Ecklonia radiata*, collected from the Wairarapa, Hawke's Bay, far north, and Coromandel regions. The seaweed is mostly collected manually. The company expects to expand, and anticipates using *Macrocystis pyrifera* collected from around Oamaru. A second fertiliser company imports dried beach-cast *Durvillaea potatorum* from King Island, in southern Australia. They state that the imported seaweed comes to them in better condition (uniform water content and species composition) than they can source locally. Other, smaller-scale operations produce concentrated extracts and other products out of harvested beach-cast seaweed (Muriwhenua 1988, Vause 2001, Cooper 2002).

The value of fertilisers produced from beach-cast seaweed may be limited, as a number of seaweed-based products have been shown to be ineffective (Feyter et al. 1989). However, some orchardists believe the products to be beneficial, with better health and fewer diseases on trees treated with seaweed fertiliser (Anon. 1999).

Paua farms

The main seaweed used for feeding paua in New Zealand is *Gracilaria* spp., which is not strictly beach-cast but is collected in the intertidal zone where it attaches to shells and other hard substrata. Although some growers do use beach-cast *Gigartina* spp. and *Lessonia* spp, precise information on the feeding of paua is difficult to come by. Most New Zealand paua farmers use artificial feeds, only using live seaweed to supplement feed. One grower uses 200–300 kg wet weight of beach-cast seaweeds per month.

Mussel spat

As mentioned above, the mussel farming industry in New Zealand currently relies on spat collected from Ninety Mile Beach. This spat settles onto detached floating seaweeds, some of which is cast up on the beach where it is collected and sent to the mussel farms. The total weight of spat and seaweed collected is about 70000 t wet weight per year (Alfaro & Jeffs 2002), but the seaweed component of this has not been quantified.

4.7 Legislative review

Fisheries regulation

Overview

Seaweeds are managed under New Zealand's fisheries legislation, which incorporates them into the same statutory regime as other aquatic life forms, including fish and shellfish. The Fisheries Act 1996 is a comprehensive statute dealing with the utilisation and sustainability of fisheries resources, which under the Act includes all fish, aquatic life and seaweed. The definition of "seaweed" under the Act includes all kinds of algae and sea-grasses that grow in New Zealand fisheries waters at any stage of their life history, whether living or dead. This all-embracing definition means that microalgae as well as macroalgae are subject to the statutory permit regime in the Fisheries Act. The definition also means that macroalgae, either whole plants or fragments that have become detached and are free-floating or that have been cast ashore, are subject to the same management system as intact living plants.

Present management regime

The statutory regime controlling the commercial harvest of aquatic organisms under the Fisheries Act 1996 currently relies on permits to control access to the seaweed fishery. In particular, section 89 of the 1996 Act provides that no person shall take seaweed for the purposes of sale by any method unless the person does so under the authority of and in accordance with a current fishing permit. Permits may be subject to a range of detailed conditions that can include restrictions on areas, quantities, seasons, and fishing methods. However, there is a specific exemption in section 89 to the requirement to hold a fishing permit for seaweeds of the Division Rhodophyceae while they are unattached and cast ashore.

The exemption of beach-cast red seaweed from the commercial fishing permit requirement has an historical basis. During the Second World War, New Zealand was isolated from its regular suppliers of agar and the government promoted the development of a domestic industry. Part-time collectors in small rural coastal communities were encouraged to undertake seaweed collection (primarily beach-cast *Pterocladia lucida*) to help the war effort. This largely unregulated industry has remained to the present day. There are many individuals in remote coastal areas involved in collecting small quantities of beach-cast seaweed to supplement other income. Requiring them to apply for commercial fishing permits for what has been viewed by the public as a natural waste product has until now been considered either impractical or unnecessary.

A moratorium currently in place under section 93 of the Fisheries Act 1996 prevents the issue of any new or additional commercial fishing permits, including any permit for harvesting attached seaweed. All existing permits may be renewed on an annual basis, but have been gradually declining in number as permit holders retire or leave the industry. The section 93 moratorium does not apply to the issue of new permits for the harvesting of beach-cast seaweeds.

There are currently only a few commercial fishing permits authorising the harvesting of seaweeds, due in part to a limited commercial demand and in part to the moratorium that has been in place since 1992.

In addition to the commercial fishing permit regime, section 97 of the Fisheries Act provides for the issue of special permits for a range purposes, including those approved by the Minister of Fisheries. Under this authority, special permits have been issued for some commercial harvesting of seaweeds, including seaweed for paua (abalone) farmers to supplement the feeding of farmed paua and the harvesting of seaweed that has attached mussel spat for the mussel farming industry. Some of these special permits are now being replaced through the issue of commercial fishing permits for the harvesting of beach-cast seaweeds.

Future management

The present seaweed management regime is largely ad hoc and has been established over time in reaction to pressures rather than as a coherent management approach. The principal tool for the management of commercial fisheries under the Fisheries Act 1996 is the Quota Management System (QMS) which is based around setting total allowable commercial catches to meet sustainability needs with access to harvesting rights allocated as individual transferable quotas. There are plans to bring the harvesting of attached macroalgal species into the QMS in the future so that the fishery is managed in a coherent and sustainable fashion.

Resource management regulation

Overview

Under the Resource Management Act there are three levels of statutory framework relevant to the collection of seaweed from the foreshore. These are the Resource Management Act (RMA) itself, the New Zealand Coastal Policy Statement (NZCPS), and the relevant regional coastal plan for the area where the seaweed is to be collected. The relevant aspects of the RMA and NZCPS are discussed below, and the Auckland Regional Plan: Coastal and Hawke's Bay Regional Coastal Plan are used as examples of regional coastal plans.

Resource Management Act

Section 12 of the RMA contains several clauses relevant to the collection of seaweed from the foreshore. These are as follows.

1. *No person may, in the coastal marine area......*

    c) *Disturb any foreshore or seabed (including by excavating, drilling, or tunnelling) in a manner that has or is likely to have an adverse effect on the foreshore or seabed (other than for the purpose of lawfully harvesting any plant or animal); or.....*

    e) *Destroy, damage, or disturb any foreshore or seabed (other than for the purpose of lawfully harvesting any plant or animal) in a manner that has or is likely to have an adverse effect on plants or animals or their habitat; or....*

    unless expressly allowed by a rule in a regional coastal plan and in any relevant proposed regional coastal plan, or a resource consent.

2. *No person may, in relation to land of the Crown in the coastal marine area, or land in the coastal marine area vested in the regional council......*

    b) *Remove any sand, shingle, shell, or other natural material from the land*

    unless expressly allowed by a rule in a regional coastal plan and in any relevant proposed regional coastal plan, or by a resource consent.

4. b) *"Remove any sand, shingle, shell, or other natural material" means to take any of that material in such quantities or in such circumstances that, but for the rule in the regional coastal plan or the holding of a resource consent, a licence or profit à prendre to do so would be necessary.*

In summary, under the RMA, Sections 12(2)(b) and 12(4)(b) have the most relevance with respect to the collection of seaweed from the foreshore. Under both of these the collection of seaweed in significant quantities would require a resource consent or appropriate licence.

New Zealand Coastal Policy Statement

The RMA requires that at all times there be an active NZCPS. The policy statement is intended to help guide local authorities in their day to day management of the coastal environment. With respect to the gathering of seaweed from the foreshore, there are a number of policies that have relevance. These are as follows.

Policy 1.1.2

It is a national priority for the preservation of the natural character of the coastal environment to protect areas of significant indigenous vegetation and significant habitats of indigenous fauna in that environment by:

a. *avoiding any actual or potential adverse effects of activities on the following areas or habitats:*

   i. *areas and habitats important to the continued survival of any indigenous species; and*
   ii. *areas containing nationally vulnerable species or nationally outstanding examples of indigenous community types;*

b. *avoiding or remedying any actual or potential adverse effects of activities on the following areas:*

   i. *outstanding or rare indigenous community types within an ecological region or ecological district*
   ii. *habitat important to regionally endangered or nationally rare species and ecological corridors connecting such areas; and*
   iii. *areas important to migratory species, and to vulnerable stages of common indigenous species, in particular wetlands and estuaries;*

c. *protecting ecosystems which are unique to the coastal environment and vulnerable to modification including estuaries, coastal wetlands, mangroves and dunes and their margins; and*

d. *recognising that any other areas of predominantly indigenous vegetation or habitats of significant indigenous fauna should be disturbed only to the extent reasonably necessary to carry out approved activities.*

Policy 1.1.4

It is a national priority for the preservation of natural character of the coastal environment to protect the integrity, functioning, and resilience of the coastal environment in terms of:....

b. *natural movement of biota;....*

Policy 2.1.2

Protection of the characteristics of the coastal environment of special value to the tangata whenua should be carried out in accordance with tikanga Maori. Provision should be made to determine, in accordance with tikanga Maori, the means whereby the characteristics are to be protected.

Policy 3.3.1

Because there is a relative lack of understanding about coastal processes and the effects of activities on coastal processes, a precautionary approach should be adopted towards proposed activities, particularly those whose effects are as yet unknown or little understood. The provisions of the Act which authorise the classification of activities into those that are permitted, controlled, discretionary, noncomplying or prohibited allow for that approach.

Policy 4.2.1

All persons exercising functions and powers under the Act in relation to land of the Crown in the coastal marine area shall recognise and facilitate the special relationship between the Crown and the tangata whenua as established by the Treaty of Waitangi (Te Tiriti o Waitangi).

Policy 4.2.2

All persons exercising functions and powers under the Act in relation to land of the Crown in the coastal marine area should follow these general guidelines:....

b. make provision for consultation with tangata whenua which is early, meaningful and on-going and which is as far as practicable in accordance with tikanga Maori:.....

Although the NZCPS does not actually restrict the gathering of seaweed from the foreshore, it does provide guidance on a number of matters that should be considered by regulatory authorities issuing resource consents for such activities.

Regional Coastal Plans

Auckland Proposed Regional Plan: Coastal

Within the proposed coastal plan the extraction of natural material from any location outside of Coastal Protection Areas (CPA) 1 or 2 is a discretionary activity requiring a resource consent (Rule 14.5.3). Although it is likely that the ARC will grant consents for the extraction of seaweed from the foreshore outside CPAs 1 and 2, the extraction of sand, shingle, or other natural material is a non-complying activity in CPA 2, and a prohibited activity in CPA 1.

Appendix B of the Proposed Regional Plan: Coastal, although not forming part of the plan, outlines objectives and methods adopted for the management of the natural and physical resources of the coastal marine area. Although these policies do not specifically relate to the gathering of seaweed from the foreshore, they do provide some guidance on what the council will consider when assessing an application to remove seaweed from the foreshore

Hawke's Bay Regional Coastal Plan

Within the operative Hawke's Bay Regional Coastal Plan the removal of natural material from the coastal marine area is a discretionary activity if undertaken for commercial purposes (Rule 7.4.17). Removal for non-commercial purposes is a permitted activity (Rule 7.4.16).

Within Section 4 of the plan there are a number of general policies with respect to the Hawke's Bay Regional Council's management of the coastal marine area. Although none of the policies specifically relate to the gathering of seaweed from the foreshore, as with the Auckland Proposed Regional Plan: Coastal, they provide guidance on what the council will be considering during any assessment of an application to remove seaweed from the foreshore.

Summary

Under the current legislative regime the removal of seaweed from the foreshore within the coastal marine area requires a resource consent under the Resource Management Act, Section 12(2)(b), unless expressly allowed for by a rule within a proposed or operative regional coastal plan. The Proposed Auckland Regional Plan: Coastal, and Hawke's Bay Regional Coastal Plan, have rules that relate to the removal of natural material from the coastal marine area, with both deeming the activity to be discretionary, requiring a resource consent.

The policies within these coastal plans, and within the New Zealand Coastal Policy Statement, provide guidance for the regional councils when assessing resource consent applications for the removal of natural material from the coastal marine area. All regional councils should refer to the NZCPS when assessing resource consent applications. The NZCPS is a useful guiding document for the assessment of removing natural material from the coastal marine area, and should be referred to by anyone wishing to commercially remove seaweed from the foreshore.

4.8 Nature and extent of removal of beach-cast seaweed in New Zealand

Beach cleaning operations

Many beaches around the world, including New Zealand, are "cleaned" or "raked" daily, weekly, monthly, or on a seasonal basis. These activities are usually carried out on beaches used by humans for recreation and range from cleaning by hand, putting debris into garbage bags, to highly mechanised cleaning where the sand is taken into a machine, sieved, sorted, and sanitised before being placed back on the beach. This type of operation has been criticised both publicly and scientifically for removing ecologically important organisms (BBC 2001, Cromwell & Ryan 2002).

Beach cleaning has been taking place in New Zealand for some years by both local authorities and regional councils to maintain the beaches' visual appeal and remove odours caused by decomposing seaweed. To determine the extent of beach cleaning activities in New Zealand, a survey was sent to all regional, city, and district councils that have any coastline. The questions asked were:

1. Do you have any information (published or otherwise) on the quantities/species of seaweed washed ashore in your area?
2. Do you currently remove or have removed any seaweed from the beaches in your area for cosmetic or other reasons?
3. Have you granted any resource consents for the removal of any beach-cast seaweeds in your area?

Sixty-three councils were contacted (see Table 1) comprising 12 regional and 51 city or district councils. There were 44 responses received, 7 from regional councils and 37 from city or district councils. Far North District, North Shore City, Auckland City, Waitakere City, Manukau City, Tauranga District, Gisborne District, Hutt City, and Timaru District report that they undertake beach cleaning for cosmetic purposes.

Beach cleaning activities are restricted to:

- Summer, when the public are using the beaches;
- periods following storms when large piles of seaweed accumulate; or
- following blooms of particular species, e.g., blooms of *Ulva* spp. (sea lettuce) in Tauranga harbour.

For example, in the Auckland region, most beaches are cleaned by contractors on a regular basis during the summer, and then on demand during the rest of the year following large storms that cast piles of seaweed on the beaches. Beaches within North Shore City Council's jurisdiction are generally cleaned six times per year with additional occasional cleaning to remove storm wrack (Jellard 2003). Beach cleaning not only clears the beach-cast seaweed, but also any other washed up debris, including drift wood and rubbish. Seaweed collected in this way is mixed with other debris and has little commercial value and is sent straight to landfill. Its salt content prevents the collected seaweed from being mulched as greenwaste (Jellard 2003).

Beach-cast seaweed is also regularly collected and used as fertiliser by home gardeners (Grant 1995, Lovell-Smith 1999, Anon 2004).

Cleaning methods

City and district councils use a variety of means to clean the beaches, from rakes, shovels, and trailers pulled by 4-wheel drive vehicles, to dedicated purpose-built machines. In other countries this machinery can clean to very strict specifications. For example the Unicorn brand of cleaners can "penetrate the sand to a depth of 30 cm with a thorough, continuous sifting action. Dry and ventilate the sand using air and ultraviolet light. Multi-gauged mesh sieves collect rubbish, depositing it in easily-emptied containers. Disinfectant attachment as optional extra to protect against fungus, bacteria and viruses" (www.beach-trotters.com).

There are currently no such machines operating in New Zealand, but contractors use purpose-built machines to rake and clean the sand on North Shore and Auckland beaches.

4.9 Environmental effects of seaweed removals

Seaweed deposited on beaches and other coastal margins plays an important role in both terrestrial and marine ecosystems. The effect of human removal of this seaweed on these ecosystems is however unclear.

Vehicle impacts decrease the rate of decay of driftline wrack, by lowering the numbers of bacteria (Leatherman & Godfrey 1979), but vehicle use in the intertidal produced minimal effects on beach fauna especially if the traffic was during the day as many of the organisms are nocturnal (Stephenson 1999).

Beach cleaning was also listed as a threat to sandy coastlines in some parts of Europe, the disappearance of macrofauna and birds that prey on the macrofauna being of particular note (Weslawski et al. 2000). In a review of sandy shorelines and the threats facing these ecosystems in the future, beach cleaning was highlighted as having mostly detrimental effects on these systems (Brown & McLachlan 2002). These authors noted that cleaning not only removes debris left behind by human visitors, but also kelp, wrack, and other dead or stranded biota, thus depriving beach ecosystems of valuable nutritional input. Semi-terrestrial organisms including talitrid amphipods, oniscid isopods, and ocypodid crabs were considered most affected, with talitrid populations being effectively eliminated by this process. The authors also noted that the mobile machinery used could crush more deeply buried invertebrates below the raking depth in their burrows.

We could find only four published studies that empirically tested the effects of removing beachcast seaweeds. One that investigated removal for commercial purposes (Lavery et al. 1999), and three that investigated the effects of cosmetic removal (Llewellyn & Shackley 1996, Engelhard & Withers 1999, Nordstrom et al. 2000). These studies are summarised below.

An investigation of the effects of both short and long term removal of beach-cast seaweeds in the Peel-Harvey estuary, Western Australia, was undertaken by Lavery et al. (1999). They found that short-term harvesting caused an immediate decrease in the densities of epifauna and fish, but these values recovered to pre-harvest levels within two months.

This study demonstrated some important points.

- Beaches with large inputs of beach-cast seaweeds had a different infauna from beaches with little beach-cast seaweeds.
- Even short-term harvesting results in changes in species composition, and although these beaches recovered within two months, this could affect other species depending on the time of harvesting; for example if disturbance/harvesting/removal were during a nesting or breeding time for birds or during the time of settlement for fishes.
- Beaches that were harvested continually resembled beaches that had no input from beach-cast seaweeds.

The effects of beach cleaning on beach community structure was investigated in Swansea Bay, Wales, where mechanical beach cleaning has been undertaken since 1983 (Llewellyn & Shackley 1996). Two different machines had been used for cleaning, a converted potato harvester capable of operating to a depth of 20 cm and a conveyor-belt raking machine with an operating depth of 5 cm. Llewellyn & Shackley (1996) concluded that beach cleaning had a serious deleterious effect on strandline related species diversity and population abundance. Where not subjected to beach cleaning, a fully balanced, representative selection of strandline invertebrates was present, with amphipods present throughout the year and typical seasonal fluctuations in dipteran and coleopteran populations. Where mechanical cleaning had occurred, there was a very poor selection of strandline invertebrates, with only the occasional amphipod present along with adult flying Coleoptera. Only a few Coleoptera larvae were present on well decomposed patches of algae missed by the machines. When material was left on the beach for 5 months, amphipods and other associated strandline fauna appeared to recover (Llewellyn & Shackley 1996).

Recovery of both invertebrate macrofauna and organisms associated with wrack was observed 14 days after beach cleaning to remove accumulations of beach-cast seaweeds (primarily *Sargassum* spp.) on the Padre Island National Seashore, Texas, USA (Engelhard & Withers 1999). Both groups of organisms were affected by mechanical raking to some extent and the greatest differences between raked and unraked sites were found within three days of cleaing. Mean density and biomass of all macrofauna were significantly higher in unraked areas. No differences in bird abundance were observed between raked and unraked areas.

In addition to the effects on infauna, the removal of seaweed could affect beach morphology, as much sand is removed along with the debris. In Puerto Madryn, Argentina, between 2500 and 12 000 t wet weight seaweed per year is removed for cosmetic purposes, and it is estimated that between 100 and 400 m^3 of sand are removed as part of this process, accelerating erosion and changing the topography of the beaches (Piriz et al. 2003).

Dramatic differences in beach topography and habitat values were noted between raked and unraked beaches in New Jersey, USA (Nordstrom et al. 2000). Raking eliminated new plant growth by removing material that trapped sand and seeds and removing a primary source of nutrients to the beach system. Raking interrupted the successional vegetation processes that typically occur in sandy environments, eliminating the formation of new foredune areas and effectively leaving flat, raked beaches not representative of the natural coastal landscape. Nordstrom et al. (2000) suggested that the uppermost strandline on beaches should be left intact, with beach cleaning restricted to summer or when necessary to remove excessive material such as after massive fish kills.

4.10 Areas for future research

Beach-cast seaweeds play a role in coastal ecosystems, but there has been little research on the effects of removing seaweed from these areas. The only experimental evidence of the effects of commercial removal comes from an estuary in Australia (Lavery et al. 1999). Before being able to determine effects of removals, Kirkman & Kendrick (1997) pointed out that it is necessary to understand the link between the living resource offshore and the beach-cast seaweed. As the natural availability of the seaweed appears to play a significant role in coastal ecological processes, including the types and abundance of associated flora and fauna, research into this link is essential for determining the effects of its commercial removal. This information should be obtained at least for the main species and areas subject to commercial harvest. Kirkman & Kendrick (1997) suggested that this is not an easy task, with no direct link between offshore annual production on a 16 km stretch of coast and the amount of unattached subtidal and beach-cast seaweeds found. This was because the direction, distance, and time over which detached seaweeds travel is unknown. Surface drifting seaweeds may be affected by winds, while bottom drifting seaweeds may be more affected by currents. Only a small number of drifting seaweeds become beach-cast and may spend several days drifting before becoming stranded.

In New Zealand, there are several key research gaps that need to be addressed in order to make decisions on the management of this resource or to determine the effects of removal. These gaps fall into two classes relating to biomass and availability of the resource followed by the effects of its removal on coastal ecosystems.

1. Quantitative data on the distribution of beach-cast seaweeds.

This information should include the amount of each species that washes up in each location, and the seasonality of this distribution (or at least for the most commonly gathered).

2. Relationship between beach-cast seaweeds and the offshore algal stands.

To manage this resource and to better understand the relationship between the source of the seaweed and the beaches where it ends up, it is necessary to determine where the seaweed comes from and where it ends up. Is it concentrated on to certain beaches? How much of the annual productivity is beach-cast? What proportion of the coastline is accessible for the collection of these seaweeds?

3. Residence time of seaweed on the beach.

It is likely that the aspect and slope of the beach, wind direction and strength and the tidal cycle will all play a part in the residence time of the seaweeds.

4. What species are collected and what proportion of beach-cast seaweed is removed during collection?

When do collections take place, where and what species are harvested? What proportion of the total biomass of beach-cast seaweed is harvested from the beach? Is everything removed or only a proportion on the total input?

5. Impact of collection methods.

If heavy vehicles and/or mechanical equipment are to be used in the collection of beach-cast seaweeds, the effects of these types of equipment on beach infauna should be determined. The area below the high water line is where many infaunal organisms live and is where most vehicles are likely to drive, taking advantage of low tides and the firmer sand to collect the seaweed.

6. The role of floating seaweeds in fisheries in New Zealand.

Although it has been shown overseas that floating seaweeds play a vital role in some life stage of some commercial important fish species, this information is not available for New Zealand.

7. What is the fate of beach-cast seaweed when not collected?

The energetic contribution to near shore ecosystems that beach-cast seaweeds make should be determined, particularly if it is found that beach-cast seaweeds are being transported some distance before being stranded, as this may mean that some "sink" areas may be in part supported by imported nutrients. In addition, it should be determined how much of seaweed is being used by New Zealand's native birds and reptiles as many of these species are under threat.

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Table 1: Regional and Territorial Authorities surveyed for this report.

	Response	Activity	Amount
Auckland City Council	yes	yes	Eastern beaches
Christchurch City Council	yes	no	
Dunedin City Council	yes	no	
Hutt City Council	yes	yes	Annual at Petone and Eastbourne – resource consent says impact is minimal
Invercargill City Council			
Manukau City Council	yes	yes	Eastern Beaches
Napier City Council	yes	no	
Nelson City Council			
North Shore City Council	yes	yes	Heaps regularly
Waitakere City Council		yes	Piha occasionally
Wellington City Council			
Buller District Council	yes	no	
Far North District Council	yes	yes	Ti Tii beach after storms in holiday season
Franklin District Council			
Gisborne District Council	yes	yes	Regular cleaning of local beaches
Grey District Council	yes	no	
Hastings District Council			
Hauraki District Council	yes	no	
Horowhenua District Council	yes	no	
Hurunui District Council			
Kaikoura District Council	yes	no	
Kaipara District Council	yes	no	
Kapiti Coast District Council	yes	no	
Manawatu District Council	yes	no	
Marlborough District Council	yes	no	
Masterton District Council	yes	no	
New Plymouth District Council	yes	no	
Opotiki District Council			
Otorohanga District Council	yes	no	
Rangitikei District Council			
Rodney District Council	yes	no	
South Taranaki District Council	yes	no	

Table 1: continued.

South Wairarapa District Council	yes	no	Maori committee gave approval in principle for 2 harvesting applications to go to MFish
Southland District Council			
Tararua District Council	yes	no	
Tasman District Council	yes	no	
Taupo District Council			
Tauranga District Council	yes	yes	Sea lettuce every 2–3 years
Thames Coromandel District Council	yes	Didn't know	
Timaru District Council	yes	yes	Caroline Bay occasionally
Waikato District Council	yes	no	
Waimakariri District Council	yes	no	
Waimate District Council	yes	no	
Wairoa District Council			
Waitati District Council	yes	no	
Waitomo District Council			
Wanganui District Council	yes	no	
Western Bay of Plenty District Council			
Westland District Council	yes	no	
Whakatane District Council	yes	no	
Whangarei District Council			
Auckland Regional Council	yes		Must be consents for the cleaning activities
Canterbury Regional Council			
Environment BOP	yes		No consents granted
Environment Canterbury	yes		Consent for Avon/Heathcoat Estuary
Environment Southland			
Environment Waikato			
Hawke's Bay Regional Council	yes	no	
Manawatu Wanganui Regional Council			
Northland Regional Council	yes	no	
Otago Regional Council	yes	no	
Wellington Regional Council			
West Coast Regional Council	yes	no	

Table 2: Generalised successional sequence of micro-organisms and invertebrates on beach-cast seaweeds, (*Koop et al. 1982a; Inglis 1992*).

	Day 1	Day 3	Day 3 +
Micro-organisms	Coccoid bacteria align along superficial cell borders	Epidermal lesions develop along cell borders Cells swell to form rounded protuberances Shedding of most of epidermal layer Leachates formed	Large amounts of rod-like bacteria, yeasts and fungi,
Invertebrates	Macrofauna amphipods, isopods, coleopterans, dipterans adults	Macrofauna peak – meiofauna take over nematodes, dipteran larvae, mites	

Table 3: Invertebrate species found in beach cast seaweeds on South Brighton beach, New Zealand (Inglis 1989).

Species	% of community
Amphipoda	
Talorchestia quoyana	27.2
Diptera	
Leptocera aucklandica	47.2
Anabarynchus bilineatus	1.3
Tethinosoma fulvifrons	0.3
Mallochomaquartia sp.	0.2
Coleptera	3.2
Sitonia humeralis	3.2
Bledius sp.	4.2
Lagrioida brouni	5.0
Phycosecis atomaria	1.5
Pericoptus truncates	0.9
Cafius littoreus	0.4
One unidentified species of Ptiliidae	0.3
Two unidentified species of Elateridae	0.3
One unidentified species of Scydmaenidae	0.2
Thelyphassa diaphana	0.1
Actizeta albata	0.1
Geophilomorpha	
Nesogeophilus xylophagus	6.7
Hemiptera	
Nysius huttoni	0.7
Juliformia	
Ophyiulus pilosus	0.1
Hymenoptera	
Hipoponera eduardi	0.1

Table 4: Bird species known to forage beach-cast seaweed (Daniel 1982, Dowding & Chamberlin 1991, Dowding 1994, Diane Brunton pers comm.).

Common name	Scientific name
Tui	*Prosthermadera novaeseelandiae**
New Zealand Dotterel	*Charadrius obscurus***
Pukeko	*Porphyrio porphyrio*
Fantail	*Rhipidura fulginosa*
Brown teal	*Anas aucklandica*
Bellbird	*Anthornis melanura*
Red billed gull	*Larus novaehollandiae*
Black-backed gull	*Larus dominicanus*
Pied oystercatcher	*Haematopus ostralegus*
Variable oystercatcher	*Haematopus unicolor*
Saddleback	*Philesturnus carunculatus*
Spur-winged plovers	*Vanellus miles novaehollandiae*
White heron	*Egretta alba modesta*

Table 5: Abundance of fish associated with drift algae and open water in northern New Zealand (Kingsford 1992).

Family	Species	Drift algae	Open ocean
Clupeidae	*Sardinops neopilchardis*	59	284
Galaxiidae	*Galaxias maculatus*	3	11
Engraulididae	*Engraulis australis*	104	229
Moridae	*Auchenoceros punctatus*		14
	Pseudophysis spp	1	
Hemiramphidae	*Hyporhamphus ihi*	3	1
Syngnathidae	*Lissocampus filum*	3	
	Stigmatophora longirostris	43	
	Hippocampus abdominalis	20	1
Carangidae	*Seriola grandis*	3	
	Pseudocaranx dentex	10	
	Decapterus koheru	1	
	Trachurus spp	150	71
Arripidae	*Arripis trutta*	134	
Emmelichthyidae	*Plagiogeneion rubiginosus*	218	
Sparidae	*Pagrus auratus*	1	6
Mullidae	*Upeneichthys lineatus*	93	
Kyphosidae	*Kyphosus sydneyanus*	10	
	Girella tricuspidata	43	
	Scorpis violaceus	10	
Pomacentridae	*Chromis dispilus*	2	5
Mugilidae	*Aldrichetta fosteri*	340	99
Labridae	*Pseudolabris celidotus*	19	8
Creedidae	*Tawera cranwelli*		23
Uranoscopidae	*Genyagnus novaezelandiae*		5
Blenniidae	*Parablennius laticlavius*	4	53
Tripterygiidae	*Forsterygion* spp	170	150
	Notoclinus fenestratus	21	
	Gilloblennius spp	409	126
Gobiidae			24
Clinidae	*Cristiceps auranticus*	44	
Scombridae	*Scomber australasicus*	28	81
Bothidae	*Lophonectes gallus*		44
Monacanthidae	*Parika scaber*	125	
Total number		2068	1312

Table 6: Species and distributions of the main commercial species of seaweeds from New Zealand.

Species	Distribution
Ecklonia radiata	Found throughout New Zealand, absent only at the Chatham Islands (Nelson 1994)
Lessonia variegata	Found in the North Island and northern South Island (Nelson 1994)
Lessonia brevifolia	Has a more southern distribution to that of *L. variegata* with distribution restricted to the Subantarctic Islands (Nelson 1994)
Durvillaea antarctica	Found through New Zealand coastal waters but is most common south of Cook Strait (Moore 1961).
Macrocystis pyrifera	Common on the east coast of the South Island (Moore 1961).
Pterocladia lucida	Found north of Kaikoura and northwest Nelson (Moore 1961). The main areas of commercial collection are the Wairarapa coast, Bay of Plenty, Hawke's Bay, Poverty Bay and Northland (mainly at Brampton Shoals) (Gerring et al. 2001).
Gracilaria chilensis	An intertidal species found throughout New Zealand (Nelson 1994).
Gigartina spp	The *Gigartina spp* that has been targeted from beach-cast deposits are of uncertain taxonomic distinction, but are similar in morphology to *Gigartina atropurpurea which* is distributed throughout New Zealand in low intertidal to subtidal areas (Nelson 1994).

Table 7. Quantities of beach cast seaweeds.

Location	Quantity (kg m^{-1} yr^{-1})	Reference
Australia	2000	Robertson & Hansen (1982)
California	473	Hayes (1974)
South Africa	2000	Koop et al. (1982a)
New Zealand	14 approx. 2000	Inglis (1989) Ian Miller (pers. comm.)

Table 8: Beach-cast seaweed species collected as part of mussel spat collection along Ninety Mile Beach (Alfaro & Jeffs 2002).

Category	Species
Coarse-branching algae	*Osmundaria colensoi*
	Carpophyllum angustifolium
	Rhodymenia dichotama
Medium-branching algae	*Melanthalia abscissa*
	Laurencia thyrsifera
	Pterocladia lucida
	Pterocladia capillacea
	Gigartina marginifera
	Gigartina alveata
	Pachymenia lusoria
Fine-branching algae	*Champia laingii*
	Plocamium costatum
	Haliptilon roseum
	Corallina officinalis

Figure 1: Incorporation of beach-cast seaweed into coastal dune habitat (Photo: L. Zemke-White).

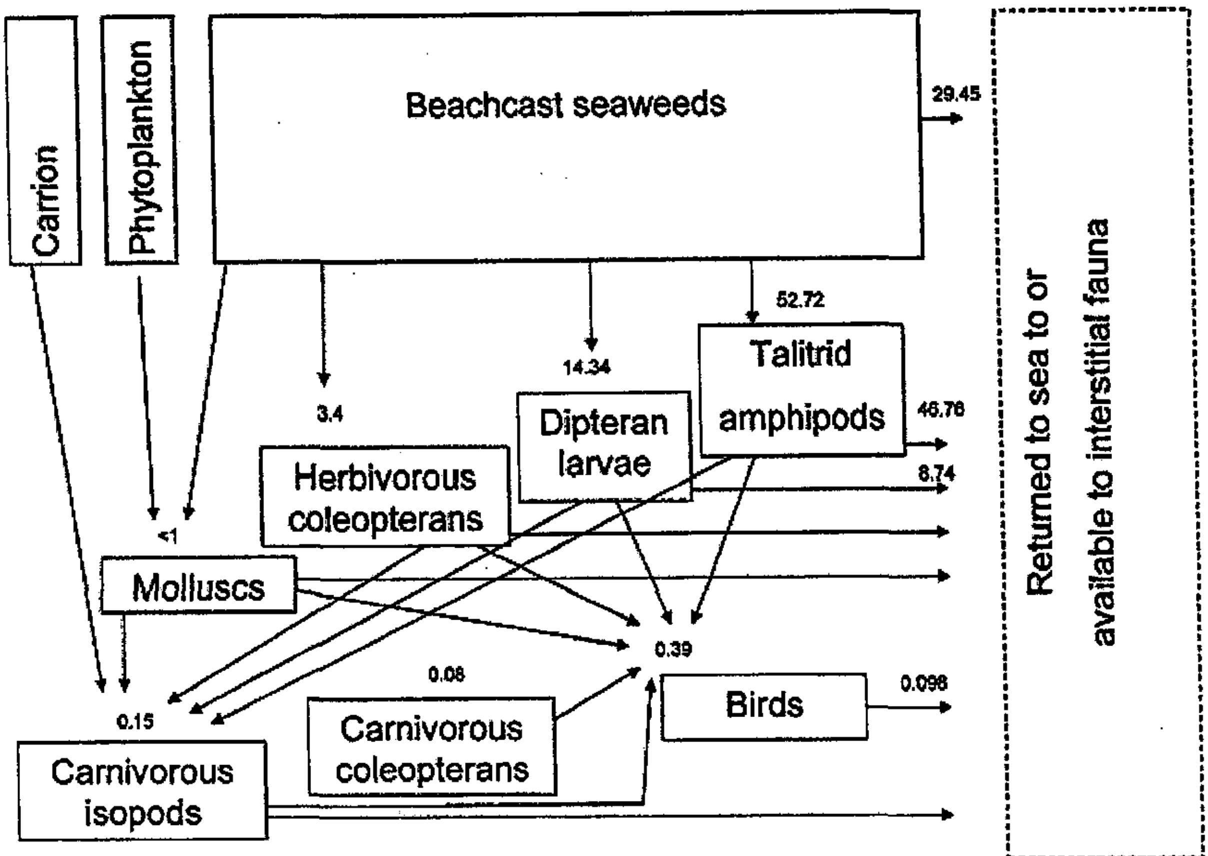

Figure 2: Energy cycling of beach-cast seaweeds (adapted from Griffiths et al. 1983). Numbers represent percentage of beach-cast seaweed transferred to next level.

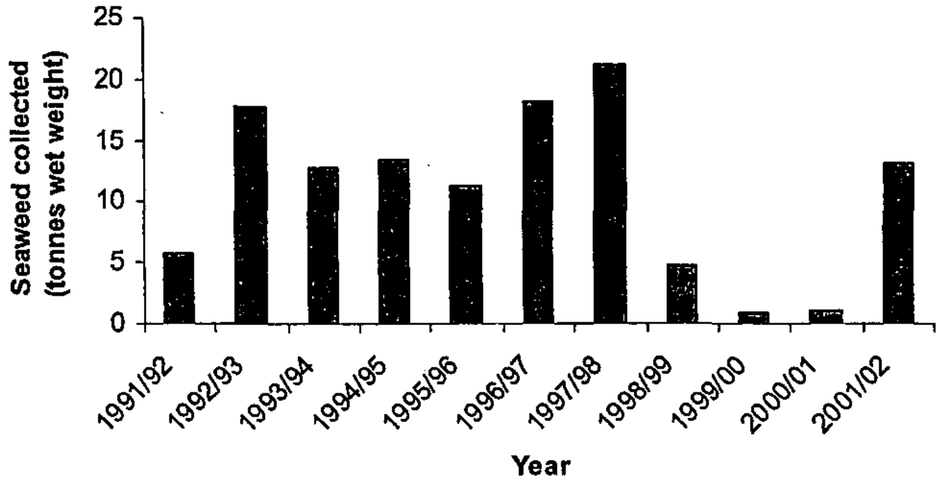

Figure 3: Total beach-cast seaweed landed in New Zealand, 1991–2001.

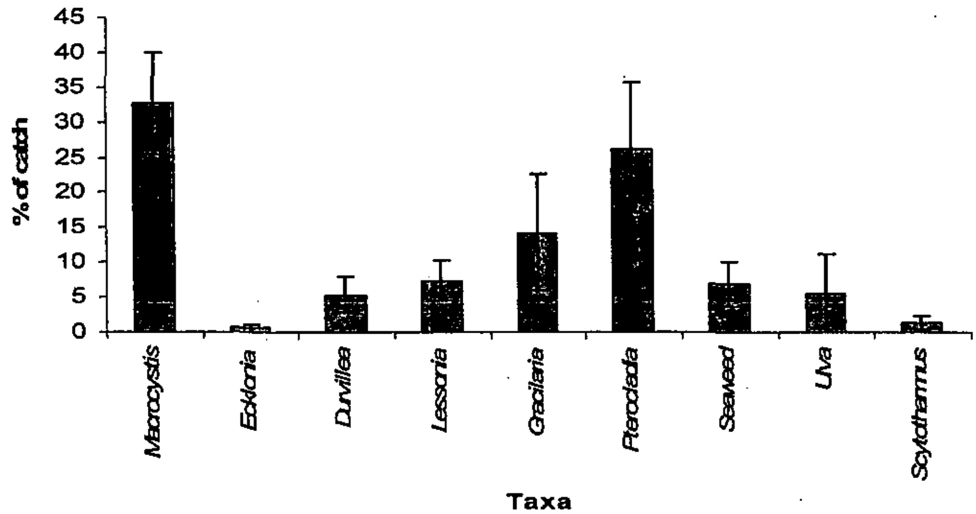

Figure 4: Mean percentage of total landings from 1991 to 2001 (± standard error).

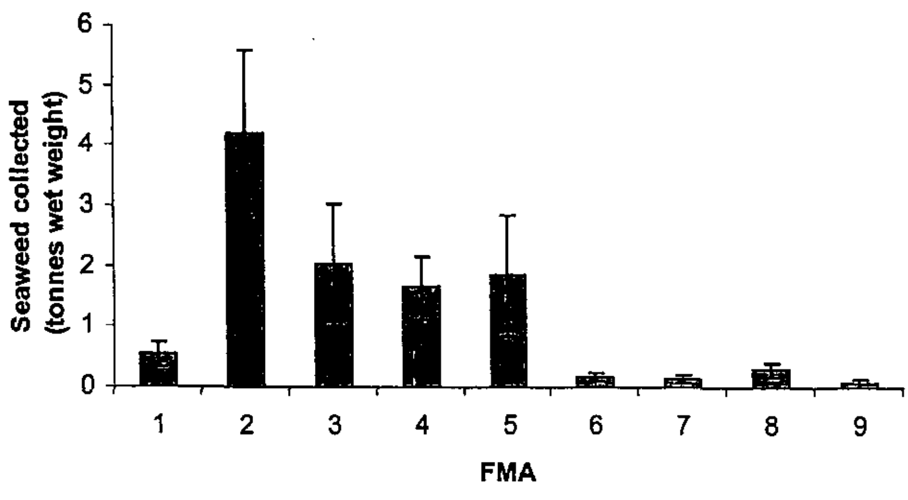

Figure 5. Mean annual landings of beach-cast seaweed collected from 1991 to 2001 by Fisheries Management Area (± standard error).

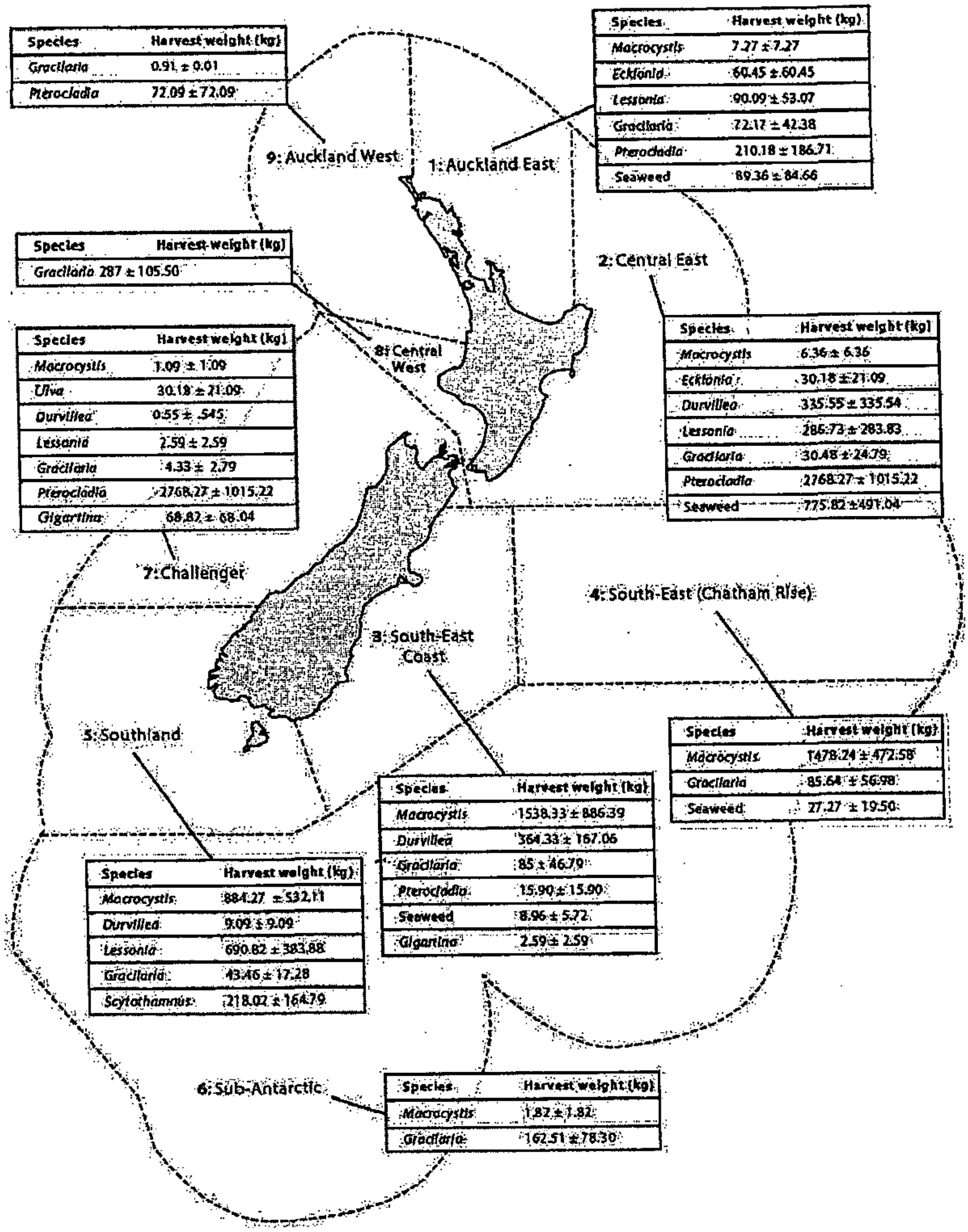

Figure 6: Geographic distribution of mean annual landings of beach-cast seaweed collected from 1991 to 2001 (± standard error)..

APPENDIX 1. SURVEY QUESTIONS

We would like to circulate survey questions to individuals and organizations in New Zealand that are or have been involved in collecting beach-cast seaweeds.

Survey questions:

If you currently collect beach-cast seaweeds please answer the questions in section A if you anticipate collection of seaweeds in the future please answer questions in section B.

Section A

1. How much seaweed do you harvest per year?
2. Is there any seasonal variation in your collection?
3. Where do you collect your seaweed from?
4. Do you target particular species? If so which one or ones?
5. What method of collection do you use? e. g. trailer, tractor, mechanical means
6. What do you use your collected seaweed for?

Section B

1. How much seaweed do you require per year?
2. Do you anticipate any seasonal variation in your collection?
3. Where will you collect your seaweed from?
4. Will you target particular species? If so which one or ones?
5. What method of collection do you plan to use? e. g. trailer, tractor, mechanical means
6. What will you use your collected seaweed for?

APPENDIX 2. - LETTER TO TERRITORIAL AUTHORITIES

To whom it may concern,

Kingett Mitchell has recently been contracted by the Ministry of Fisheries to review the impacts of harvesting beach-cast seaweeds for both commercial and cosmetic purposes (ENV2002-03). As part of this review we are seeking information in three main areas from coastal Territorial Authorities.

1. Do you have any information (published or otherwise) on the quantities/species of seaweed washed ashore in your area?
2. Do you currently remove or have removed any seaweed from the beaches in your area for cosmetic or other reasons?
3. Have you granted any Resource Consents for the removal of any beach-cast seaweeds in your area?

Any information regarding this topic would be very much appreciated and it is expected that the resulting report will assist the Ministry in making future decisions regarding the management of this resource. Please contact Scott Speed at .... One of our representatives will follow up this letter by phone in the next few weeks.