The Importance of Macroalgae on Rocky Reefs: A Critical Aspect for Fish and Epifauna of the East Otago Coastline

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“The present generation is the trustee for future generations and it behoves us to preserve our fish and maintain a reasonable supply”

David H. Graham

A Treasury of New Zealand Fishes

1953
ABSTRACT

The East Otago coastline north of the Otago Peninsula, New Zealand, is an area of rocky macroalgal dominated reefs, which contain *Macrocystis pyrifera* kelp forest and dense mixed macroalgal beds. These areas are considered crucial habitats for finfish and epifaunal invertebrates, providing habitat complexity, abundant food sources, protection from predators and kōhanga (nurseries) habitats. The present study concentrated on three distinct macroalgal habitats, including those dominated by *Carpophyllum flexuosum* and *Cystophora* spp. (0-3 m depth), *Macrocystis pyrifera* kelp forest (3-10 m) and *Ecklonia radiata* beds (10-15 m). The work was conducted within a locally managed fishery called the East Otago Taiāpure, a 24-km² area of coastline established in 1999. The primary objective of this study was to gain a better understanding of reef fish and epifaunal associations with macroalgal habitats. This was achieved through the use of three primary methods: Firstly, SCUBA stationary visual point surveys of finfish populations in different macroalgal habitats. Secondly, the deployment of novel epifaunal invertebrate collectors, which simulate rocky coralline turf or macroalgal habitats (known as coralline cobble and seaweed simulat); and thirdly food web studies through the use of stable isotope and gut contents analysis performed upon reef, soft sediment and pelagic associated fish species. The results from this study indicate strong associations of reef fish and epifaunal species with macroalgal habitats. Ninety-one percent of all fish observed in this study were encountered within *M. pyrifera* kelp forests and *E. radiata* beds. Epifaunal species showed tight associations to macroalgae with gammarid amphipods found in high abundances within the *M. pyrifera* canopy. Small snails and crab species dominated coralline cobble simulators, while amphipods dominated seaweed simulators within all macroalgal habitats sampled. Food web analysis revealed that reef fish use a combination of both macroalgal and phytoplankton primary productivity in food sources. Furthermore, for soft sediment and pelagic associated fish species, over 90% (on average) of primary productivity comes from macroalgal primary productivity. This study shows that macroalgal habitats, especially *Macrocystis pyrifera* kelp forests, are important to reef fish and epifauna. This study also reveals that macroalgal productivity also plays an important role in driving food webs within soft sediment and pelagic associated species in coastal areas. This indicates that rocky reefs are extremely valuable to coastal areas and should be protected for healthy finfish populations to exist.
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CHAPTER ONE

Habitats of Reef Fish and Epifauna on the East Otago Coastline.

Huriawa Peninsula and Matainaka taken from Brinns Point at dawn on a winter’s day.
1.1 Introduction

Temperate reef ecosystems are areas of rock reef and boulders usually close to coastal regions, which are dominated by a great diversity of macroalgae, invertebrates and fish (Morton and Miller 1968, Stephens and Zerba 1981, Kingsford and Battershill 2003). These areas are one of the most highly productive in the ocean; as a result they are of great importance to commercial, recreational and customary fisheries around the world, yet they occupy only a small portion of the world's total marine area (Worm et al. 2006, Beaumont et al. 2007). Rocky reefs occupy a zone strongly influenced by the land and sea with high water motion, nutrients and light providing ideal areas for macroalgae to flourish. This productivity in turn provides abundant food sources and crucial habitat to many organisms, playing an important role in the life history of many species (Anderson and Millar 2004).

Worldwide, coastal ecosystems are under threat from human activities, which have profoundly changed marine communities and caused habitat loss and degradation; affecting a wide range of habitats from salt marshes, rocky reefs, coral reefs, and mid-ocean surface waters to the deepest oceanic waters (Bertness et al. 2001). Major causes of habitat degradation include over-fishing of marine organisms, both commercial and recreational (Botsford et al. 1997, Pauly et al. 1998, Pauly and Palomares 2005); introduction of invasive species e.g. Undaria pinnatifida (Russell et al. 2008); harvesting of key structure forming macroalgae e.g. Macrocystis pyrifera (Schiel and Nelson 1990, Vasquez 1995); environmental change (severe storms, coral bleaching etc) (Atwood et al. 1992, Hoegh-Guldberg 1999, Camber et al. 2008) and terrestrial runoff causing nutrient enrichment (Grigg 1994), eutrophication (Cooper and Brush 1993, sedimentation (Devinnny and Volse 1978, Schiel et al. 2006) and toxic algal blooms (Chang et al. 1990).

1.2 Importance of macroalgae

Temperate rocky reef subtidal macroalgae and in particular large brown algae such as the giant kelp Macrocystis pyrifera play important roles in coastal ecosystems as important primary producers, providing organic sources of carbon both by direct consumption and through detrital pathways (Mann 1973, Jackson 1977, Duggins et al. 1989, Bustamante et al. 1995). The ecology of large macroalgal habitats have been extensively studied throughout the world. Many examples exist where macroalgae are the major structural component of habitat (Hepburn & Hurd 2005). Temperate macroalgal communities are indispensible to the organisms that live there, providing habitat complexity, abundant food sources (Meekan and Choat 1997) and refugia from predators (Levin and Hay 1996). Macroalgal communities also
provide habitats for a large range of important commercial fish species within New Zealand, such as greenbone (*Odax pullus*), blue cod (*Parapercis colias*), and blue moki (*Latridopsis ciliaris*) (Choat and Ayling 1987) as well as worldwide (Steneck *et al.* 2002).

Macroalgal habitats are an important factor in structuring the coastal marine environment for a variety of species and can influence various stages of their life cycles (Graham 2007). Studies have shown that macroalgae strongly influence habitat choices of adult fish on temperate reefs, the composition of fish assemblages, and the density at which they are encountered (Bodkin 1988, Jones 1988, Carr 1994, Levin and Hay 1996, Meekan and Choat 1997, Tegner and Dayton 2000, Cole 2001, Anderson and Millar 2004). An example of how macroalgal habitats influence the abundance of reef fish was found by Carr (1994); in this study manipulation of macroalgal density strongly affected the recruitment and abundances of kelp bass (*Paralabrax clathratus*) in a rocky reef habitat off the Californian coast (USA). By manipulating *Macroystis pyrifera* kelp density (via removal), juvenile recruitment and fish abundance were significantly reduced at low densities compared to high-density areas. Jones (1984) provides an example within New Zealand where macroalgal habitat manipulation affected the abundance of spotties (*Notolabrus celidotus*). This study also found that the addition of macroalgae led to an increase in recruitment of juveniles as well as adults.

Macroalgal habitats also play an important role in the distribution of epifaunal and benthic invertebrates that reside upon both macroalgal and benthic reefs. As well as providing food sources and productivity, macroalgae provide dense beds, which are an important habitat for a wide variety of sessile and mobile epifauna (Edgar and Moore 1986, Duffy and Hay 1990, Taylor and Cole 1994, Taylor 1998, Hepburn and Hurd 2005, Cowles *et al.* 2009). These animals provide a large amount of biomass in macroalgal beds, which are thought to be the basal source of organic matter in the food web for fish. These epifauna and benthic invertebrates either feed directly upon macroalgae and epiphytic algae or planktonic organisms in the water column or both. Taylor (1998) found on northern New Zealand reefs that a great diversity and abundance of epifauna exist and are thought to contribute a significant percentage of the secondary productivity associated with macroalgae. Epifauna are also thought to provide ample prey sources to reef fish species. Russell (1983) found that epifaunal species such as gammarid amphipods were present in the gut contents of almost all species of fish sampled gut contents and in some cases were considered the primary prey source.
1.3 Reef fish macroalgal associations

Reef fish are often found in specific macroalgal communities (Anderson and Millar 2004). Macroalgal communities differ in quantity and quality from reef to reef and among depth strata. As reef fish are highly mobile, tight habitat associations are not usually found between fish and specific macroalgal species. Instead they are often associated with the mix of understorey and canopy species such as *Ecklonia radiata* and *Macrocystis pyrifera*, which provide a complex three-dimensional structuring component of the habitat. Small cryptic fish species such as juvenile reef fish and triplefin species are thought to be tightly associated with macroalgal habitats whereas larger reef fish such as *Latridopsis ciliaris* and *Parapercis colias* are thought to be more loosely associated with these habitats (Anderson and Millar 2004).

Examples of fish association with macroalgal habitat from northern New Zealand include Choat and Ayling (1987) who found that reef fish species such as wrasses *Notolabrus celidotus*, *Notolabrus fucicola*, *Pseudolabrus miles* and herbivorous *Odax pullus* were more numerous and smaller in macroalgal beds. These fish took shelter among the macroalgal holdfasts and were considered cryptic within these habitats. In comparison, fish found in barren habitats, were observed to contain larger sized fish of the same species, as well as large benthic feeding species, which were found to avoid algal cover. These habitat associations are thought to be primarily driven by feeding preferences. Fish species found feeding within the coralline barrens, which are continuously grazed by echinoids and small molluscs, which were the primary food source for these fish (Choat and Ayling 1987). Within another study in the same area Anderson and Millar (2004) found differences between kelp forest habitats and echinoid barren habitats. Species found in greater abundance and frequency in kelp forest habitat include *Parika scaber*, *Odax pullus* and *Pseudolabrus miles*, *Notolabrus celidotus* and *Notolabrus fucicola*. Clear distinctions can be made to why and where a fish species will reside due to the availability of prey and life history stage. Pérez-Matus and Shima (2010) found that complex interactions exist among reef fish around central New Zealand, with positive effects of habitat heterogeneity and complexity upon fish species abundance and diversity. The fish species spotty *Notolabrus celidotus* and triplefin *Forsterygion varium* also show habitat preference shifts between juvenile and adult stages from macroalgal to habitat with reduced shelter. Furthermore in mixed beds of macroalgae, the presence of *Macrocystis pyrifera* yielded far greater abundances of fish species than when it was absent.

1.4 Habitat associations of epifaunal reef invertebrates

Epifaunal invertebrates in many studies are found to be tightly associated to macroalgae and form important and often dominant part of the communities within macroalgal habitats (Hepburn and Hurd 2005). Epifauna primarily use seaweeds as either a food source or a site of attachment to obtain the majority of their food from the water column. Epifauna can be either sessile (attached directly to the thallus) or mobile, gaining direct benefit as refugia from predation and easy access to water column food sources (Hepburn and Hurd 2005). Epifauna are thought to be important consumers of macroalgae, either feeding directly upon their host plant or indirectly through detrital food webs originating from the macroalgae (Edgar and Moore 1986). Epifauna are found in a variety of habitats but are primarily found within dense macroalgal beds in which they find ample attachment sites. There they find refugia from predators and water motion, which they would be inherently more exposed to in other environments such as rocky exposed coralline barrens (Choat and Kingett 1982). Examples exist where a great percentage of secondary productivity is due to high abundance and biomass of epifaunal organisms (especially amphipods) within subtidal macroalgal environments (Edgar and Moore 1986, Taylor 1998). An example of the close association epifauna have to macroalgae include (Taylor 1998) who found in northern New Zealand that epifaunal species such as gammarid amphipods were by far the most abundant species present upon the thallus of *Carpophyllum* species.
1.5 Reef fish and epifaunal associations

Reef fish and epifauna play an important role within rocky reef ecosystems, as they are the primary prey source for many species (epifauna) or predator (fish). These predator prey interactions have been found to be important where the removal of an important link has led to detrimental effects. Some classic examples exist where the removal of key predators has resulted in significant top-down effects. One such example is that of the California sea otter (*Enhydra lutris*), which feeds primarily on epibenthic invertebrates such as sea urchins (*Strongylocentrotus polyanthus*), which in turn feed primarily on macroalgae. The removal of this apex predator through human hunting allowed the population of sea urchins to grow to such proportions as to eliminate macroalgae as the main source of primary productivity, resulting in an urchin barren (Estes *et al.* 1978). In another example from New Zealand Shears and Babcock (2003) found that the establishment of a marine reserve led to a shift in trophic cascade of urchins removing macroalgae due to loss of top predators such as reef fish. The establishment of a marine reserve resulted in the re-establishment of abundant apex predators such as snapper (*Pagrus auratus*) and crayfish (*Jasus edwardsii*), leading to drastic declines in the number of kina (*Evechinus chloroticus*). This led to a habitat shift from kina-dominated urchin barrens to macroalgae-dominated reefs with very few kina. These examples illustrate the drastic changes that can occur with the absence of apex predators such as reef fish, and their role in controlling population numbers of other species.

Fish species on rocky reefs are considered to be important predators in New Zealand (Choat and Ayling 1987), consuming a wide variety of epifauna, benthic invertebrates and other small fish species (Russell 1983). Reef fish are usually generalist opportunistic predators, which exhibit no specific prey choice. However some species do specialize in certain prey groups. For example, common wrasse species *Notolabrus celidotus* and *Notolabrus fucicola* were thought to feed predominantly on bivalves such as mussels, due to the morphology of their jaw structures (Jones 1984a). However, studies of gut contents have shown that these species feed on an expansive array of prey items found upon rocky and macroalgal reefs (Russell 1983, Jones 1984b, Denny and Schiel 2001). Reef fish also feed upon epifaunal species such as gammarid amphipods in large quantities (Russell 1983).
The role of epifaunal invertebrates and reef fish on rocky reefs is relatively poorly understood in southern New Zealand with only a few studies in northern New Zealand concentrating on the effects of habitat on reef fish (e.g. Choat and Ayling 1987, Anderson and Millar 2004). Furthermore, northern New Zealand lacks *Macrocystis pyrifera* kelp forests and is dominated by more diminutive *Ecklonia radiata* beds (Schiel 1990). Morphological and structural differences exist between areas with *E. radiata*, which only grows up to 2 m in length and is found in dense beds (Schiel 1988) and *M. pyrifera*, which has high biomass as dense canopies on the surface, with subcanopy species dominating close to the benthos (Brown *et al.* 1997). The complex and productive nature of southern New Zealand kelp forests (Fyfe *et al.* 1999) makes it an interesting system to study, with interactions between epifaunal invertebrates and reef fish species. *Macrocystis* kelp forests could be considered under threat in the East Otago area with future plans to dredge the Otago harbour, dumping approximately 7.2 million cubic metres of dredge spoils close to the Blueskin Bay area. There are also plans to develop a fishery of *M. pyrifera*, which has recently come into the quota management system. The quota for *M. pyrifera* is set at 1,238 t (MFish info website 2010). The potential harm to these areas includes the removal of crucial adult fish and nursery habitat for fish species in southern coastal areas. By gaining an understanding of the interactions and productivity associated with epifauna and reef fish and elucidating the importance of macroalgal productivity as a food source and habitat it is hoped that this study will be better able to identify the roles of *M. pyrifera* forests in finfish fisheries and biodiversity.

### 1.6 The East Otago Taiāpure the setting for this study

The East Otago Taiāpure is located in the Blueskin Bay area on the East Otago coastline, north of Dunedin. Otago occupies the southeast region of New Zealand’s South Island (Figure 1.1). The Taiāpure is on the northern side of the Otago Peninsula, which has a large inlet called the Otago Harbour. The hydrology of this area is dominated by the Southland Front, which is a component of the subtropical convergence, which separates the inshore southland current from the sub-Antarctic surface waters offshore (Heath 1985). Within the Taiāpure the dominant swell direction is southeast. This area is sheltered from the large southerly swells that affect the southern areas of the Otago Peninsula. The dominant current direction is southwards alongshore into the Blueskin gyre at Warrington (Jillett 1969).
Figure 1.1. Map of the East Otago Taiāpure on the East Otago coast. Illustrating the locality of Karitane, Otago Harbour and the boundary to the Taiāpure.

1.7 Taiāpure and Mātaitai

Within New Zealand, coastal rocky reefs have been an important traditional source of kaimoana (seafood) to Māori. The 1998 Ngāi Tahu Settlement Act with the crown states that many fish species are considered taonga (treasure) and thus tangata whenua (people of the land) have a special interest in ensuring sustainable harvest and the overall health of the ecosystem. Taiāpure and Mātaitai are local fisheries areas established in regions of cultural and food gathering significance to local tangata whenua under the Fisheries Act 1996. This act contains provisions allowing local fisheries management committees to make regulations for the conservation and management of fisheries and seaweeds in the local fishery area. Once a Taiāpure or Mātaitai has been established, a management committee is appointed on the basis of nominations from the local community (MFish bulletin 2003). These management committees either recommend the establishment of general fisheries regulations to the Minister of Fisheries (Taiāpure) or establish bylaws (Mātaitai) for the management of resources within the Taiāpure or Mātaitai area, including regulations relating to commercial fishing, recreational fishing (bag limits, size limits), fishery closures (rahui) and customary fishing (MFish bulletin 2003). The management of customary and recreational and
commercial fisheries in New Zealand is based on a ‘large scale’ approach, where the setting of bag limits and quota are based on large fisheries regions monitored and enforced by the Ministry of Fisheries. These areas do not account for local variability in habitat quantity and quality as well as local fishing intensity (Moller et al. 2000). Due to the use of this broad scale management of fisheries the local matauranga (traditional knowledge) of Māori and other local people (recreational fisherman, SCUBA divers etc) who are the most familiar with the local coastal area are often ignored. The ability to manage local populations is thus compromised (Moller et al. 2000).

The East Otago Taiāpure was first mooted by the Kati Huriapa ki Puketeraki Rūnanga to the Ministry of Fisheries in 1992 and was established in 1999 and was one of the first instituted under the Māori Fisheries Act, 1996. The Taiāpure encompasses 24 km² areas of coastline, extending from Matainaka Point to Blueskin Bay in the south and eastwards to Potato Point (Figure 1.1). The Taiāpure also extends up all estuaries in the area such as Purakanui, Waitatai, Waikouaiti and Hawkesbury lagoon. The guiding principal of the Taiāpure is to manage the area in a sustainable manner, with the specific objectives are to establish appropriate research projects; develop relationships with stakeholders and other interested parties within the East Otago area; establish monitoring regimes; establish an active role in consent processes in the area; have active fisheries management plans; apply for grants and monitory gifts for the management of the area; liaise with local government and establish appropriate accountability systems; employ persons with required skills to further the Taiāpure; and make recommendations on management regulations to the Ministry of Fisheries (MFish info website 2003, Taiāpure guiding principals doc.). The Taiāpure management committee is made up of the local Kati Huriapa Runanga and user groups such as commercial and recreational fishers, environmental groups, government departments and a scientific advisor from the University of Otago.

Since the establishment of the Taiāpure the management committee believe they have witnessed a decline in the status of the local fisheries. The committee asked for scientific information to support management initiatives that will address the concerns of overfishing, loss of habitat (degradation and kelp harvest) and sedimentation of reefs. The East Otago Taiāpure has an extensive history of commercial and recreational fishing that has led to the serial depletion of fisheries stock in the Taiāpure area. Important flatfish, crayfish and paua fisheries existed in the Taiāpure in the past supporting over 40 fishing vessels fifty years ago (Graham 1973) dropping to only a few in 2010 (MFish website 2010). These fisheries are
thought to have been largely overexploited by commercial and recreational fishing and are in decline forcing fisherman to look elsewhere.

1.8 Macroalgal communities on the East Otago coast

This study was conducted upon a wave-exposed coastline, where macroalgal communities are dominated by large brown macroalgal species such as giant kelp *Macrocystis pyrifera*, bull kelp *Durvillaea antarctica* and *Ecklonia radiata*. The East Otago coastline has upon a New Zealand scale nationally large *M. pyrifera* kelp forests close to shore. This species of macroalgae is considered to be the most extensive and productive macroalgal type in the area, providing large areas of quality habitat and detrital biomass (Fyfe et al. 1999). Rocky coastal areas have many diverse and complex macroalgal communities; these communities are usually fairly distinct and can be categorised by their exposure (waves, currents etc) and depth gradients. Many shorelines have distinct depth profiles that will be comparable between areas of similar environmental conditions. Areas that are considered exposed usually contain *Durvillaea antarctica*; areas that are considered to be of a mid to low exposure (sheltered) usually do not support *D. antarctica*. Upon the East Otago coast a diverse collection of rocky shore communities exist ranging from the exposed *D. antarctica* dominated to the sheltered *M. pyrifera* dominated habitats. Three distinct macroalgal communities are easily identified upon on the East Otago coastline, which can be characterised by large macroalgal species providing the dominant structuring component to the community. The three dominant macroalgal communities in this area (Figure 1.2 and 1.3) are usually found within the following depths.

1.8.1 Shallow (0-3 m) *Carpophyllum flexuosum* and *Cystophora* spp. beds

This shallow moderately sheltered macroalgal community, is dominated by brown, morphologically-complex seaweeds *Carpophyllum flexuosum*, *Cystophora retroflexa*, *Cystophora torulosa* and *Cystophora scalaris*, which are found at depths from 0 to 3 metres (Figure 1.3). These species form dense stands up to 2 m high with a great diversity of epifauna, mesograzers, invertebrates and fish living on and amongst them (Taylor and Cole 1994). This shallow sheltered macroalgal community also harbours a number of other seaweed species such as *Ulva* spp. *Caulerpa brownii*, *Codium* spp., *Halopteris virgata*, *Dictyota kunthii*, *Desmarestia ligulata*, *Macrocystis pyrifera*, *Xiphophora* spp. and *Sargassum sinclairii*. In certain locations the invasive kelp species *Undaria pinnatifida* is also present (Russell et al. 2008).
1.8.2 Mid-depth (3-10 m) *Macrocystis pyrifera* kelp forest

*Macrocystis pyrifera* kelp forests form large dense stands in sheltered coastal rocky areas throughout most of the world’s temperate waters (Steneck *et al.* 2002) (Figure 1.4 (c)). Kelp forests provide vital habitat complexity (Carr 1989), shelter from predation (Carr 1994) and abundant food sources (Holbrook *et al.* 1990); in addition they provide important ecosystem services, including protection from coastal erosion, dissipation of waves and currents (Jackson and Winant 1983, Stevens *et al.* 2002, Gaylord *et al.* 2007). Many species of macroalgae are present below the kelp canopy (e.g. *Ecklonia radiata, Carpophyllum flexuosum, Halopteris virgata, Landsbergia quercifolia* etc) many of which are found within shallow and deeper waters. Kelp forests around New Zealand usually inhabit a large depth range up to 30m (Brown *et al.* 1997). Within the East Otago Taiāpure water clarity is poor most of the time and are limited in depth to around 15 m depth (pers obs.).

1.8.3 Deep (10-15 m) *Ecklonia radiata* beds

*Ecklonia radiata* on the East Otago coastline is found at depths up to 20 metres and inhabits a zone starting around 8 m among and on the outer edge of *Macrocystis pyrifera* kelp forest (Richards 2010) (Figure 1.4 (d)). *Ecklonia radiata* can form a dense bed of individuals with few other large macroalgal species found. A number of small turfing red macroalgal species and encrusting corallines also exist in this depth zone.
Figure 1.2 Photos of the shallow habitats surveyed within this study (a) *Carpophyllum flexuosum* and (b) *Cystophora retroflexa* (0-3 m depth) which occur in mixed beds as well.
Figure 1.3 Photos of the two deeper habitats surveyed within this study. (c) Mid-depth *Macrocystis pyrifera* kelp forest (3-10 m) and (d) Deep *Ecklonia radiata* beds (10-15 m).
Previous studies of *Macrocystis pyrifera* kelp forests and associated macroalgal species around the Otago coastline include those of Kain (1983), Brown *et al.* (1997), Fyfe *et al.* (1999), Hepburn (2003), Hepburn and Hurd (2005), Hepburn *et al.* (2006), Hepburn *et al.* (2007) and Richards (2010). These studies indicate that *M. pyrifera* plays an important role within Otago coastal areas. Fyfe *et al.* (1999) found that the extent of the kelp forest just north of the East Otago Taiāpure covers an area 300 ha and have an estimated biomass of around 8100 tonnes. This biomass is thought to have driven the productive fisheries for crayfish (*Jasus edwardsii*) and pāua (*Haliotis iris*) in the past, with significant amounts of crayfish (84.5 tonnes) and pāua (89 tonnes) presently taken every year from the Otago fisheries (MFish info website 2010).

Kelp are considered ecosystem engineers, providing food sources both directly and indirectly through detrital food webs (Duggins and Eckman 1997). They also offer habitat complexity for reef fish species (Anderson 1994) as well as vital nursery areas for juveniles (Carr 1991). Kelp forests are also thought to dissipate wave energy within coastal areas slowing coastal erosion and sedimentation within these areas (Jackson and Winant 1983, Stevens *et al.* 2002, Gaylord *et al.* 2007). Previous studies within *Macrocystis pyrifera* kelp forests within the Otago area, have focused on growth, physiology and nutrient uptake (Kain 1983, Hepburn 2003, Hepburn and Hurd 2005, Hepburn *et al.* 2006) with little known about the ecology of fish and invertebrates the reside within kelp forests within southern New Zealand. A few studies have attempted to quantify the extent of kelp forests (Fyfe *et al.* 1999) and the associated epifauna (Hepburn 2003) and number of gastropod grazers such as *Cookia sulcata, Haliotis iris* and *Evechinus chloroticus* present within kelp forest habitats (Richards 2010).

### 1.9 Structure of thesis

Within the Otago area, to my knowledge no studies have been conducted investigating the associations of macroalgae (specifically *Macrocystis pyrifera*) to reef fish and epifaunal assemblages. The overall goal of this study was to investigate the importance of macroalgal habitats as a major structuring component and source of productivity to prey sources of reef fish within the East Otago Taiāpure. To achieve this goal a range of approaches were adopted including seasonal fish surveys within three distinct macroalgal habitats. The deployment of seaweed and coralline cobble simulators to capture epifauna (which are common food sources to fish); and food web studies using stable isotope analysis and gut contents analysis of reef, soft sediment and pelagic fish species. The initiative for this study came from the local East Otago Taiāpure management committee, which had purportedly witnessed a decline in local
fisheries in the past 10 years and were concerned about habitat degradation due to sedimentation. A lack of information exists about kelp forest communities in Otago and their importance in fish population structure. An outline of each chapter follows:

**Chapter Two**

*Preferred macroalgal habitat for coastal reef fish assemblages within the East Otago Taiāpure, New Zealand.*

This chapter investigates reef fish assemblages abundance and diversity within three distinct macroalgal habitats (shallow *Carpophyllum/Cystophora* beds (0-3 m depth), *Macrocystis pyrifera* kelp forest (3-10 m) and deep *Ecklonia radiata* beds (10-15 m) within the East Otago Taiāpure. In order to achieve this, seasonal subtidal SCUBA surveys at five locations were conducted at three depths using stationary visual point counts. To quantify characteristics of macroalgal habitats and benthic invertebrates 4 m² quadrats were used, which were conducted simultaneously to the fish survey.

**Chapter Three**

*Seasonal sampling of epifaunal assemblages using coralline cobble and seaweed simulators within Butterfly Bay, East Otago Coast*

This chapter describes epifaunal community abundance and diversity within three distinct macroalgal habitats from spring to autumn within the East Otago Taiāpure. This involved the use of seaweed and coralline cobble simulators as standard monitoring units.
Chapter Four

*Coastal Food Webs of the East Otago Coastline*

This chapter describes through the use of stable isotope analysis and gut contents analysis, the importance of macroalgae and phytoplankton productivity in supporting reef, soft sediment and pelagic associated fish species upon the Otago coastline. By undertaking this analysis it was hoped to elucidate the source of primary productivity driving the local food webs within the East Otago Taiāpure and surrounding areas.

Chapter Five

This chapter will discuss the main findings of this study and implications of the findings and will give some general conclusions.
CHAPTER TWO

Preferred Macroalgal Habitat for Coastal Reef Fish within the East Otago Taiāpure

Blue cod (*Parapercis colias*) moving through a stationary visual point survey within a *Macrocystis pyrifera* kelp forest.
2.1 Introduction

The distribution, abundance and diversity of temperate reef fish are influenced by a complex interplay between large and local scale ecological processes. Large-scale variation in factors such as environmental stress, dispersal and productivity impact local-scale processes such as predation and competition (Menge and Olsen 1990). An important goal in ecological studies is to understand patterns of distribution of organisms in different environments and the mechanisms that drive them. Among temperate reef fish species, there are many studies that provide evidence that the structure of habitats affects the spatial distributions of assemblages, both in tropical coral reefs (Roberts and Ormond 1987, Tolimieri 1995, Caley and St John 1996, Friedlander and Parish 1998, Holbrook et al. 2000) and temperate rocky reefs (Carr 1989, Holbrook et al. 1990, Levin and Hay 1996, Tupper and Boutilier 1997) with many such examples from New Zealand (Choat and Ayling 1987, Jones 1988, Connell and Jones 1991, Anderson and Millar 2004).

The complex nature of the New Zealand coastline and detrimental environmental factors affecting it (e.g. land derived sedimentation, overfishing, habitat degradation etc) make it a challenging and fascinating place to work. The East Otago Taiāpure has a diverse range of habitats with large *Macrocystis pyrifera* kelp forests on near shore and offshore rock and boulder reefs. It also supports a wide range of reef-dwelling and sandy-bottomed associated fish and invertebrate species. Blueskin Bay and the kelp forests within this area are known for their high productivity and ability to support large numbers of commercially and customary important fish species in the past (Graham 1973). Reef fish communities within this area are thought to be fairly typical of species observed along the Otago coastline (Graham 1973, Franklin 1999). There are however physical and biological characteristics, such as the Blueskin Bay gyre (Jillet 1969), relatively high macroalgal productivity (Brown et al. 1997), existence of large *M. pyrifera* kelp forests (Fyfe et al. 1999) and threats posed by sedimentation from dredge spoil and potential harvesting of *M. pyrifera* kelp, which could lead to habitat degradation. Studies of reef fish ecology, habitat associations and assemblages in New Zealand are heavily biased towards our northern coastlines (e.g. Schiel 1984, Choat et al. 1988, Jones 1988 and Kingsford 1989). In contrast, the ecology, habitat associations and assemblages of reef fish have been largely neglected on the southeast coast of the South Island with only a few systematic and anecdotal accounts of reef fish species presence and broad ecological studies available within published literature (Graham 1973, Paulin and Roberts 1992, Rutledge 1992, Hickford and Schiel 1995). To date, only one study has examined the community composition of the fish assemblages on the Karitane coastline, in a
study over ten years old (Franklin 1999). As outlined above, the lack of knowledge and the threats to this area make understanding the habitat dynamics that govern reef fish abundances amongst macroalgal communities crucial for the East Otago Taiāpure committee to make informed decisions regarding future management decisions.

### 2.1.2 Importance of macroalgal habitats to temperate reef fish

Multiple studies have demonstrated that the distribution of temperate reef fish is directly influenced by habitat. Factors such as reef structural complexity, macroalgal patchiness, suitability of habitat, availability of food sources and protection from predators all influence fish assemblages (Jones 1984a,b, Jones 1988, Choat and Ayling 1987, Carr 1994, Levin and Hay 1996, Babcock et al. 1999, Anderson and Millar 2004). Habitat requirements of fish are usually species specific and vary throughout their life history (Anderson et al. 1981). Recruitment and settlement processes are strongly influenced by habitat type and quality for many fishes (Gillanders and Kingsford 1996, Williams et al. 2008). On temperate rocky reefs in the South Island of New Zealand, the majority of habitat structure is provided by macroalgal species, especially large kelps such as *Macrocystis pyrifera*, *Carpophyllum* spp., *Cystophora* spp., *Marginariella* spp., *Ecklonia radiata* and *Durvillaea* spp. (Schiel 1990). The structure and extent of such habitat forming macroalgae can vary dramatically year to year (Dayton 1985, Schiel and Foster 1986, Nisbet and Bence 1989) and this variation is also thought to strongly contribute to the dynamics of distribution and abundance of reef fishes (Anderson 1994). One example is the variation observed in recruitment of kelp bass (*Paralabrax clathratus*) in California U.S.A.; which was explained by the spatial and temporal variation in density of *M. pyrifera* (Carr 1994). Similarly, structural features of *M. pyrifera* affect the distribution and abundance of kelp perch (*Brachyistius frenatus*), with several measures of *M. pyrifera* density positively correlated to both abundance of adults and recruitment success (Anderson 1994). Conversely, similar relationships of greater reef fish density and species richness were observed within understorey species such as *Sargassum filipendula* in California, U.S.A. (Levin and Hay 1996) suggesting understorey seaweeds may also play a role in determining recruitment.
The complexity provided by macroalgal habitat can also be driven by reef characteristics and topography. Areas of reef that provide overhangs, caves and crevices support a wide range of diverse invertebrate fauna, which many species of reef fish prey upon. In New Zealand, evidence suggests that habitat not only influences the distribution of reef fish, but reef fish themselves affect the quality and quantity of habitat types through direct grazing of macroalgae and predation of sessile grazers (Babcock et al. 1999). However, macroalgae probably affect fish more than vice versa (Jones 1988).

2.1.3 Reef fish species observed within the East Otago Taiāpure

Throughout the study period from winter 2009 to autumn 2010, 18 fish species were observed using underwater visual census (UVC) methods, however not all species were observed during each survey event. Some appeared to be rare at all times (Latris lineata, Parika scaber, Notolabrus cinctus, Pseudolabrus miles, Nemadactylus macropterus and Aplodactylus arcticidens). Of the 18 species surveyed, seven are targeted in commercial and recreational fisheries including: blue moki (Latridopsis ciliaris), trumpeter (L. lineata), blue cod (Parapercis colias), red cod (Pseudophycis barbata), greenbone (Odax pullus), tarakihi (N. macropterus) and yellow-eyed mullet (Aldrichetta forsteri). The majority of reef fish in New Zealand are carnivorous, feeding upon benthic invertebrates and small reef fish. Two species are herbivorous (O. pullus and A. arcticidens) and one species is known to be omnivorous (P. scaber) (Francis 2001). Reef fish are thought to be the top predator within subtidal reef communities, playing a significant consumer role in controlling the population and size structure of invertebrates (Russell 1983, Jones 1984a,b, Choat and Clements 1992). A brief description of the feeding habits and life history of all species encountered follows:

**Exploited fish species**

**Blue moki** (*Latridopsis ciliaris*) Māori name: *Moki.*

Blue moki are a long-lived (~30 years) demersal fish species, which are found mainly over, on and around rocky reefs. They are large (~90 cm) and are found throughout New Zealand up to 100 m depth; but found in greatest abundance in the South Island, where they have been largely overfished in the past by commercial and recreational fisheries (Paulin and Roberts 1992). Blue moki diet consists of a wide range of benthic invertebrates including gastropods, bivalves, starfish, crustaceans, as well as other fish and worms which they suck from sand and mud (Francis 2001). The life history is fairly well known with adults maturing around 5 to 6 years at around 40 cm (Francis 1981a). Breeding adults migrate to spawning
grounds off the East Cape near Gisborne in early winter and no other spawning grounds are known. Eggs are carried southwards by the East Cape current and juveniles settle from the plankton at about 10cm length after 8 to 12 months (Francis 1981b). Adult fish are usually found near subtidal reefs, while juveniles are frequently seen in surge pools and tidal channels where they form loose aggregations of up to twenty or more (Paulin and Roberts 1992). The Ministry of fisheries has set the total allowable catch (TAC) for 2011 at 608.112 tonnes (t) for the whole of New Zealand and 127.206 t for the southeast coast fisheries area (MFish info website 2010).

**Trumpeter** (*Latridopsis lineata*), Māori name: *Kohikohi*

Trumpeter are large demersal fish that share many features with *Latridopsis ciliaris*, reaching the same maximal size of around one metre and occupy similar habitats, living for ~30 years. Trumpeter, however have a distinct concave head profile and coloration that is of olive green to yellow/brown with three lateral stripes down its side (Francis 2001). They are common south of Cook Strait to the Snares Islands and in the Chatham Islands. Trumpeters are usually seen singularly or in small groups over shallow reefs, but may form large aggregations in deeper water. They frequently school with blue and copper moki (*L. ciliaris, Latridopsis forsteri*). Trumpeters consume any large prey including invertebrates (crabs, octopus, squid) and small fishes. They have also been seen feeding on large planktonic swarms of crustaceans. The biology and life history of this fish are poorly known though spawning is thought to occur in winter with fish moving into deeper water off the continental shelf during this period. Trumpeter also supports a commercial fishery in the South Island (Paulin and Roberts 1992). The Ministry of Fisheries have set the TAC for 2011 at 144 t for the whole of New Zealand and 33 t for the southeast coast area (MFish info website 2010).

**Blue Cod** (*Parapercis colias*), Māori names: *Raawaru* or *Paakirikiri*.

Blue cod are endemic to New Zealand and are found throughout coastal waters, with highest abundances found in cooler southern regions south of East Cape, but can be found in northern regions in lower numbers (Francis 2001, Beentjes and Carbines 2005). This species is found on or around reef areas, usually towards the edges or by rocky outcrops, occupying waters from 0 to 100 m, though are more common up to 50 m (Beentjes and Carbines 2005). *Parapercis colias* are a long-lived species (~20 years) that can obtain lengths up to 60cm, and are top predators in southern temperate reefs (Russell 1983). Prey choice consists predominantly of small fish, molluscs and crabs, but they will take any marine animal of suitable size from the sea floor or in midwater (Francis 2001). Juveniles eat small
invertebrates associated with turf communities (Russell 1983). Blue cod defend loosely defined territories and exhibit spatial structuring (Cole et al. 2000). Studies of tagged individuals and stable isotope analysis suggest adults move only on the scale of tens of kilometres (Beentjes and Carbines 2005, Rodgers and Wing 2008). Little is known of their spawning behaviour but it is thought to occur in late winter to early spring. *Parapercis colias* are sequential hermaphrodites, beginning life as females with some individuals later changing to males. All large blue coloured fish are males, but brown coloured fish can be male or female. Juveniles appear at around 5 cm on sandy or shelly-bottomed areas close to reefs below 15 m depth during January and February; sub adult (immature) fish usually inhabit deeper waters. During the summer months blue cod are found close to shore, but move to deeper offshore water in winter. Blue cod are fished commercially and are important recreational and customary fish in the South Island (Bradford 1998, James and Unwin 2000). Ministry of Fisheries have set the TAC for 2011 at 2671.185 t for the whole of New Zealand and 162.732 t for the southeast coast area (MFish info website 2010).

**Red Cod** (*Pseudophycis barbata*) Māori name: Hoka

The red cod is a nocturnal bottom dwelling species found in rocky reef habitat near caves and overhangs, which migrates seasonally to deep water over the edge of the continental shelf. They are found throughout New Zealand from 0 to 400 m depths but are more common south of the Cook Strait. Diet consists of small fishes and a wide range of bottom living invertebrates, which are detected in the muddy bottom by the sensory chin barbel. Spawning occurs in mid winter to spring, and eggs are found in the plankton in summer. Juveniles grow rapidly reaching 20-25 cm in the first year and mature at about 50 cm at 4 years. Red cod is an important commercial species and is taken in quantity around Banks Peninsula (Francis 2001). Ministry of Fisheries have set the TAC for 2011 at 9278.383 t for the whole of New Zealand and 4600 t for the southeast coast area (MFish info website 2010).
Greenbone (*Odax pullus*) Māori name: *Mararii*

Greenbone are an herbivorous diurnal species, feeding preferentially upon fucoids and laminarian brown algae (Clements and Choat 1993). The greenbone forages by nipping off the small reproductive branches of some species and circular disks in others (Taylor and Schiel 2010). This species is found in cold shallow waters throughout New Zealand. *Odax pullus* reach maximum lengths of around 70 cm and are likely to live for over 10 years, during which time they undergo several colour changes. Juveniles are more slender and elongate than adult fish. Greenbone are serial spawners releasing 2000 to 6000 eggs per spawning event, with the large blue male maintaining a territory. Spawning occurs from July to February, peaking in spring. Although eggs are planktonic, larvae settle soon after hatching. Juvenile fish are found in dense seaweed in shallow water (0-1 m) and move to deeper water as they grow larger. Small fish less than 35-40 cm occur to about 10 m depth and are females while larger fish are males and are usually found below 15 m (Francis 2001). Ministry of Fisheries have set the TAC for 2011 at 162 t for the whole of New Zealand and 3 t for the southeast coast area (MFish info website 2010).

**Tarakihi** (*Nemadactylus macropterus*)

Tarakihi are common throughout New Zealand and are found above mud and sandy-bottomed areas or near reef edges. They are usually found in over 25 m of water in the north and shallower in the south. *Nemadactylus macropterus* reach a maximum length of 70 cm and live up to 45 years. Foraging occurs around dusk and prey sources include worms, crabs, brittlestars and shellfish. Life history is fairly well documented with specific spawning areas known around New Zealand. Spawning occurs from February to June in most areas with periodic spawning during these months. Larvae have a planktonic stage of around 7-10 months after which juveniles settle at 7-9 cm in length on a rough bottom during early summer. Maturity is reached at 4 to 5 years (Paulin and Robert 1992, Francis 2001). Ministry of fisheries have set the TAC for 2011 at 6439.173 t for the whole of New Zealand and 1403 t for the southeast coast region (MFish info website 2010).

**Yellow-eyed mullet** (*Aldrichetta forsteri*) Māori name: *Aua*.

Yellow-eyed mullet are found throughout New Zealand from Cape Reinga to Stewart Island. They form large schools in sheltered waters, harbours and estuaries as well as over reefs. Maximum length reached is around 40 cm and live for around 8 years. Prey includes planktonic crustaceans and food digested from mud scooped up from the bottom. Spawning occurs from late winter to summer, with juveniles found in estuaries in early summer.
Maturity is reached at around 3 years, at a length of 14-17 cm (Francis 2001). Ministry of fisheries have set the TAC for 2011 at 68 t for the whole of New Zealand and 8 t for the southeast coast region (MFish info website 2010).

Unexploited species

**Banded wrasse** (*Notolabrus fucicola*) Māori name: *Taangahangaha*

*Notolabrus fucicola* are abundant throughout New Zealand, are generally found on exposed reefs in areas of high macroalgal cover, at depths up to 30 m and reaching 50 cm in length. They are omnivorous, taking hard-shelled molluscs such as mussels, limpets, paua as well as a variety of amphipods, crabs and hermit crabs, barnacles, polychaete worms and sea urchins. The life history of banded wrasse is poorly known, but individuals are strongly territorial towards conspecifics (Denny and Schiel 2002). Sex change from female to male may occur at any age. Growth is slow and large fish maybe ~25 years or older. Spawning occurs between July and November with juveniles (3-4 cm long) found hiding in seaweed during January and February, and reaching 12 cm by the end of their first year. Maturity occurs in their second year at about 18 cm unlike most other wrasse, some *N. fucicola* mature as males without passing through a female stage. The alternative also occurs where females do not mature into males. Thus both very large females and small males can be found (Russell 1983, Paulin and Roberts 1992, Francis 2001, Denny and Schiel 2001, Denny and Schiel 2002).

**Spotty** (*Notolabrus celidotus*) Māori name: *Pakirikiri*

Spotties are an endemic wrasse species found throughout New Zealand. They are often extremely abundant and both juveniles and adults may be seen in large numbers in dense seaweed beds (Jones 1984a). *Notolabrus celidotus* live up to 7 years and reach around 30 cm length. Diet consists of a wide variety of small bottom dwelling invertebrates such as crabs, amphipods, shrimp, barnacles, shellfish and worms. The life history of this species has been well studied. Spawning occurs in late winter and early spring. Males control a territory during the spawning season, but these areas are not permanent or well defined. Female fish do not remain within defended areas and each male may breed with several females. After a courtship display the female releases eggs into the water a short distance above the bottom where the male fertilizes them. Eggs and larvae are planktonic and drift for about two months, with juveniles settling at around 2 cm length from December to February. Juveniles remain in areas of dense brown algae until around 4 cm length and are usually all female fish which are
sexually mature at the end of the first year at about 12 cm. Fish change sex to male at ~20 cm (Jones 1984a,b,c, Francis and Ling 1985, Francis 2001).

**Scarlet wrasse** (*Pseudolabrus miles*) Māori name: *Puuwaiwhakarua*

Scarlet wrasses are endemic to New Zealand and are found widely throughout. Common at subtidal depths below 15 m, especially in southern waters; this species is usually found in areas of broken rock and crevices, rather than favouring areas of weed. When disturbed the scarlet wrasse will hide in a crevice or hole. Diet consists of invertebrates, predominately crabs, urchin, shellfish and brittle stars. Spawning occurs in late winter and spring when breeding fish move to deeper waters. Each male breeds with a number of females. Fish change sex at around 20 cm and attain a maximum size of 30-35 cm (Russell 1983, Paulin and Roberts 1992, Francis 2001).

**Girdled wrasse** (*Notolabrus cinctus*)

Girdled wrasse are endemic to New Zealand, found at depths over 15 m on rocky reefs and are abundant in southern South Island, but rare past Cook Strait. Prey consists of shellfish, crabs, worms and planktonic crustaceans. Two colour phases exist, juvenile and adult. Colour change occurs at around 15 cm with a maximal length of 41 cm. Life history is poorly known for these fish though spawning occurs in summer. Sex change from female to male occurs at around 22-28 cm and is not accompanied by a colour change (Francis 2001).

**Marblefish** (*Aplodactylus arctidens*), Māori name: *Kehe*

Marblefish are herbivorous, grazing on fine red or green algae. However they also consume small invertebrates living on algae utilizing downward pointing mouths and slicing teeth (Choat and Clements 1992). They are active at twilight and are usually found by day resting in crevices or amongst dense macroalgae. Life history of *Aplodactylus arctidens* is relatively unknown. Juveniles settle from the pelagic stage at around 4 cm length in late spring to early summer. They are widespread throughout New Zealand though more common south of the Cook Strait at 0-20 m depth. Colour of head and body is olive green or brown with fine mottled lines of white, giving a marbled appearance. Pelagic juveniles have bright silvery sides and a blue grey dorsal area. Maximum size attained is around 60 cm (Paulin and Roberts 1992, Francis 2001).
**Leatherjacket** (*Parika scaber*) Māori name *Kōkiri*

Leatherjackets are a distinctive species with a diamond shaped body and dorsal spine. Found throughout New Zealand over reefs and sandy bottoms. Diet consists of sessile invertebrates sponges, ascidians and also mid-water jellyfish and salps. Spawning occurs in August to November in nests on the bottom. Juveniles (less than 1cm) settle from the plankton and hide in dense macroalgae. Maturity is reached around two years at 19-22 cm, and they may live for ~7 years. Maximum length observed is around 45 cm.

**Blue-eyed triplefin** (*Notoclinops segmentatus*)

This species of triplefin is common but poorly known. It is found throughout New Zealand in a variety of habitats, but prefer areas of rock, cobble, steep rock faces and overhangs in areas without large stands of algae and with a thick cover of coralline algae to around 10 m depth. Diet includes small crustaceans such as amphipods and copepods and this species has been recorded cleaning parasites off larger fish. Spawning occurs from August to January. Males defend small territories during mid to late spring while females lay eggs in crevices, which are guarded by the males until they hatch. Maximum length obtained of ~6 cm with a coloration of pinkish body and iridescent blue eyes (Paulin and Roberts 1992, Francis 2001).

**Spectacled triplefin** (*Ruanoho whero*)

Spectacled triplefins are endemic and widespread throughout New Zealand and are usually found in crevices or under boulders to 6 m depths. Food consists of a wide range of invertebrates, especially crustaceans such as amphipods and crabs. Spawning occurs from June to November and males defend a territory and guard eggs. Juveniles appear in September on reefs and mature during first year. These fish reach a maximum size of 10 cm and live for up to 2 years (Francis 2001).

**Variable triplefin** (*Forsterygion varium*)

A widespread common endemic species to New Zealand found from 0-30 m depths. Prey includes a diverse range of species of invertebrates, especially crustaceans, crabs, shellfish and other small fish. Spawning occurs from May to November with a midwinter peak. Individuals may breed several times in a season. Eggs are deposited in a single layer on a rocky surface and are guarded by the male. Several females may deposit eggs in a single nest, which may contain a few hundred to several thousand. Eggs hatch after 7 to 10 days. Larvae are pelagic for over 2 months during which settlement occurs in shallow rocky reefs,

**Oblique-swimming triplefin** (*Obliquichthys maryanae*)

This triplefin species is found throughout New Zealand and is endemic. They are generally found swimming in a school up to 5 m above dense macroalgae covered reef. Prey includes small crustaceans and other plankton, which is caught while facing into the current. Spawning occurs in mid winter with males building a nest. Schools of juveniles appear on reefs during September; maximum length reached of around 8 cm (Paulin and Roberts 1992, Francis 2001).

**Long-finned triplefin** (*Ruanoho decemdigitatus*)

This species is widespread throughout New Zealand found in waters from 0 to 15 m depths. Habitat is usually on rocky reefs in rock crevices and caves. Feeding habits and life histories are poorly known with spawning occurring in June to October on flat rocks; maximum length of around 12 cm recorded (Paulin and Robert 1992, Francis 2001).

### 2.1.4 Underwater SCUBA fish census techniques

Underwater visual census (UVC) techniques were first pioneered in the 1950s by Brock (1954) and have since been widely used to estimate abundance, biomass and size structure of reef fish populations (Bell *et al*. 1985, Bortone *et al*. 1986, McCormick and Choat 1987, Watson and Quin 1997, Connell *et al*. 1998, Samoilys and Carlos 2000, Zeller and Russ 2000). Much discussion has taken place regarding the accuracy and ability of a survey to encompass all fish species abundance accurately. Problems that are associated with visual techniques include poor water visibility, visibility of study species, errors in estimates of size, variable visibility of fish in different habitats, recounts of fish, lack of experience of the observer, variation of diver swimming speed and search patterns of the observer (Kingsford and Battershill 2003). To counter these problems studies have found that surveys are most accurate when only selected groups of fishes are studied, or the species are relatively sedentary, easily distinguished, and fairly abundant; observers are experienced, and underwater visibility is sufficient for detection of species within the survey (McCormick and Choat 1987, Buxton and Smale 1989, Thompson and Mapstone 1997, Samoilys and Carlos 2000). Thus, in most cases survey accuracy can be high; however, many methods have high variability, low precision, and low power (Samoilys and Carlos 2000). The power and
accuracy of surveys can be improved by surveying small areas (i.e. 5 X 5 m invisible box) and by increasing the number of replicates (Samoilys and Carlos 2000).

2.1.5 Objectives

The primary objective of this study was to gather baseline information on reef fish populations abundance, seasonal distribution and diversity; and relate this information specifically to the major habitat macroalgal habitat types (shallow *Carpophyllum flexuosum/Cystophora* spp. (0-3 metres depth), mid *Macrocystis pyrifera* kelp forest (3-10 m) and deep *Ecklonia radiata* (10-15 m)) found within the East Otago Taiāpure. In particular the following questions will be addressed:

1. *What are the patterns of reef fish species abundance and diversity with macroalgal habitats on the East Otago coastline?*

2. *Do patterns of reef fish species abundance and diversity change seasonally within the East Otago Taiāpure?*

3. *Do patterns of reef fish abundance and diversity change spatially within the East Otago Taiāpure?*

It was predicted that reef fish abundance and diversity would be greatest within *Macrocystis pyrifera* forests (3-10 m) and deep *Ecklonia radiata* (10-15 m) macroalgal habitats; due to macroalgal habitats providing refugia, availability of prey items, habitat complexity and protection from water motion by diffusion provided by macroalgae (Jackson and Winant 1983). It is also thought that certain species will be more closely associated to different macroalgal habitats. Greenbone (*Odax pullus*), banded wrasse (*Notolabrus fucicola*), triplefin spp. and juvenile reef fish (e.g. *Latridopsis ciliaris*) will be found in greater abundance in shallow *Carpophyllum/Cystophora* habitats due to protection from predators by dense macroalgae and availability of prey. Spotties (*Notolabrus celidotus*) are generalist feeders and will be found evenly distributed between habitats; with smaller juveniles found in shallow *Carpophyllum/Cystophora* habitats. Large species such as blue moki (*Latridopsis ciliaris*) and trumpeter (*Latris lineata*) will be found predominantly within the *M. pyrifera* kelp forest and *E. radiata* beds due to the presence of habitat complexity and abundant food sources.
It was hypothesised that seasonal variation with different reef fish species will exist and have specific patterns of abundance and diversity. Herbivorous *Odax pullus* and wrasse *Notolabrus fucicola* and *Notolabrus celidotus* are predicted to be resident fishes with little migration seasonally. Greatest numbers will be found during spring and summer and during winter all species will be found in lower abundances. Blue cod (*Parapercis colias*) will be found in greatest abundance during summer and least in winter when many migrate offshore to spawn. Large legal sized (>45cm) blue moki (*Latridopsis ciliaris*) will be only found during spring and summer due to spawning migrations north to East Cape during autumn and winter (Francis 1981a). It is predicted that survey sites with easy access points and boat ramps will have lower mean abundances of reef fish due to fishing pressure. Furthermore, sites with high *Macrocystis pyrifera* kelp forest and benthic invertebrate densities that are situated upon points and not bays will contain the greatest abundance and diversity of reef fish species.

The second set of objectives relate to characterising macroalgal habitats and invertebrates found there, answering these specific questions:

1. *Do the macroalgal communities density and species type change with increasing depth of water, season and between sites surveyed upon the East Otago Taiāpure?*

2. *What are the patterns of benthic invertebrate communities in abundance and diversity within three macroalgal communities, seasonally and within sites?*
2.2 Methods

2.2.1 Survey sites

Reef fish were surveyed during winter (7th of August 2009), spring (23rd of October 2009), summer (28th January 2010) and finished with an autumn survey (8th of May 2010). Surveys were conducted within five sites spread throughout the East Otago Taiāpure, north of Dunedin, South Island, New Zealand. The five sites were located at Matainaka (Cornish head) (45°37’11. 89”S 170°41’31. 03”E), Butterfly Bay (Huriawa Peninsula) (45°38’18. 68”S 170°40’18. 23”E), Puketeraki (45°39’34. 18”S 170°39’34. 18”E), Brinns Point (45°40’24. 31”S 170°39’8. 20”E) and Omimi Bay (45°41’27. 82”S 170°37’17. 90”E) (Figure 2.1). Three distinct macroalgal communities were surveyed at three depths at each site. The macroalgal habitats included: *Ecklonia radiata* beds (10-15 metres depth), *Macrocystis pyrifera* kelp forest (3-10 m) and *Carpophyllum flexuosum, Cystophora scalaris, Cystophora retroflexa* and *Cystophora torulosa* beds (0-3 m) (Figure 1.1). These three distinct macroalgal communities were chosen as they have been identified as the important dominant macroalgal communities within the East Otago Taiāpure (Richards 2010). Within each macroalgal habitat a total of three replicate fish counts and macroalgal surveys were undertaken.

2.2.2 Survey design

Reef fish populations were quantified using a stationary visual point transect (via SCUBA) design, similar to that described in Watson and Quinn (1997), Kingsford and Battershill (2003) and Murphy and Jenkins (2010). The procedure to survey fish was achieved by the diver sitting stationary upon the bottom for 3 minutes time counting all fish that passed through an imaginary five-metre wide, five-metre high and five-metre deep (125m$^2$) box of water, directly in front of the diver (Figure 2.2). Fish species were put into different categories according to size and colour phase (Table 2.1). For example spotty (*Notolabrus celidotus*) were placed into three distinct categories based on their size and colouration. Small dark initial phases fish were classed as juveniles; larger initial phased fish were classed as females and large terminal phased fish were classed as males.

Macroalgal community structure was quantified simultaneously to fish surveys using a 4 m$^2$ transect consisting of a 4 m long piece of lead cored rope (10 mm diameter) and a one metre long piece of white plastic PVC pressure pipe (Figure 2.2). The 1 m long pipe was placed alongside the rope and any seaweeds, benthic invertebrates or cryptic fish species (triplefins and reef fish juveniles) encountered were counted (Figure 2.3). Coralline algae and
sand/sediment percent coverage as well as substrate type (boulders, reef etc) were also quantified. Furthermore within each survey depth, visibility, canopy percent cover as well as surrounding general reef characteristics were noted.

This novel method of stationary visual transect surveys was employed in this study as it was found through pilot studies and experimentation that a 50 X 5 m belt transect survey method was unsatisfactory to gain a true picture of fish assemblages in the area. Water visibility on the East Otago coastline is highly variable, ranging from just a few centimetres to over 15 m on rare occasions. By employing this method we were able to quantify fish, macroalgae and invertebrate species communities within specific macroalgal habitats.

Figure 2.1 Map of the East Otago Taiāpure, north of Dunedin, South Island, New Zealand. Dots indicate survey sites, which were surveyed seasonally.
Table 2.1 Reef fish species and size and colour criteria that species were placed into different categories within the surveys based on descriptions given in Paulin and Roberts 1992 and Francis (2001).

<table>
<thead>
<tr>
<th>Fish species</th>
<th>Category</th>
<th>Sex</th>
<th>Size</th>
<th>Colour characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spotty</td>
<td>Notolabrus celidotus</td>
<td>Juvenile Initial Terminal</td>
<td>Female Female Male</td>
<td>&gt;5cm 10-20cm 20-30cm Juvenile and female’s brownish yellow to green or greyish green with a prominent black spot on sides. Male’s similar to juveniles and females with light blue lines on head and black spot a more diffuse smudge.</td>
</tr>
<tr>
<td>Banded wrasse Notolabrus fucicola</td>
<td>Juvenile Initial Terminal</td>
<td>Female Female/male Female/male</td>
<td>&gt;5cm 10-30cm 30-50cm</td>
<td>Juveniles reddish brown, mottled green and orange. Adults becoming purple green with five indistinct yellowish bands or saddles. Both sexes similar in colour, but initial phase (usually female) fish are more brownish and bands are less distinct.</td>
</tr>
<tr>
<td>Scarlet wrasse Pseudolabrus miles</td>
<td>Juvenile Adult</td>
<td>Female Female/male</td>
<td>&gt;5cm 8-40cm</td>
<td>Juveniles with scarlet head and white chin, alternating orange and white horizontal lines on body. Adults reddish-yellow with margins of scales a darker red. Distinct black bar at base of tail.</td>
</tr>
<tr>
<td>Girdled wrasse Notolabrus cinctus</td>
<td>Juvenile Female Male</td>
<td>Female</td>
<td>10-35cm</td>
<td>Juvenile colour similar to females with pink-brown with a pale band in middle of body. Male’s similar in colour band is grey or black.</td>
</tr>
<tr>
<td>Blue Cod Parapercis colias</td>
<td>Juvenile Mid Legal</td>
<td>Female Female/male Female/male</td>
<td>&gt;10cm 10-25cm 25-65cm</td>
<td>Juveniles mottles rusty brown and white with narrow dark bands. Females whitish with two longitudinal bands along the back. Males blue to blue-grey, brownish mark at base of pectoral fin. Large fish are brightly coloured green above and bluish below.</td>
</tr>
<tr>
<td>Blue moki Latridopsis ciliaris</td>
<td>Juvenile Schooling Legal</td>
<td>Female/male Female/male Female/male</td>
<td>&gt;10cm 10-40cm 40-90cm</td>
<td>Juveniles are olive green and change slowly to the adult coloration with growth. Schooling and legal blue grey dorsally. Lighter on sides and silvery on belly with faint line along each scale row.</td>
</tr>
<tr>
<td>Trumpeter Latris lineata</td>
<td>Schooling Legal</td>
<td>Female/male Female/male</td>
<td>10-40cm 40-110cm</td>
<td>White with three black stripes on back, two continue down face, the third arcs around gill cover. Fins yellow, face and back may have yellowish tinge.</td>
</tr>
<tr>
<td>Leather jacket Parika scaber</td>
<td>Adult Female/male</td>
<td>45cm</td>
<td></td>
<td>Distinct body shape and dorsal spine. Colour varies from white to dark brown, spots on body and stripes on head. Male’s yellow-green tail with fine black stripes and Females with grey-brown tail.</td>
</tr>
<tr>
<td>Greenbone Odax pullus</td>
<td>Juvenile Female Male</td>
<td>Female Female Male</td>
<td>&gt;10cm 10-40cm 40-70cm</td>
<td>Juveniles and initial phase adults pale to dusky gold, head and body with a broken white line running from mouth along body. Terminal males are bright blue with iridescent markings. Bright blue markings present along lower portion of head.</td>
</tr>
</tbody>
</table>
Figure 2.2. Schematic of fish survey and quadrat procedures. Showing two divers (red dots), one surveying fish in 5 x 5 x 5 m (125 m²) invisible water box and the other diver quantifying macroalgal, cryptic fish and invertebrate communities.
Figure 2.3. Photographs taken during fish surveys; (a) rope transect being laid out, (b) photo of pole moving along rope counting the macroalgal community and cryptic fish etc (c) quadrat from another angle and (d) diver counting fish at the end of macroalgae transect.

2.2.3 Data treatment

To assess differences in reef fish assemblage, macroalgal community and benthic invertebrates between macroalgal habitats, seasons and sites; Permutational Multivariate Analysis Of Variance (PERMANOVA Anderson 2001) was used. PERMANOVA uses a permutation procedure to assess significance, and does not rely on the assumption of multivariate normality, which is frequently violated by ecological data and cannot be properly tested. Analyses were conducted on square-root transformed data, to reduce the influence of highly abundant taxa. PERMANOVA tests were carried out using Bray-Curtis similarity index with the addition of a dummy variable of one. Pair wise tests were performed if significant differences were found within the PERMANOVA analysis. To present the differences between mean abundances as letters upon graphs of fish, macroalgae and invertebrates between seasons, site and macroalgal habitat a PERMANOVA was performed using square-root transformed data and analysis was carried using Euclidian distances similarity index. The Euclidean system is obtained as the arithmetic average for each of the variables, so each of the groups has its own group centroid located in the centre of each of the
clouds of points identified as each group (Anderson 2001). To present relative dissimilarities among fish assemblages visually Principal Coordinate Ordination (metric MDS ordination) (PCO) was used. Fish assemblage data were also tested for homogeneity of multivariate dispersions using PERMDISP (Anderson 2000) using the same permutational strategies for relative factors. To assess differences in fish diversity, a Shannon Weaver index was used on raw data; a PERMANOVA was then performed on Euclidian distance similarity to assess differences in diversity. Graphs of fish assemblages were presented as mean abundance of fish per 3-minute stationary visual transect (SVT) as density per 125 m² did not take into account the affects of divers as attractants of fish.

2.3 Results

Reef fish assemblages observed in this study showed distinct patterns between macroalgal habitats, season and survey sites. With a total of 1495 fish observed during 153 three-minute surveys (7.65 hours of surveys) (Table 2.2). The most abundant of all species was spotties (*Notolabrus celidotus*) with a total of 404 fish, followed by moki (*Latridopsis ciliaris*) (347) and banded wrasse (*Notolabrus fucicola*) (302) indicating these species are dominant upon the East Otago reefs.

2.3.1 Reef fish macroalgal habitat preferences

Reef fish were more abundant in the deeper *Macrocystis pyrifera* kelp forest (3-10 m) and *Ecklonia radiata* beds (10-15 m) than in the shallower *Carpophyllum/Cystophora* beds (Figure 2.4). Reef fish assemblages were found through multivariate analysis to be significantly different between macroalgal habitats (PERMANOVA Pseudo $F_{2,150} = 12.173 \ P(perm) = 0.001$). Pairwise comparisons revealed significant differences between *Carpophyllum/Cystophora* beds and *Macrocystis pyrifera* kelp forest habitat fish assemblages and *Carpophyllum/Cystophora* beds and *Ecklonia radiata* habitat ($t = 4.1317 \ P(perm) = 0.001, t = 4.5423 \ P(perm) = 0.001$). No difference was found in the fish assemblages within *M. pyrifera* kelp forest and *E. radiata* beds ($t = 0.61131 \ P(perm) = 0.862$). There was also a statistically significant difference found in the dispersion of fish assemblages (PERMDISP $F_{2,150} = 4.5974 \ P(perm) = 0.028$). Pairwise comparisons revealed a significant difference between *Carpophyllum/Cystophora* beds and *M. pyrifera* kelp forest and *E. radiata* beds fish abundance and species composition ($t = 1.8614 \ P(perm) = 0.0087, t = 3.1275 \ P(perm) = 0.0006$). No difference was found between *M. pyrifera* kelp forest and *E. radiata* beds ($t =$
1.066 P (perm) = 0.373). The significant difference for both the PERMANOVA and PERMDISP tests revealed that there is both a dispersion effect and perhaps a location effect as well.

The Principal Coordinate Ordination (PCO) generated from the combined seasonal fish surveys within the macroalgal habitats (Figure 2.5) showed no clear patterns of reef fish abundance and species composition between macroalgal habitats. Some small clustering of points was observed in the *Macrocystis pyrifera* and *Carphophyllum/Cystophora* habitats fish assemblages. There is however a clear grouping of points (red circles) which could be driven by spotties and blue-eyed triplefin according to the vector analysis.

Specific patterns of abundance exist for reef fish species between the three-macroalgal habitats and show clear increases in abundance within the deeper macroalgal habitats. *Macrocystis pyrifera* kelp forest and *Ecklonia radiata* beds (Figure 2.6 and 2.7) had higher fish abundance than that encountered within shallow *Carphophyllum flexuosum/Cystophora* spp. beds.

Blue moki (*Latridopsis ciliaris*) (Figure 2.6 (a)) was found in the greatest abundance at schooling (10-40 cm) size (refer to Table 2.1) in both *Macrocystis pyrifera* and *Ecklonia radiata*. Juveniles (<10 cm) and legal (>40 cm) were encountered in greatest abundance within *M. pyrifera* kelp forest and *E. radiata* beds. Blue cod (*Parapercis colias*) (Figure 2.6 (b)) were only found within the *M. pyrifera* kelp forest and *E. radiata* beds. Trumpeter (*Latridopsis lineata*) (Figure 2.6 (c)) was only observed in the schooling (10-40 cm) size class at very low abundance and only observed within *M. pyrifera* kelp forest and *E. radiata* beds. Greenbone (*Odax pullus*) (Figure 2.7 (d)) was observed at very low abundances in all macroalgal habitats surveyed. Banded wrasse (*Notolabrus fucicola*) (Figure 2.7(e)) at both terminal and initial phases were found in greatest abundance within the *M. pyrifera* kelp forest and *E. radiata* beds at similar abundance. Spotties (*Notolabrus celidotus*) (Figure 2.7 (f)) initial and terminal phased fish were most abundant in the *M. pyrifera* and *E. radiata* beds with very few juveniles observed in all habitats. Cryptic triplefin species (Figure 2.8) show a steady increase in abundance from shallow *Carphophyllum/Cystophora* to deep *E. radiata*. The most abundant triplefin species was *Obliquichthys maryannae* (0.85 per 3 min SVT) in *E. radiata* beds. The dominant species in shallow *Carphophyllum flexuosum* and *Cystophora* spp. was *Forsterygion varium* (0.4) and within *M. pyrifera* it was *Ruanoho decemdigitatus* at (0.6).
2.3.2 Seasonality of reef fish communities

The map graphic illustrating seasonal differences in reef fish abundances (Figure 2.10) within the three-macroalgal habitats (left to right on the map) shows clear patterns of seasonality and habitat preferences. The greatest abundances of reef fish were observed in summer at all sites within the *Macrocystis pyrifera* kelp forest and *Ecklonia radiata* beds. Lowest abundances of fish are observed in winter at all depths with very few fish found in shallow *Carpophyllum/Cystophora* beds throughout all seasons. The mean abundances of reef fish assemblages were greatest in summer and lowest during winter (Figure 2.9). Multivariate analysis of reef fish assemblages found significant differences between seasons (PERMANOVA Pseudo F$_3$, 148 = 6.4053, P (perm) = 0.001), with summer having significantly greater abundances of fish to winter. See Appendix I for pairwise comparisons. There was no statistically significant difference in the multivariate dispersion of fish assemblages seasonally (PERMDISP F$_3$, 149 = 1.3938 P (perm) = 0.279). The PCO generated for combined fish surveys illustrated no pattern of fish abundances seasonally with points spread randomly over the plot.

The patterns of individual reef fish species seasonally follow a pattern of greatest abundance during summer and lowest during winter, with spring and autumn between these high and low abundances. Blue moki (*Latridopsis ciliaris*) (Figure 2.11 (a)) was found in the greatest abundance of all species in a single season (3 per 3 min SVT in spring for schooling sized fish). Blue cod (*Parapercis colias*) (Figure 2.11 (b)) were observed in greatest abundance during summer. Trumpeter (*Latris lineata*) (Figure 2.11 (c)) were found in greatest abundance in summer, with less than 0.1 per 3 min SVT during the rest of the year. Greenbone (*Odax pullus*) (Figure 2.12 (d)) were observed in very low abundances throughout the seasons with a maximum abundance in summer (0.1 per 3 min SVT). Banded wrasse (*Notolabrus fucicola*) (Figure 2.12 (e)) initial and terminal phased fish were observed at similar abundance throughout the year with greatest abundance found during summer. Low variation (<1 change throughout seasons) in abundance of *N. fucicola* was observed in this study with comparatively little difference between size classes. Spotty *Notolabrus celidotus* (Figure 2.12 (f)) were observed to be the most consistently abundant fish species, with very little variation between seasons. Cryptic triplefins (Figure 2.13) from the species *Obliquichthys maryannae*, *Ruanoho decemdigitatus*, *Notoclinops segmentatus*, *Ruanoho whero* and *Forsterygion varium* were observed in greatest abundance during summer and lowest during winter.
2.3.3 Site differences of reef fish communities

The patterns of reef fish abundance between sites was fairly even throughout the seasonal surveys. Figure 2.14 illustrates how similar the abundance of fish species were. Matainaka, Puketeraki and Brinns Point mean abundance of fish was very similar, with Butterfly Bay and Omimi having slightly lower mean abundances. Significant differences were found within the PERMANOVA analysis of fish assemblage between sites (Pseudo $F_{4, 148} = 3.1069 \text{ P (perm)} = 0.002$). With sites situated on points having significantly greater fish abundance compared to bays. See Appendix I for pairwise comparisons. There was also statistically significant difference in the multivariate dispersion of fish assemblages between sites (PERMDISP $F_{4, 148} = 3.1185 \text{ P (perm)} = 0.048$) indicating a dispersion and location effect upon fish populations. See Appendix I for pairwise comparisons.

2.3.4 Reef fish diversity

The diversity of reef fish was greatest within *Macrocystis pyrifera* kelp forest and *Ecklonia radiata* beds and least in shallow *Carpophyllum/Cystophora* habitat. Diversity of fish was greatest during summer and least during winter. Sites differences were less clear with Matainaka, Brinns Point and Puketeraki having similar diversity of fish species. Through statistical analysis it was found that significant differences between macroalgal habitats (Pseudo $F_{2, 150} = 18.605 \text{ P (perm)} = 0.001$), seasons (PERMANOVA Pseudo $F_{3,149} = 12.859 \text{ P (perm)} = 0.001$) and sites (Pseudo $F_{4, 148} = 2.9428 \text{ P (perm)} = 0.021$) exist. See Appendix Table I for pairwise comparisons.

2.3.5 Substrate and sedimentation

Substrate types among macroalgal habitats (Figure 2.15) were found to be fairly similar throughout. Shallow *Carpophyllum/Cystophora* and *Macrocystis pyrifera* kelp forest habitats were dominated by crustose coralline algae and sediments, which accounted for over 50% of total cover. Deep *Ecklonia radiata* habitat was composed of crustose and articulate coralline algae with less sediment present. Substrate types did not differ between seasons, there were however differences between sites (Figure 2.16). The sites had reef substrates that were dominated by crustose coralline algae and bare rocks (over 50% in most cases). Sites also contained similar amounts of sand and silt present as sediment (10-20% on average).
2.3.6 Macroalgae and invertebrates communities within macroalgal habitats

The densities of the habitat forming macroalgae were found to be fairly similar between all depths surveyed (Figure 2.17). *Carpophyllum/Cystophora* was found at mean densities of 2 per m\(^2\), *Macrocystis pyrifera* at 1.5 per m\(^2\) and *Ecklonia radiata* at 2.5 per m\(^2\). The density of macroalgal community within each macroalgal habitat was greatest within the shallow *Carpophyllum/Cystophora* habitat (9 per m\(^2\)) compared to *M. pyrifera* kelp forest (5 per m\(^2\)) and deep *E. radiata* beds (4 per m\(^2\)) (Figure 2.18). Multivariate analysis revealed significant differences between macroalgal communities at the three habitats surveyed (PERMANOVA Pseudo F\(_{2, 150}\) = 20.655 P (perm) = 0.001). See Appendix I for pairwise comparisons.

The mean density of invertebrates found within the three macroalgal habitats were fairly similar (Figure 2.19), with *Carpophyllum/Cystophora* having slightly lower densities of benthic invertebrates (0.8 per m\(^2\)) compared to *Macrocystis pyrifera* kelp forest and *Ecklonia radiata* beds which were similar (1.1 per m\(^2\)). Multivariate analysis reveals significant differences between invertebrate assemblages in macroalgal habitats (PERMANOVA Pseudo F\(_{2, 150}\) = 3.119 P (perm) = 0.003) with greater abundance and diversity of invertebrates found in the *M. pyrifera* kelp forest and *E. radiata* beds than in *Carpophyllum/Cystophora* beds. See Appendix I for pairwise comparisons.

2.3.7 Macroalgal and invertebrates community seasonality

The density of macroalgal communities was observed to be fairly similar throughout seasons, with greatest densities observed in spring (7 per m\(^2\)) and least during summer (5 per m\(^2\)) (Figure 2.20). Significant differences were found between macroalgal community density and species composition between seasons (PERMANOVA Pseudo F\(_{3, 149}\) = 2.6834 P (perm) = 0.001) with significant differences found between spring and summer. See Appendix I for pairwise comparisons.

The density of benthic invertebrates found during the surveys varied among seasons (Figure 2.21). The greatest density of invertebrates was found during autumn (1.8 per m\(^2\)) and least during summer (<0.5 per m\(^2\)). Multivariate statistical analysis revealed significant differences in invertebrate assemblages among seasons (PERMANOVA Pseudo F\(_{3, 149}\) = 7.1231 P (perm) = 0.001). See Appendix I for pairwise comparisons.
2.3.8 Macroalgal and invertebrate communities within survey sites

The densities of macroalgal communities within survey sites were similar among four of the five survey sites (Butterfly Bay, Puketeraki, Brinns Point and Omimi) at around 7 per m$^2$ (Figure 2.22). Multivariate analysis of macroalgal assemblage reveals significant differences in macroalgal community among sites (PERMANOVA Pseudo F$_{4,148}$ = 3.4949 P (perm) = 0.001) with sites situated on points having different macroalgae communities to bay sites. See Appendix I for pairwise comparisons.

Benthic invertebrate density within survey sites was observed to be similar between three of the five sites (Butterfly Bay, Puketeraki and Brinns Point); two sites were found to have greater invertebrate density (Matainaka and Omimi) (>1.5 per m$^2$). Multivariate analysis using PERMANOVA revealed significant differences between sites (Pseudo F$_{4,148}$ = 3.1352 P (perm) = 0.018). See Appendix I for Pairwise comparisons.
Table 2.2. Mean abundance, standard error and total counts of reef fish species encountered during the combined surveys within the East Otago Taiāpure.

<table>
<thead>
<tr>
<th>Species</th>
<th>Mean</th>
<th>Standard Error</th>
<th>Count (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Latridopsis ciliaris</em></td>
<td>2.27</td>
<td>0.42</td>
<td>347</td>
</tr>
<tr>
<td><em>Latris lineata</em></td>
<td>0.17</td>
<td>0.06</td>
<td>26</td>
</tr>
<tr>
<td><em>Parapercis colias</em></td>
<td>0.95</td>
<td>0.20</td>
<td>146</td>
</tr>
<tr>
<td><em>Pseudophycis bachus</em></td>
<td>0.04</td>
<td>0.03</td>
<td>6</td>
</tr>
<tr>
<td><em>Odax pullus</em></td>
<td>0.08</td>
<td>0.03</td>
<td>13</td>
</tr>
<tr>
<td><em>Notolabrus fucicola</em></td>
<td>1.97</td>
<td>0.22</td>
<td>302</td>
</tr>
<tr>
<td><em>Notolabrus celidotus</em></td>
<td>2.65</td>
<td>0.28</td>
<td>406</td>
</tr>
<tr>
<td><em>Pseudolabrus miles</em></td>
<td>0.12</td>
<td>0.04</td>
<td>19</td>
</tr>
<tr>
<td><em>Notolabrus cinctus</em></td>
<td>0.04</td>
<td>0.03</td>
<td>6</td>
</tr>
<tr>
<td><em>Parika scaber</em></td>
<td>0.06</td>
<td>0.02</td>
<td>9</td>
</tr>
<tr>
<td><em>Aplodactylus arctidens</em></td>
<td>0.01</td>
<td>0.01</td>
<td>1</td>
</tr>
<tr>
<td><em>Nemadactylus macropterus</em></td>
<td>0.02</td>
<td>0.01</td>
<td>3</td>
</tr>
<tr>
<td><em>Ruanoho decemdigitatus</em></td>
<td>0.51</td>
<td>0.07</td>
<td>78</td>
</tr>
<tr>
<td><em>Forsterygion varium</em></td>
<td>0.37</td>
<td>0.09</td>
<td>56</td>
</tr>
<tr>
<td><em>Obliquichthys maryannae</em></td>
<td>0.37</td>
<td>0.17</td>
<td>56</td>
</tr>
<tr>
<td><em>Notoclinops caurulepunctus</em></td>
<td>0.12</td>
<td>0.03</td>
<td>18</td>
</tr>
<tr>
<td><em>Ruanoho whero</em></td>
<td>0.02</td>
<td>0.01</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total fish observed</strong></td>
<td></td>
<td></td>
<td><strong>1495</strong></td>
</tr>
</tbody>
</table>
Figure 2.4. Mean abundance of reef fish species per 3 min stationary visual transect (3 min SVT) from three macroalgal habitats (shallow (0-3 metre depth) *Carpophyllum/ Cystophora* spp., mid (3-10 m) *M. pyrifera* kelp forest and deep (10-15 m) *E. radiata*). Error bars represent +/- one standard error of the mean (n = 3). Different letters indicate significant differences between macroalgal habitats.

Figure 2.5. Principal coordinates (metric MDS) ordination (PCO) of all reef fish surveys from three macroalgal habitats (shallow *Carpophyllum/Cystophora* spp., mid-depth *Macrocystis pyrifera* kelp forest and deep *Ecklonia radiata* beds within the East Otago Taiāpure. Red circles indicate separation of data; according to those surveys, which contained spotties (top) and those that did not.
Figure 2.6. Mean abundance of reef fish species in size classes per 3min stationary visual transect (3min SVT) of (a) blue moki (L. ciliaris), (b) blue cod (P. colias) and (c) trumpeter (L. lineata) found between three macroalgal habitat forming species (shallow (0-3 m) C. flexuosum/Cystophora spp., mid M. pyrfera (3-10 m) and deep (10-15 m) E. radiata. Error bars equal +/- one standard error of the mean (n = 3).
Figure 2.7. Mean abundance of reef fish species in size classes per 3 min stationary visual transect (3 min SVT) of (d) greenbone (\textit{O. pullus}), (e) banded wrasse (\textit{N. fucicola}) and (f) spotty (\textit{N. celidotus}) found between three macroalgal habitat forming species (shallow (0-3 m) \textit{Carpophyllum/Cystophora} spp., mid \textit{M. pyrifera} (3-10 m) and deep (10-15 m) \textit{E. radiata}). Error bars equal +/- one standard error of the mean (n = 3).
Figure 2.8. Mean abundance of cryptic triplefin species (*O. maryannae*, *R. decemdigitatus*, *N. segmentatus*, *R. whero* and *F. varium*) per 3-minute stationary visual transect (3 min SVT) found between three macroalgal habitat forming species (shallow (0-3 m) *C. flexuosum*/*Cystophora* spp., mid *M. pyrifera* (3-10 m) and deep (10-15 m) *E. radiata*). Error bars equal +/- one standard error of the mean (n = 3).

Figure 2.9. Mean abundance of reef fish per season from winter (7/08/09), spring (23/10/09), summer (28/01/10) and autumn (8/04/10). Error bars represent +/- one standard error of the mean (n = 9). Letters indicate significant differences between mean abundance of fish per season.
Figure 2.10. Mean abundance of reef fish surveyed seasonally: (a) winter 7/08/09, (b) spring 23/10/09, (c) summer 28/01/10 and (d) autumn 8/04/10. At three depths (dots from shore to right of page) shallow *C. flexuosum/Cystophora* (0-3 m), mid *M. pyrifera* kelp forest (3-10 m) and deep *E. radiata* (10-15 m) From five sites within the East Otago Taiāpure. As from top to bottom on map on graphs: Matainaka, Butterfly Bay, Puketeraki, Brinns Point, Omimi. The larger size of circle the greater the mean abundance of fish per (3 min SVT) as seen in (e). Circles with no fill equal zero, or very low mean abundances of fish.
Figure 2.11. Mean abundance of reef species per 3 min stationary visual transect (3 min SVT) surveyed seasonally from winter 7/08/09 to autumn 8/04/10. Of (a) blue moki (*L. ciliaris*), (b) blue cod (*P. colias*) and (c) trumpeter (*L. lineata*). Error bars represent +/- one standard error of the mean (n = 9).
Figure 2.12. Mean abundance of reef species per 3 min stationary visual transect (3 min SVT) surveyed seasonally from winter 7/08/09 to autumn 8/04/10. Of (d) greenbone (*O. pullus*), (e) banded wrasse (*N. fucicola*) and (f) spotty (*N. celidotus*). Error bars represent +/- one standard error of the mean (n = 9).
Figure 2.13. Mean abundance per 3 min stationary visual transect (3 min SVT) of combined cryptic triplefin species (*O. maryannae, R. decemdigitatus, N. segmentatus, R. whero* and *F. varium*) surveyed seasonally from winter 7/08/09 to autumn 8/04/10. Error bars represent +/- one standard error of the mean (n = 9).

Figure 2.14. Mean abundance of reef fish species per 3 min stationary visual transect (3 min SVT) between five sites within the East Otago Taiāpure from combined seasons from 7/8/09 to 8/04/10. Error bars represent +/- one standard error of the mean (n = 3). Letters indicate statistically significant difference found between sites.
Figure 2.15. Percentage (%) cover of crustose coralline algae (cca), articulate coralline algae, bare rock, sand/silt/sediment, turfting red and encrusting sponge species from three macroalgal habitats (shallow (0-3 m) *C. flexuosum/Cystophora* spp, mid (3-10 m) *M. pyrifera* and deep (10-15 m) *E. radiata* bed) within the East Otago Taiāpure (n = 3).

Figure 2.16. Percentage (%) cover of crustose coralline algae (cca), articulate coralline algae, bare rock, sand/silt/sediment, turfting red and encrusting sponge species from five sites (Matainaka, Butterfly Bay, Puketeraki, Brinns Point and Omimi) within the East Otago Taiāpure (n = 9).
Figure 2.17. Mean density per metre squared (m$^2$) of the habitat forming macroalgal species (C. flexuosum/Cystophora spp., M. pyrifera kelp forest and E. radiata) at three depths shallow (0-3 metres depth), mid (3-10 m) and deep (10-15 m) from all sites and seasons surveyed. Error bars represent +/- one standard error of the mean (n = 3).

Figure 2.18. Mean density of all macroalgal species per square metre (m$^2$) within shallow (0-3 metres depth) C. flexuosum/Cystophora, mid (3-10 m) M. pyrifera and deep (10-15 m) E. radiata over four seasons and from five sites within the East Otago Taiāpure. Error bars represent +/- one standard error of the mean (n = 3). Letters indicate significant difference between habitats.
Figure 2.19. Mean density per square metre (m$^2$) of combined sessile invertebrate species from three macroalgal habitats (C. flexuosum/Cystophora spp., M. pyrifera kelp forest and E. radiata) from five sites over four seasons within the East Otago Taiāpure. Error bars represent +/- one standard error of the mean (n = 3).

Figure 2.20. Mean density per square metre (m$^2$) of combined macroalgal species encountered within the quadrat surveys from all sites surveyed within the East Otago Taiāpure. Error bars represent +/- one standard error of the mean (n = 9). Letters indicate significant difference between seasons.
Figure 2.21. Mean density per square metre (m$^2$) of combined sessile invertebrates species found within the quadrat surveys per season (winter 7/08/09, spring 23/10/09, summer 28/01/10 and autumn, 8/04/10) from five sites and three macroalgal habitats within the East Otago Taiāpure. Error bars represent +/- one standard error of the mean (n = 9). Letters indicate significant differences found between seasons.

Figure 2.22. Mean density per square metre (m$^2$) of combined macroalgal species encountered within the quadrat surveys from all seasons’ surveys within the East Otago Taiāpure. Error bars represent +/- one standard error of the mean (n = 9). Letters indicate significant difference between sites.
2.4 Discussion

Communities of fish, macroalgal and benthic invertebrates observed within the East Otago Taiāpurū are typical of southern New Zealand, which is characterised by the absence of warm-temperate species found in northern N. Z. Reef fish species such as wrasse *Notolabrus celidotus*, *Notolabrus fucicola*, blue cod *Parapercis colias* and moki *Latridopsis ciliaris*, which are dominant southern species, were observed in greatest abundance during this study. Distinct patterns of abundance, distribution, diversity and macroalgal habitat preference were evident from analyses of the 2009-2010 surveys. Macroalgal abundances were dependent on depth, with greater abundances of fish found within deep *Macroystis pyrifera* kelp forest and *Ecklonia radiata* beds. The abundance and diversity of reef fish varied substantially between seasons, with summer having the highest and winter the lowest fish abundance and diversity. Survey sites with highest abundances of fish supported extensive kelp forests and benthic invertebrate densities. Several fish species demonstrated close habitat associations that appear to be strongly linked to environmental processes and location, particularly the density and extent of dense macroalgae and substrates conducive to macroalgal growth.
2.4.1 Associations between reef fish and macroalgal habitats

Upon most temperate reefs worldwide, the biotic and physical habitats influence the distribution, abundance and diversity of associated organisms (Underwood and Fairweather 1989). Reef habitats are usually comprised of discrete islands of suitable habitat, represented by great variation in macroalgal communities with depth, which are separated by large areas of unsuitable habitats. Studies have demonstrated that quality and quantity of suitable habitat are the driving factors that influence the distribution patterns and habitat associations of reef fish during larval settlement as well as juvenile and adult phases (Jones 1984a, Choat and Ayling 1987, Menge and Olsen 1990, Carr 1991, Holbrook et al. 1994, Levin and Hay 1996, Curley et al. 2002, Anderson and Millar 2004, Figueira and Crowder 2006, Perz-Matus and Shima 2010). Most temperate reefs possess extensive lush growths of canopy-forming macroalgal species such as *Macrocystis pyrifera* and understorey species such as *Ecklonia radiata* (Schiel 1990). In most areas the relationship between algal structure and fish assemblages is well documented; species relationships generally exist within specific habitat forming macroalgal species (Levin 1993, Carr 1994, Anderson 1994, Anderson and Millar 2004).

Reef fish assemblages of the East Otago Coastline show clear macroalgal habitat preferences with the greatest abundances of fish species found within *Macrocystis pyrifera* kelp forest and *Ecklonia radiata* beds. Very few fish were observed within shallow *Carpophyllum flexuosum* and *Cystophora* spp. beds. There were significant differences found in reef fish abundance between *M. pyrifera* kelp forest, *E. radiata* beds and shallow *C. flexuosum* and *Cystophora* spp. Differences were also observed between the dominant reef species moki (*Latridopsis ciliaris*), blue cod (*Parapercis colias*), Trumpeter (*Latris lineata*), wrasse *Notolabrus fucicola*, *Notolabrus celidotus* and cryptic species *Obliquites maryannae* and *Ruanoho decemdigitatus*; which were most abundant within the *M. pyrifera* and *E. radiata* habitats. This suggests that tight associations exist between the common reef fish species and deeper macroalgal habitats. Spotties (*N. celidotus*) and some cryptic triplefin species were the only species observed at similar abundances within *C. flexuosum* and *Cystophora* spp. habitat. Greenbone (*Odax pullus*) was also the only species found in greater abundance within shallow habitats than in the deeper habitats.
Previous studies of reef fish habitat preferences in New Zealand have focused on macroalgal habitat associations of fish found around Auckland (Choat and Ayling 1987, Anderson and Millar 2004) and Wellington (Perez-Matus and Shima 2010). This study was based in southern New Zealand, where macroalgal habitats are different to northern New Zealand. For example, a typical northern macroalgal community depth profile might include: 0-1 m deep *Xiphophora chondrophylla* dominated, 1-2 m *Carpophyllum maschalocarpum*, with large extensive barrens grazed by urchins (*Evechinus chloroticus*) and algal turf (coralline, *Delia* spp. etc). From 5-20 m kelps such as *E. radiata* and in some cases stands of *Carpophyllum flexuosum* dominate (Choat and Schiel 1982). In southern New Zealand, a typical moderately exposed depth profile could include macroalgal species: 0-1 m depth *Xiphophora gladiata, Cystophora torulosa* and *Dictyota kunthii* dominates; at 1-3 m *Carpophyllum flexuosum, Cystophora scalaris, Cystophora retroflexa* and *Marginariella urvilliana*. At 3-10 m *Macrocystis pyrifera* kelp forest dominates and from 10-20 m Ecklonia *radiata* is dominant with a mixture of corallines, filamentous reds and sponges (pers obs).

One of the most likely reasons for differences in reef fish assemblages among macroalgal habitats is water depth. Macroalgal species are limited in distribution due to biotic and abiotic characteristics that are associated with water depth such as light limitation, exposure to water motion, nutrient limitation etc. The macroalgal habitats surveyed in this study, occur within distinct depth bands, with *Carpophyllum flexuosum* and *Cystophora* spp. occupying a narrow depth range from the low water neap tide, while large kelps *Macrocystis pyrifera* are dominant in depth bands from 3-10 m and *Ecklonia radiata* dominates from 10-15 m. This profile is prevalent on the East Otago Coastline (per obs). Pervious studies have shown how the abundance and diversity of fish are affected by depth and exposure of habitat in northern New Zealand (e.g. Choat and Ayling 1987, Meekan and Choat 1997, Brook 2002 and Anderson and Millar 2004); northern Pacific (California) (e.g. Carr 1989, Levin and Hay 1996) and tropical reefs (e.g. Roberts and Ormond 1987, Friedlander and Parrish 1998). Reef topography also played a role with reef fish assemblages generally having strong relationships to water depth, due to the greater protection and complexity provided by caves, overhangs and guts (Kingsford 1989; Vacchi et al. 1998; Hyndes and Lavery 1999; Anderson and Millar 2004). In this study we found that there was no significant difference between the fish assemblages found in either *M. pyrifera* kelp forest or *E radiata* beds. It was also found that there was a significantly greater diversity of fish species found at deeper habitats in comparison with shallow areas. However it is also thought that the effects of water depth upon macroalgal habitat and reef topography are not acting alone in the distribution of fish assemblages.
Another possible explanation of this depth pattern of fish abundance, involves fundamental differences in feeding and foraging habits of common reef fish species; which is suggested by Choat and Ayling (1987) and Anderson and Millar (2004). Fish species such as moki (*Latridopsis ciliaris*), blue cod (*Parapercis colias*), banded wrasse (*Notolabrus fucicola*) and spotties (*Notolabrus celidotus*) are all known to be generalist predatory fish, feeding primarily on benthic invertebrates such as bivalves, crustaceans and gastropods (Russell 1983, Francis 2001). Although these species all have slightly different feeding niches and prey species upon which they specialise (Russell 1983) most prey items such as mussels (*Aulacomya atra maoriana*), crabs (*Leptomithrax longimanus*) and amphipods are found within *Macrocystis pyrifera* kelp forest and *Ecklonia radiata* beds (Richards 2010). For herbivorous species such as greenbone (*Odax pullus*) *M. pyrifera* and *E. radiata* are thought to provide important sources of food; but algal species with shallower distributions such as *Marginariella urvilliana* and *Carpophyllum flexuosum* are thought to be the preferred food source (Clements and Choat 1993).

There are many other possible mechanisms explaining differences in fish assemblages. One such mechanism may include the natural differences in density and morphological structures associated with the three-macroalgal habitats surveyed. The shallow *Carpophyllum flexuosum* and *Cystophora* spp. macroalgal habitat was found to have the greatest density with over 9 plants per m². The morphology of these dominant species is of a finely branched nature (Figure 1.2) with many places for the attachment of prey species (Taylor and Cole 1994) and places for juvenile fish to hide (Francis 2001). The pattern in this study, where very few juvenile fish and triplefin species (*Forsterygion lapillum*, *Forsterygion varium* etc) were observed, could be due to the dense and finely branched nature of this habitat, providing places to hide from divers during the transect.

Within *Macrocystis pyrifera* kelp forests, complex three-dimensional biogenic structuring to the water column exists (Anderson and Millar 2004). Several studies have found that large dense kelp forests positively correlate to the density, abundance and diversity of newly recruited and adult reef fishes (e.g. Dayton 1985, Choat and Ayling 1987, Bodkin 1988, Carr 1989, Andrews and Jones 1990, Demartini and Roberts 1990, Holbrook *et al.* 1990, Carr 1991, Anderson 1994, Carr 1994, Levin and Hay 1996, Paddock and Estes 2000, Ruitton *et al.* 2000, Perez-Matus and Shima 2010); thus these structures provide habitat complexity, ample food sources and protection from predators, especially for juvenile fish, by modifying predation pressure as a result of the refugia and camouflaging nature of macroalgae (Connell and Jones 1991, Hixon and Beets 1993, Caley and St John 1996,
Beukers and Jones 1997, Tupper and Boutilier 1997, Steele 1999, Johnson 2006). These patterns are confirmed in this study with the complexity, density and three-dimensional structure offered by macroalgal species providing ample habitat for fish species.

2.4.2 Seasonal patterns of reef fish

There was strong seasonal variation in abundance of individual fish species and the communities as a whole. Patterns included decreased numbers for all species during winter and increases during spring, with maximum abundances during summer and decreasing again during autumn. Several studies in New Zealand specifically (e.g. Francis 1981a, Choat et al. 1988, McCormick 1989, Cole et al. 1992, Franklin 1999, Brook 2002, Denny 2005) and around the world (Schmitt and Holbrook 1986, Ebeling et al. 1990, Holbrook et al. 1994, Holbrook et al. 1997, Schafer et al. 2002) have found seasonality in reef fish community abundances. The abundance of large fish species declined during winter while a few species were found in consistent numbers throughout the year, which include the wrasses *Notolabrus celidotus* and *Notolabrus fucicola* and smaller moki (*Latridopsis ciliaris*). Blue cod (*Parapercis colias*) exhibited the greatest decline in abundance during winter, when very few were encountered.

The patterns of abundance among fish species suggest seasonal migration and movements offshore, possibly to spawn during winter. Blue moki (*Latridopsis ciliaris*) showed a clear pattern of seasonal abundance where large breeding adult fish (40 cm +) (Francis 1981b) were completely absent during winter and autumn and only a few were observed in spring existing in highest abundance during summer. However, non-breeding schooling sized (>40 cm) individuals were found in consistent numbers throughout the seasons, peaking during spring and not summer like most other species. *Latridopsis ciliaris* fish classed as juveniles (>10 cm) were only observed during summer, suggesting recruitment events occur during spring. These patterns of abundance are supported by Francis (1981a,b), who studied the spawning migrations of adult moki, whereby large fish caught in the commercial fishery were all ripe breeding fish around Gisborne and Napier during winter with pulses of large fish caught in Wellington and Kaikoura during autumn. These fish were assumed to be migrating northwards during autumn to breed and returning south during late winter and spring to feed in the summer months. Additionally, if spawning occurred in winter, larvae are thought to spend 8-12 months in the plankton (Francis 2001) and recruitment of juveniles to reefs should occur in late winter to spring onto reef areas. This is consistent with what is observed in this study. A study by Francis (1981b) found that maturity of moki
occurred at ~40 cm length and at an age of 5-6 years. Small immature fish were also observed to be resident fish, found year round in areas such as Kaikoura and further south.

Blue cod were observed in greatest abundance during summer with most fish at 10-25 cm, and very few larger fish (>25 cm) observed during surveys. Large legal sized fish (>33 cm) were found only during summer and juveniles were not observed at all during the surveys. *Parapercis colias* were absent from the reefs surveyed during winter and returned during spring. These patterns of abundance can be explained by offshore migration, thought to occur for spawning and feeding during winter (Carbines 2004). Spawning is thought to occur in deeper coastal and outer shelf waters from late winter to early summer (Francis 2001). Furthermore, juveniles appear during January and February in waters deeper than 15 m (Francis 2001). This depth was not surveyed during this study possibly explaining the absence of juveniles. The dominance of smaller size classed fish, which are below the recreational size limit for this species, could explain the lack of larger fish in this study. The Taiāpure has high fishing pressure from recreational fisheries in which *P. colias* are the main target species. During the summer months it is not uncommon to observe up to 5 boats fishing within the Taiāpure, which represents significant recreational fishing pressure.

The herbivorous fish species greenbone (*Odax pullus*) was observed in low abundances throughout all the seasons, with slightly greater mean abundance of brown females found during spring and summer, with very few large blue males and juveniles observed throughout the year. Adult *Odax pullus* feed upon brown algae in a diet consisting of ~80% fucoids and laminarians (Clements and Choat 1993, Skea *et al.* 2005, Taylor and Schiel 2010). Studies suggest that *O. pullus* is resident upon reef areas year round, feeding upon similar algal species year round (Clements and Choat 1993). Greenbone are also serial spawners close to reef areas with males defending territories in which females reside. The larvae of *O. pullus* have a relatively short planktonic stage settling in shallow turbulent macroalgal habitats (1-2 m) (Francis 2001). The life history, feeding habits and patterns found during this study suggest this species is resident year round upon the east Otago coastline, but only found in low abundance in the habitats surveyed during this study. Greenbone would possibly be found in areas of greater wave exposure with abundant bull kelp *Durvillaea* spp, and *Marginariella* spp.

Banded wrasse (*Notolabrus fucicola*) were found at high abundances for fish in both the initial and terminal phases throughout the year. There was, however, a drop in initial phased fish during winter and autumn, which suggests colour change during summer and
autumn to terminal phased individuals. The life history and habitat preferences of this species suggests fish are resident upon reefs year round with individuals spawning during winter to spring close to reef and defending territories year round. Juveniles are thought to settle in dense macroalgae (Denny and Schiel 2002, Harwood and Lokman 2006). No fish classed as juveniles were encountered in this habitat during the study, possibly due to difficulties of locating them (Willis 2001).

The small wrasse Spotty (*Notolabrus celidotus*) was present year round in consistent abundance for the initial phased fish during spring, summer and autumn, only decreasing in abundance during winter. The abundance encountered was lower than expected during this study compared to other studies in northern New Zealand such as Anderson and Millar (2004). *Notolabrus celidotus* are generalist in habitat preferences and feeding ecology, found in great abundances throughout New Zealand over rocky reefs as well as within harbours and estuaries (Jones 1984a,b). The life history of this fish also suggests residence upon reefs year round, with terminal phased males defending territories and fish spawning close to reefs with recruitment within shallow dense macroalgae (Jones 1984a,b).

### 2.4.3 Spatial patterns of reef fish on the east Otago coast

The pattern of reef fish abundance was fairly similar between three of the five survey sites, with similar mean abundances of fish at Matainaka, Puketeraki and Brinns Point. Butterfly Bay and Omimi had significantly lower abundances of fish compared to Brinns Point. These patterns of abundance could be confounded by the fact that Matainaka was only surveyed twice (winter and summer) as well as Omimi, which was not surveyed in summer. This could lead to significant differences being found among sites when in reality they may not be. Matainaka was a survey site, that had far greater abundances of reef fish in summer compared to any other sites.

The patterns of reef fish assemblages suggest a clear seasonality among sites with other possible influences such as fishing pressure, complexity of reef topography, availability of food sources, as well as quantity and quality of macroalgal habitats. Butterfly Bay and Omimi are both bays whereas Puketeraki, Matainaka and Brinns are all points. The two sites within bays had lower abundances of fish, which could be directly associated to the poor habitat quality associated with bays. The sites situated on points are exposed to greater currents and would be considered to contain better quality habitats, which in turn has greater food sources. Butterfly Bay is a survey site that may be affected by higher localised fishing pressure; this site is close to the Karitane estuary mouth where small boats from Karitane...
village fish in the relatively sheltered area provided by the Huriawa Peninsula. High complexity of reef topography is observed at the sites of Matainaka and Puketeraki, which possess a complex series of reef outcrops and guts, which are found in 15 m of water to just 5 m from the surface (pers. obs.). These areas provide ideal areas in which fish can rest with ample prey items to be found upon reef surfaces, guts, overhangs and caves. A site that could be considered to have good quantity and quality of macroalgal habitat would be Brinns Point. This site has dense *Macrocystis pyrifera* kelp forest off shore, sloping off to deeper water over 15 m in depth. It also is upon a point, that is exposed to greater currents, supplying nutrients and food sources to fish.

### 2.4.4 Diversity of reef fish assemblages among macroalgal habitats, seasons and sites

The diversity of fish assemblages increased with depth of macroalgal habitat. This pattern suggests that there is more diversity of fish in the deeper habitats compared to shallow *Carpophyllum flexuosum* and *Cystophora* spp. beds, which is expected with the greatest abundances of fish found in deeper habitats and smaller abundances in shallow areas. Seasonal patterns in fish diversity were different between winter and all other seasons and summer and autumn. Diversity of species was greatest in summer and lowest during winter. Site differences in reef fish diversity were complex in nature, with analysis revealing significant differences between Butterfly Bay and Brinns Point as well as between Brinns Point and Omimi. This pattern is a result of differences in the average abundance of fishes between sites, where Brinns had significantly greater mean abundances of fish. This suggests that Omimi and Butterfly Bay differ due to the altered habitat types associated with bays versus points.

The diversity of fish species were related to the abundance of fish encountered within habitats, seasons and sites, with the greatest abundances of fish having the greatest diversity of fish species. At these sites rare fish species such as *Pseudolabrus miles*, *Notolabrus cinctus*, *Parika scaber*, *Odax pullus*, *Parapercis bachus*, *Nemadactylus macropterus* were more likely to be encountered when high overall abundances of common reef fish were encountered.
2.4.5 Substrate characteristics

The characteristics of the substrate associated with macroalgal habitats was fairly typical of temperate rocky reefs around the world, with coralline species in crustose and articulate forms dominating the cover of rocks and reef (Dayton 1985). The amount of sand and sediment cover seemed to be nominal, with small areas between rocks and boulders. Bare rock was also a considerable component, which could be a result of high grazing pressure from gastropods, wave action and fluctuating sediment loads and light levels. Substrate type didn’t show any correlation to macroalgal density or abundance of fishes within habitats, as similar patterns of percent coverage are found throughout the macroalgal communities. Percent cover did not change seasonally either but there could be longer-term temporal trends.

2.4.6 Macroalgal community patterns within three macroalgal habitats, seasonality and sites differences

Patterns of macroalgal habitat forming species showed clear density patterns of species within each habitat. *Carpophyllum flexuosum*, *Cystophora* spp. had the greatest mean density in shallow areas and *Ecklonia radiata* had the greatest density in deep water. Within the mid depth habitats *Macrocystis pyrifera* was found only in slightly higher abundance than *E. radiata*. The possible explanation for low density of *M. pyrifera* is that it is a canopy forming species upon the water’s surface, whereas *E. radiata* forms a subcanopy, which was found between the large *M. pyrifera* stipes. *Ecklonia radiata* can grow high densities in its preferred habitat. *Macrocystis pyrifera* has been found to shade understory species such *E. radiata* (Reed and Forster 1984), which is also found at water depths deeper than *M. pyrifera* kelp forests, subsisting in low light conditions.

The patterns of macroalgal community density and composition were different among macroalgal habitats, seasons and sites. Variable patterns existed between the habitats with the composition of macroalgal communities changing between depths. Changes throughout seasons were expected, with annual species such as *Desmarestia ligulata* and juvenile macroalgal species often appearing and growing during late winter and spring and senescing (loss of tissues) during summer and autumn or being damaged by large storms in autumn and winter (pers obs.). Site differences in macroalgal density and composition may be due to differences in exposure to waves, currents and reef topography among sites; with some supporting higher quality habitat.
2.4.7 Invertebrate communities patterns within macroalgal habitat, season and site.

Invertebrate communities differed in density and composition between macroalgal habitats and sites but not seasonally. Macroalgal habitat differences can be explained by ease of access to food sources (e.g. Paua *Haliotis iris* grazers) and availability of prey (e.g. *Astrostole scabra*). These two species are important grazers and predators of algae and invertebrates in the subtidal environments on the East Otago coastline (Richards 2010). The quality and quantity of substrates and topography of reef habitats upon which they reside can also explain site differences between benthic invertebrates. Seasonal differences in community structure are not so easily explained and could be due to the highly variable nature of invertebrate assemblages and differences in surveying periods of some sites. For example, two sites (e.g. Matainaka and Omimi), which had high densities of invertebrate species, were not surveyed in every season.

2.4.7 Conclusions

A greater abundance and diversity of reef fish was observed in *Macrocystis pyrifera* and *Ecklonia radiata* habitats compared to the shallow *Carpophyllum flexuosum* and *Cystophora* beds. No significant differences were found between *M. pyrifera* and *E. radiata* beds suggesting habitats are homogeneous in relation to the populations of fish found in kelp forests and along their edges. These two macroalgal habitats are clearly crucial to fish assemblages and should be protected from sedimentation and harvesting of kelp, two major threats posed to East Otago Taiapure.

Each reef fish species had differing patterns of abundance. Some species had close associations with habitat, while others were found throughout all macroalgal habitats. Fish species such as *Latridopsis ciliaris*, *Parapercis colias* and *Latris lineata* show tight association with the deeper *Macrocystis pyrifera* and *Ecklonia radiata* habitats. The only species that did have tight association with the shallow habitats was *Odax pullus*, which was predominantly found in the shallow habitat, but in low abundances. The wrasses *Notolabrus celidotus* and *Notolabrus fucicola* showed preferences for deeper habitats but were also found in shallow areas at lower abundance. Cryptic triplefin species showed a pattern of steady increase in abundance with increasing depth.

Very few juveniles reef fish were encountered in all habitats. This could be due to the survey methodology whereby divers were not looking intensely enough through the dense finely branched macroalgae; but could also indicate the importance of *Macrocystis pyrifera*
canopies for juveniles and cryptic fish species as a habitat, with greater protection from wave action, availability of food sources and protection from predators.

The seasonal patterns of fish abundance showed a clear pattern of greatest abundance in summer and least in winter. These patterns can be explained by the specific fish species life histories and movements offshore to deeper waters during the winter to feed. The specific patterns of fish species were complex. Moki (*Latridopsis ciliaris*) was very much size class orientated with smaller sized individuals found year round; larger fish were only present in spring, summer and autumn with greatest abundance during summer. Blue cod (*Parapercis colias*) were only found during spring and summer. Wrasse species *Notolabrus fucicola* and *Notolabrus celidotus* were found year round in consistent numbers.

Site differences were seen, sites with greater fish were Matainaka, Puketeraki and Brinns Point. Butterfly Bay and Omimi, which had generally fewer fish and could be due to differences between geographical locations. Sites were either bays or points with points exposed to greater currents and influx of nutrients and food sources. Localised fishing pressure, the quality and quaintly of habitat as well as reef topography are also thought to play roles in the spatial distributions of reef fish.

The diversity of fish species is significantly different between macroalgal habitats (greater in deeper habitats), seasons (more species found in summer to autumn and less in winter) and sites (greater diversity at Matainaka, Brinns Point and Puketeraki). These patterns followed the pattern of fish mean abundance.

Macroalgal communities differed among macroalgal habitats (changes in assemblage with depth), seasons (greater densities found in spring) and sites (lower density of macroalgae at Matainaka, and Puketeraki). Invertebrate density was found to be similar among habitat, season and site. Greater densities were found in spring and autumn; site differences were found with fewer invertebrates at Butterfly Bay, Puketeraki and Brinns Point compared to Matainaka and Omimi sites. *Macrocystis pyrifera* and *E. radiata* were found to be very similar in invertebrate assemblage.
CHAPTER THREE

Sampling of Epifaunal Assemblages Using Standard Monitoring Units Mimicking Macroalgal and Coralline Cobble Habitats

Seaweed and coralline cobble simulators within shallow *Carpophyllum flexuosum, Cystophora* spp. habitat.
3.1 Introduction

Coastal temperate marine environments are areas of high diversity and primary productivity (Steneck et al. 2002). A complex food web exists that is fuelled by productivity provided by subtidal macroalgal communities (Littler and Murray 1974, Dayton 1985, Duggins & Eckman 1994) and by external inputs of phytoplankton (Verity et al. 1993). Macroalgal communities are thus considered key ecosystem components, providing habitat complexity, protection from predation and valuable food sources on which a great number of organisms rely (Choat and Ayling 1987, Anderson 1994, Johnson 2006). The surfaces of macroalgae provide surfaces that can be heavily colonised by sessile organisms (Hepburn and Hurd 2005) and small mobile invertebrates (Duffy 1990, Vasquez 1993, Taylor and Cole 1994, Duffy and Hay 2000).

3.1.1 Importance of macroalgal communities to epifauna

Epifaunal invertebrates play a number of important ecological roles, including being consumers of macroalgal detritus, planktonic predators, food sources for reef fish and nutrient recyclers (Taylor et al. 1998). Within coastal rocky reef habitats epifauna are extremely abundant on most substrata (macroalgal surfaces, coralline cobbles) (Choat and Kingett 1982, Holbrook and Schmitt 1989, Taylor and Cole 1994). These organisms have high metabolic rates (Edgar and Moore 1986) and fecundity (Bernard 1974) leading to high rates of secondary production in these communities. Epifaunal community characteristics of high abundance and fast growth make them highly productive in coastal macroalgal habitats. Epifauna such as gammarid amphipods have been found to contribute up to 78% of secondary productivity in coastal areas (Taylor 1998). Studies show that epifauna consume a wide range of macroalgal and planktonic foods (Zimmerman 1979, Pederson and Capuzzo 1984, Agnew and Moore 1986, Barlocher and Howatt 1986, Hay et al. 1987, DeLong et al. 1993). Epifauna are also key prey items for small reef dwelling fish species and juveniles (Russell 1983, Jones 1988). Choat and Kingett (1982) found that epifauna made up a significant proportion of the diets of snapper (Pagrus auratus) and goatfish (Upeneichthys porosis). Furthermore newly recruited spotty (Notolabrus celidotus) were found to have fed predominately upon gammarid amphipods and other small mesograzers (Jones 1984b). Temperate reef epifauna are key members of coastal ecosystems because they provide significant pathways along which primary productivity is transferred from macroalgae and phytoplankton to higher trophic levels.
3.1.2 Coralline cobble and seaweed simulators: Standard-monitoring units to quantify epifaunal assemblages

Within temperate coastal marine environments, precise monitoring of small and inconspicuous animals is difficult to achieve. A great number of devices have been designed and used to capture and survey small animals and fish; including diver-guided plankton nets (Brogan 1994), moored nets (Kingsford and Fin 1997), purse seines (Kingsford 1989), plankton pumps (Powlik et al. 1991), visual census (Kingsford and Choat 1989), aggregation devices (baited to attract to collection site) (Victor 1991), light traps (Doherty 1987, Hickford and Schiel 1999) and Standard monitoring units for recruitment of fish (SMURFS) (Ammann 2004). By using these devices a better understanding of community composition of a particular organism can be achieved in differing environments over time. Many studies have focused on the capture of newly settled reef fish species into habitats to better understand the processes that influence recruitment of individuals (Ammann 2004). There are few examples where studies have used such devices to better understand the epifauna that reside within different macroalgal habitats (e.g. Taylor 1998). By borrowing and manipulating the designs of other published studies it was hoped to simulate the substrata and physical habitat structure in which fish and epifaunal communities typically reside. Epifauna live upon substrates such as macroalgae (Hepburn and Hurd 2005) and coralline covered cobbles (Choat and Kingett 1982). By simulating these differing substrates with a standard unit that can be replicated, it was hoped that a better understanding of epifaunal community and abundance could be achieved among macroalgal habitats and throughout spring, summer and autumn. Furthermore by understanding the makeup and abundance of epifauna, a better understanding can be gained of food availability to reef fish species within macroalgae habitats and seasonally.

3.1.3 Objectives

Very few studies have investigated epifaunal communities within temperate macroalgal habitats in New Zealand (Taylor 1998). Most studies concentrate specifically on communities found upon surfaces of seaweed. The present study will investigate if standard monitoring units that simulate crucial habitat forms (coralline cobbles and seaweeds) can be used to quantify important epifaunal communities. The primary objective of this chapter was to describe epifaunal community characteristics within three differing macroalgal communities in Butterfly Bay (Figure 3.1) using standard monitoring units that simulate seaweed and coralline covered cobbles.
A comparison was made to determine differences in epifaunal abundance and diversity among three macroalgal habitats (Carpophyllum flexuosum/Cystophora spp. (0-3 m), Macrocystis pyrifera kelp forest (canopy and sub-canopy) (3-10 m) and Ecklonia radiata beds (10-15 m)) using coralline cobble and seaweed simulators. It was predicted that epifaunal abundance would differ between macroalgal communities, with the greatest abundance of epifauna found within the Macrocystis pyrifera kelp forest canopy and shallow C. flexuosum/Cystophora spp. beds due to accessibility to food sources, morphology of the macroalgae, protection from predators, ease of attachment to substrate and size of colonizers pool.

Seasonal sampling was undertaken to determine changes, which occur in epifaunal community abundance and diversity within the seaweed and coralline cobble simulators. It was predicted that the greatest abundances and diversity of epifauna will be found in spring when food availability is greatest due to macroalgal growth (Brown et al. 1997), plankton blooms (Murphy et al. 2001) and a build up of epifauna numbers during winter due to lower predation by reef fish during winter, when reef fish abundance is least (as observed in chapter 2 fish surveys). It was also predicted that epifauna diversity and abundance will vary throughout the seasons within seaweed simulators due to the highly ephemeral nature of macroalgae, whereas coralline cobble simulators will show a steady increase of abundance and diversity from spring to autumn due to seasoning of the baskets growing diatom films and corallines algae on its surfaces (Edgar 1991).

Two types of simulators were deployed in each habitat to determine epifaunal abundance, diversity and species differences between the macroalgal and coralline cobble associated communities. It was predicted that epifaunal assemblages would differ with respect to simulator type; highly mobile epifaunal species such as gammarid amphipods will be found within the seaweed simulators due to movement of seaweed simulators in the water due to waves (as macroalgae naturally do) and less mobile species sessile species such as gastropods would be found within coralline cobble simulators which are less mobile and susceptible to water motion.

Simulators were also deployed to capture small predatory and juvenile reef fish. It is predicted that the greatest number of small predatory and juveniles fishes will be found with coralline cobble simulators as they are meant to simulate the preferred substrate of coralline turfing algae upon which they reside (Willis and Anderson 2003). Abundance is predicted to increase with depth, lower exposure to water motion (Willis 2001).
Macroalgal species were sampled to determine the actual epifaunal communities found upon the dominant macroalgal species (*Carpophyllum flexuosum*, *Cystophora scalaris*, *Macrocystis pyrifera* and *Ecklonia radiata*) compared to epifauna caught within the coralline cobble and seaweed simulators.

### 3.2 Methods

#### 3.2.1 Description of study site

This study was conducted within Butterfly Bay (45°38′19. 63″S 170°40′14. 82″E), on the northern side of Huriawa Peninsula Karitane, Dunedin, New Zealand. Butterfly Bay is a semi-sheltered rocky bay, which is a mix of boulders, cobbles and sand that extends offshore to around five metres depth before steadily dropping off to deeper water. The bay has dense mixed macroalgal beds from 0 to 15 metres dominated by *Carpophyllum flexuosum*, *Cystophora* spp., *Macrocystis pyrifera* kelp and *Ecklonia radiata*. Seaweed and coralline cobble simulators were deployed within the same three-macroalgal communities that were surveyed in Chapter 2. By surveying epifauna within the same macroalgal habitats as the fish surveys it is hoped to link epifaunal abundance to habitat preferences of reef fish.

**Butterfly Bay study site**

Initially during a pilot study three separate sites within the East Otago Taiāpure were chosen. The sites were situated at the same sites as the fish surveys and included Butterfly Bay, Matainaka, and Big Rock just south of Omimi (Figure 3.1). During the first sampling period a large southeasterly swell occurred and 45 out of 60 seaweed simulators deployed were either lost or destroyed. A decision was made to focus upon one site (Butterfly Bay) as it faced a northerly direction, is sheltered from the predominant southeasterly swells. All simulators were retrieved from this site.

#### 3.2.2 Seaweed simulators design

The seaweed simulators were adapted from those used by Ammann (2004). These were constructed using 60 X 90 cm sections of forest green plastic garden mesh (NYLEX) with 2.5 cm square grid rolled into a cylinder and held together with four plastic cable ties (Figure 3.2 (a)). Each cylinder contained a 1m² piece of used fishery trawl netting (made from polypropylene chord), haphazardly folded and stuffed inside the mesh cylinder, which was closed at either end using a further three cable ties at each end. On each end of the simulator a
loop of the 4 mm monofilament was crimped together, with a small shark clip threaded onto the loop for attachment purposes (Figure 3.2 (b)).

### 3.2.3 Coralline cobble simulators design

Coralline cobble simulators comprised of a plastic 35 cm long by 23 cm wide and 175 cm high open topped handled plastic storage basket (Plastic Box, item No. SC3712); with 5 X 5 mm square grid holes on four sides and the bottom. The open top of the baskets was covered in a piece of 30 X 20 cm; 2.5 cm grid white plastic garden mesh (NYLEX), which was attached to the top using 5 cable ties per side (Figure 3.3). Within the bottom of the baskets five to ten cobbles and rocks encrusted with encrusting coralline algae were placed. On top of the cobbles and rocks a 1m² piece of used fishery trawl netting (the same as used in the seaweed simulators) was inserted (Figure 3.4). By constructing the baskets in this way the simulators would have similar characteristics as turfing coralline community.

The used fishery trawl netting was initially pre-treated to remove any contaminants, by soaking a net bag (containing all netting used in experiment) initially in Butterfly Bay and then within a large tank with running seawater for a total of a month. The seawater used within holding tanks was sourced from a sand filtered well at Shane Flavell's paua farm at Karitane (45°39'3. 73″S, 170°39'14. 45"E). Pre-treating the netting enabled settlement of a diatom bio-film, reducing the amount of time the seaweed and coralline cobble simulators would need to be in the water for colonization of epifauna to occur. Existing biofilms on artificial substrates are thought to promote epifaunal settlement as a food source (Greze 1968, Russo 1988, Edgar 1991).

### 3.2.4 Deployment of seaweed simulators

Deployment of seaweed simulators within each macroalgal community was achieved by attaching a 14 m long benthic lead cored (10 mm diameter) rope looped around a large rock at each end and tied using a bowline secured with large cable ties parallel to shore. At 2 m intervals, two small monofilament trace (4 mm thick) loops were attached by threading the line through the rope and crimped (long-line crimps 3mm inside diameter) together. Each loop was 30 cm apart on the rope, with the seaweed simulator being connected with a small long-line shark clip (Figure 3.2).

Simulators deployed within the *Macrocystis pyrifera* kelp forest canopy were fixed to stipes within the canopy (roughly 1 m from the surface at high tide). This was achieved by forming a loop of soft tree tie wire (NYLEX) around both the seaweed simulator and two kelp stipes. This loop was left slightly loose to avoid damage to the stipe while the simulator was
attached. Replication within 3 macroalgae habitats was 5. Within the *M. pyrifera* canopy replication was 10. This replication was required due to inherent loss of simulators within the kelp forest canopies, due to stipe breakage in periodic wave events.

### 3.2.5 Coralline cobble simulators deployment

Deployment of the coralline cobble simulators was completed at the same time as seaweed simulators. Each coralline cobble simulator was placed no further than 2 metres away from each seaweed simulator within the three-benthic macroalgal communities (Figure 3.4). The coralline cobble simulators were negatively buoyant and were wedged between two rocks to stop movement during large swell events.

### 3.2.6 Seaweed and coralline cobble simulator sampling

Simulators were sampled by a team of six people, two upon the shore (sampling retrieved simulators), one in a kayak (ferrying simulators to and from the shore) and three people in the water (two on SCUBA and one snorkelling). Sampling occurred by a diver enclosing a half metre wide hinged (1 mm square nylon mesh) WIN net similar to the BINKE (Benthic Ichthyofauna Net for Coral/Kelp Environments) net described by Anderson and Carr (1998) (Figure 3.5) quickly around each simulator and closing to stop any animals escaping (Figure 3.6). The seaweed simulators were first enclosed and then detached from the rope; coralline cobble simulators were each flipped into an open net and enclosed. Each seaweed and coralline cobble simulator was then removed from the bottom and handed to a snorkeler who dove down to retrieve the sampled simulator. This occurred in the *Ecklonia radiata* and *Macrocystis pyrifera* habitat deployed simulators. Simulators within the shallow *Carpophyllum/Cystophora* and *M. pyrifera* kelp canopy were sampled by snorkel.

The simulator while still enclosed within the net was then brought back to shore by the Kayak for sampling. To sample the simulators, they were firstly removed from the net and placed in an 80L clear plastic fish tub. Fish and epifauna were washed into the tub by pouring seawater over the simulators while shaking (coralline cobble simulators were shaken upside down with the trawl netting on bottom). Small fish and invertebrates entrapped in the net were also added to the samples. The samples were then washed from the plastic tub into a metal sieve (1 mm mesh size), shaken into labelled plastic bag and placed in a cool bin. Once sampling was complete each simulator was returned to the same macroalgal community it was taken from. Any coralline cobble or seaweed simulators damaged during the period between sampling were replaced with pre-treated new simulators and noted. To quantify the epifaunal assemblages, samples were first separated out in large plastic tray with freshwater
poured over the sample. All epifauna and fish were then removed, counted and identified to the lowest possible taxonomic level (family level for amphipods and species for most other taxa).

3.2.7 Sampling schedule

Sampling of simulators occurred from the 21st of September 2009 until the 23rd of April 2010 when weather and water visibility allowed as good water visibility was needed to locate the simulators. A total of four sampling events occurred, two within spring (early 21/9/09 and late 16/11/09), one during summer (7/1/10) and one during autumn (23/4/10). Approximately two weeks prior to each sampling event ten *Macrocystis pyrifera* kelp forest canopy attached seaweed simulators were deployed. When the last sampling event occurred all simulators were taken back to the lab and deconstructed. This allowed collecting of all grazing invertebrates that were attached to the rocks or fish stuck within the baskets, which may have been missed during the normal sampling process.

![Figure 3.1. Map of the East Otago Taiāpure and the site where seaweed and coralline cobble simulators were deployed. Butterfly Bay, upon the Huriawa Peninsula, Karitane. Also shown upon the map are previous pilot study simulators sampling sites (Matainaka and Big Rock).](image-url)
Figure 3.2. Benthic attached seaweed simulators. Photo (a) illustrating the entire simulator design with green NYLEX garden netting covering outside and trawl netting haphazardly placed inside. Photo (b) shows the attachment point a long lining shark clip attached to a loop of monofilament trace and crimped at the other end). Photo (c) illustrates the attachment point design for the *Macrocystis pyrifera* kelp forest canopy deployed seaweed simulators (with rubber-coated wire that wrap around the kelp stipes).
Figure 3.3. Photos of the coralline cobble simulator design. Photo (a) illustrates the view from above where the 5 to 10 rocks were placed in the bottom and 1 m$^2$ piece of trawl netting placed on the top and cable tied shut. Photo (b) shows a side view of the basket, with white garden netting attached on top by cable ties.

Figure 3.4. Photo of how the coralline cobble and seaweed simulators were deployed; coralline cobble simulators were placed within 2 m of seaweed simulators along the 10 m benthic lead cored rope at 2 m intervals.
Figure 3.5. Photo of the WIN net used to sample the simulators, shown here open with plastic PVC piping around outside, vinyl piping hinges and 1mm grid polyester netting sewn onto frame.

Figure 3.6. Photo of a shallow Carpophyllum/Cystophora benthic rope attached seaweed simulator being sampled by snorkel; by enclosing simulator in the net and detaching the long-line shark clips.
3.2.8 Macroalgal and invertebrate community comparison survey

Sampling of the epifaunal community upon macroalgal species was completed for five different species present near simulators on the 15th of May 2010. The species collected were *Carpophyllum flexuosum* (blades and holdfast), *Cystophora retroflexa* (blades and holdfast), *Macrocystis pyrifera* (top 2 m of meristem at surface leaving base) and *Ecklonia radiata* (blade and holdfast). Five replicates of each were taken. Sample collection methods for *Carpophyllum, Cystophora* and *Ecklonia* were by enclosing each replicate with large sealable plastic bags and chiselling off the holdfast from the rock with a knife. *Macrocystis pyrifera* canopy sampled from the surface in the same way with only the top 2m sampled by cutting the stem with a knife. Back at the lab, seaweed samples were first washed with fresh water and shaken above a large 80 cm diameter 1 mm mesh size sieve where identification and counting occurred. This technique was thought to capture up to 98 % of all epifauna and mesograzers upon the macroalgae being sampled (Poore and Steinberg 1999).

3.2.9 Data analysis

To assess differences in epifaunal composition between seasons, simulator type, macroalgal community, diversity and seaweed species sampled; Permutational Multivariate Analysis Of Variance (PERMANOVA Anderson 2001) was used. PERMANOVA uses a permutation procedure to assess significance, and does not rely on the assumption of multivariate normality, which is frequently violated by ecological data and cannot be properly tested. Analyses were conducted on square root transformed data, to reduce the influence of highly abundant taxa. Analysis was carried out using Bray-Curtis similarity index. Pair wise tests were performed if significant differences were found within the PERMANOVA analysis. To present any differences visually principal coordinates (metric MDS ordination) (PCO) was used. To access differences in diversity between simulators, a Shannon Weavers index was performed on a Bray Curtis similarity of all data. A PERMANOVA was then performed on Euclidian distances similarity to access differences in diversity.
3.3 Results

3.3.1 Epifaunal communities on Coralline cobble and seaweed simulators

Within the three-macroalgal communities, coralline cobble simulators contained a slightly greater mean abundance of epifaunal species compared to seaweed simulators (Figure 3.7). However within the *Macrocystis pyrifera* kelp canopy, the mean abundance of epifauna was far greater than found in any other simulator. Epifauna in the *Macrocystis* canopy were dominated by gammarid amphipods (Figure 3.8) with over 450 per simulator found in the early spring (21/9/09). A significant difference was found between coralline cobble and seaweed simulators (pseudo $F_{1,100} = 44.331$ P (perm) = 0.001). Species richness of fauna was greater within the coralline cobble simulators (Figure 3.9), with the seaweed and canopy simulators containing similar species richness. The principal coordinate ordination (PCO) generated from all taxa, macroalgal communities and sampling date (Figure 3.10) shows a clear separation between the sampling types with coralline cobble simulators showing a tight cluster and seaweed more separated.

Within both the coralline cobble and seaweed simulators the dominant taxa were gammarid amphipods, gastropods (snails) and arthropods (crabs) (Figure 3.8). Gammarid amphipods were found in greatest numbers within seaweed simulators in both *Macrocystis pyrifera* kelp canopy and shallower *Carpophyllum/Cystophora* habitat. Within the coralline cobble simulators gammarid amphipods were uncommon but those found were most abundant within the shallow *Carpophyllum/Cystophora* habitat. Gastropods were the dominant taxon within the coralline cobble simulators with average abundances of 50+ per simulator and were composed of small snails such as the opal topshell (*Cantheridus purpureus*). Within the seaweed and canopy simulators only small numbers were observed with the greatest abundances found of 30 individuals per simulator. Crabs within the coralline cobble and seaweed simulators were dominated by three species including the subtidal hermit (*Pagurus novizealandiae*), masking (*Leptomithrax longimanus*) and half crab (*Petrolisthes elongatus*). Crabs within coralline cobble simulators were hermit and half crabs which were found in abundances of 50 or more. Within the seaweed simulators crabs were most abundant at deeper depths (3-15 m) and were dominated by small masking crabs.
3.3.2 Comparing epifaunal assemblages within four macroalgal communities

Epifaunal communities within the macroalgal communities were different between macroalgal habitats. Significant differences were found in the epifauna community within the differing macroalgal habitats for seaweed simulators (Pseudo F$_{3, 109} = 9.202$, P (perm) = 0.001) and coralline cobble simulators (Pseudo F$_{3, 109} = 6.233$, P (perm) = 0.001). Pair wise tests revealed there were significant differences among seaweed and coralline cobble simulators between all macroalgal communities sampled. See Appendix II for pairwise comparison tables.

Seaweed simulators within the *Macroystis pyrifera* kelp canopy (Figure 3.11 (a)) and *Carpophyllum/Cystophora* habitat (Figure 3.11 (b)) had epifauna samples, which were dominated by gammarid amphipods in average abundances 200 and 50 per simulator, with few other epifaunal species. *Macroystis pyrifera* kelp forest (Figure 3.11 (c)) simulators were dominated by gammarid amphipods within seaweed simulators and gastropods within the coralline cobble simulators. *Ecklonia radiata* coralline cobble simulator (Figure 3.12 (d)) samples were dominated by gastropods and crabs where abundances of 30 plus were found. Different crabs species were found at differing depths, half crabs (*P. elongatus*) were abundant in *Carpophyllum/Cystophora* habitat, while hermit (*P. novaezelandiae*) and masking crabs (*L. longimanus*) were found within *M. pyrifera* kelp forest and *E. radiata* macroalgal habitats.

The principal coordinate ordination (PCO) generated for seaweed simulators (Figure 3.12) showed that most macroalgal communities are similar with clustering only seen within the *Macroystis pyrifera* canopy and *M. pyrifera* kelp forest samples. *Carpophyllum/Cystophora* and *Ecklonia radiata* samples are dispersed small clustering observed. Vector analysis reveals that sample separation is driven by gammarid and caprellid amphipods to the left of the plot and gastropods and crabs to the top right of the plot. The principal coordinate ordination (PCO) generated for coralline cobble simulators (Figure 3.13) reveals that clustering of samples within macroalgal habitats is not present with large overlaps observed between communities. These patterns according to the vector analysis shows separation due to amphipods and isopods (to the top right) and crabs, gastropods, bivalves, polychaete and echinoderms (to the top left).
3.3.3 Seasonality of epifauna communities in spring, summer and autumn

Epifaunal communities among sampling events within coralline cobble and seaweed simulators were significantly different (Pseudo $F_{3, 109} = 10.003$ P (perm) = 0.001). Pair wise tests revealed that significant differences exist between seaweed simulators epifauna community between early spring (21/9/09) and late spring (17/11/09) ($t = 1.8515$ P (perm) = 0.002) and summer and autumn ($t = 2.3745$, P (perm) = 0.001). Pair wise tests upon coralline cobble simulators reveal significant differences between all sampling days (early spring and late spring $t = 2.3484$, P (perm) = 0.002), late spring and summer $t = 1.9101$, P (perm) = 0.001 summer and autumn $t = 2.447$, P (perm) = 0.001).

Within the seaweed simulators gammarid amphipods (Figure 3.14 (a)) were prolific with greatest average abundances found within summer (>50) and the least in early spring (<35). Within coralline cobble simulators gastropods dominate (Figure 3.15 (d)) with greatest abundances found during autumn (>50) followed by summer (>45), the lowest mean abundance was found during early spring (<25). Within the coralline cobble and seaweed simulators a steady increase is observed in abundance of arthropods (crabs) (Figure 3.14 (c)) with greatest numbers observed in autumn samples. Caprellid amphipods were highly variable in numbers captured between sampling events, a marked decrease in abundance was observed in autumn in both the coralline cobble and seaweed simulators. Isopods (Figure 3.14 (b)) were most abundant during late spring within the seaweed simulators (6 per simulator), with very few found in coralline cobble simulators (<0.1). Mysid shrimp species were found a low abundance (<0.1) throughout all sampling events except within the autumn samples with an average abundance of 1.5 per simulator. Polychaetes were found in low abundance (<3 per simulator) from both seaweed and coralline cobble simulators. Bivalves were found in low abundances throughout all samples and were only found within coralline cobble simulators, with greatest abundance found during summer (2 per simulator). Polyplacophora (chiton spp.) (Figure 3.15 (e)) displayed a pattern of increasing abundance in coralline cobble simulators (0.5 in spring to 2 in autumn). Brachiopods were only found within coralline cobble simulators at low abundances, with greatest abundance found in early spring (1 per simulator). Echinoderms (sea stars) (Figure 3.15 (f)) showed a steady increase in number within coralline cobble simulators, with greatest abundance found in autumn (2 per simulator). Tunicates (solitary ascidians) were found in low numbers in both seaweed and coralline cobble simulators with a peak in autumn.
Seaweed simulators PCO plot (Figure 3.17) indicates a clear lack of clustering between sampling events, with some small clustering of autumn (23/4/10) samples towards the bottom of the plot. Which is indicative of the highly variable nature of macroalgal communities. The vector analysis reveals that sessile epifauna such as gastropods and crabs pull those samples to the top right of the plot and mobile epifauna such as amphipods pull samples to the left. Coralline cobble simulators PCO plot (Figure 3.18) shows some clustering of samples between dates. Clustering is clear within each event with only small overlap. The average point line indicated on the plot shows a successional movement of points around the plot between sampling events. Vector analysis indicates that mobile amphipods pull samples to the top right of the plot and more sessile gastropods etc to the top left of the plot.

3.3.4 Changes in diversity between coralline cobble and seaweed simulators, within macroalgal communities and season

The diversity as species richness can be observed in Figure 3.9. This plots shows the highly variable nature of diversity for seaweed simulators and a successional pattern of increase in diversity with time spent in the water. The diversity of epifaunal samples was significantly greater in the coralline cobble simulators compared to seaweed simulators (Pseudo F_{1, 109} = 133.51 P (perm) = 0.001), was also significantly different between macroalgal community types (Pseudo F_{3, 109} = 27.002, P (perm) = 0.001) and significantly different among sampling events (Pseudo F_{3, 109} = 38.03 P (perm) = 0.001). Pair wise tests indicate seaweed simulators were significantly different between *Macrocystis pyrifera* canopy and *Carpophyllum/Cystophora*, *Macrocystis pyrifera* kelp forest and *Ecklonia radiata*. Epifaunal diversity was not significantly different between *Carpophyllum/Cystophora* and *Macrocystis pyrifera* kelp forest and *Ecklonia radiata*. The diversity of epifauna between sampling dates reveal significant differences between early spring (21/9/09) and late spring (16/11/09), summer (7/1/10) and autumn (23/4/10). However late spring and summer (7/1/10) were not significantly different between sampling dates (See appendix II for pairwise comparison values). Within the coralline cobble simulators diversity of epifaunal assemblages were not significantly different between the macroalgal communities. Pair wise tests revealed significant differences between sampling dates (late spring (16/11/09) and summer (17/1/10) and summer to autumn (23/4/10)). Early spring and late spring were not significantly different (See appendix II for pairwise comparison values).
3.3.5 Patterns of small fish abundance and possible predator prey relationships

Triplefin species (Figure 3.18 (a)) were observed in relatively low numbers throughout sampling events with greatest abundance observed within the coralline cobble simulators in autumn. Clingfish species (Figure 3.18 (b)) were found in low abundance throughout the seasons with most observed in autumn (1.2 per simulator) in coralline cobble simulators, very few were found within seaweed simulators.

Greatest abundances of Gobiesocidae (clingfish) species and Tripterygiidae (triplefin) species were found within coralline cobble simulators. For the clingfish the greatest abundance was found within the *Carpophyllum/Cystophora* coralline cobble simulators with a steady decrease with depth of macroalgal community (Figure 3.19 (a)). Patterns in triplefin abundance (Figure 3.19 (b)) were variable with mean abundance increasing with depth in seaweed simulators. Within the coralline cobble simulators triplefins are found at similar abundances within both shallow and deep habitats with abundances of 1.5 fish per simulator.

3.3.6 Comparisons of coralline cobble and seaweed simulators to the real thing

Samples of the animals upon the surfaces from the four habitat forming macroalgal species reveal that similar taxonomic groups of epifauna are found upon the seaweeds to those which were found on seaweed and coralline cobble simulators (Table 3.1). Amphipods dominated that samples with only a few other species were found (Figure 3.20). A significant difference was found between the four macroalgal species sampled through PERMANOVA analysis (Pseudo $F_{3, 18} = 4.5315$ $P$ (perm) = 0.001). Pair wise comparisons of the macroalgal species revealed a significant difference between all species. The PCO plot generated from the data showed close clustering of *Cystophora scalaris* and *Carpophyllum flexuosum* samples with a small amount of overlap with other species. *Macrocystis pyrifera* and *Ecklonia radiata* were samples were spread and overlapped with other species.
Figure 3.7. Mean abundance of epifauna species found per simulator type seaweed simulator, coralline cobble simulator within four macroalgal communities Macroystis pyrifera kelp canopy (0m), Carpophyllum flexuosum/Cystophora spp. beds (3m), Macroystis pyrifera kelp forest (8m) and Ecklonia radiata beds (12m) over the entire sampling period of four sampling events from 21/9/09 to 23/4/10. Error bars represent +/- one standard error of the mean. Letters indicate significant differences between means.

Figure 3.8. Mean abundance of epifaunal species per simulator type (kelp canopy, seaweed and coralline cobble simulator) from each sampling event from 21/9/09 to 23/4/10. Error bars represent +/- one standard error of the mean.
Figure 3.9. Species richness of epifauna per simulator type (kelp canopy, seaweed and coralline cobble simulators) from each sampling event (early/late spring, summer and autumn from 21/9/09 to 23/4/10.

Figure 3.10. Principal coordinates (metric MDS) ordination from square root transformed data using a Bray Curtis similarity index of coralline cobble (blue symbols) and seaweed (red symbols) simulators from four macroalgal communities Carpophyllum/Cystophora (triangles) Macrocystis pyriforma kelp forest (pluses), Ecklonia radiata (circles) and Macrocystis pyriforma kelp canopy (crosses) from all sampling days. Percentage variability explained by the PC axes is given on the plot.
Figure 3.11. Mean abundance per simulator of epifaunal taxa in coralline cobble and seaweed simulators within four macroalgal communities (a) *Macrocystis pyrifera* canopy (b) *Carpophyllum/Cystophora* (c) *Macrocystis pyrifera* kelp forest and (d) *Ecklonia radiata* from all 4 sampling events from the 21/9/09 to 23/4/10. Error bars are +/- one standard error of the mean.
Figure 3.12. Principal coordinates (metric MDS) ordination from seaweed simulators within 4 macroalgal communities; *Carpophyllum/Cystophora* spp. (green triangle), *Macrocystis pyrifera* kelp forest (blue plus), *Ecklonia radiata* (black circle) and *Macrocystis pyrifera* kelp canopy (red cross) taken from all sampling days. Percentage variability is explained by the PCO axes as given on the plot.

Figure 3.13. Principal coordinates (metric MDS) ordination from coralline cobble simulators within 3 macroalgal communities; *Carpophyllum/Cystophora* spp. (green triangle), *Macrocystis pyrifera* kelp forest (blue plus) and *Ecklonia radiata* (black circle) taken from all sampling days. Percentage variability is explained by the PCO axes as given on the plot.
Figure 3.14. Mean abundance per replicate of epifaunal taxonomic groups found in coralline cobble and seaweed simulators over the sampling period (early spring 21/9/09, late spring 16/11/09, summer 7/1/10 and autumn 23/4/10) for (a) gammarid amphipod, (b) isopods, (c) arthropod (crabs). Error bars represent +/- one standard error of the mean (n=5).
Figure 3.15. Mean abundance per replicate of epifaunal taxonomic groups found in coralline cobble and seaweed simulators over the sampling period (early spring 21/9/09, late spring 16/11/09, summer 7/1/10 and autumn 23/4/10) for (d) gastropod (snails) (e) polycladophora (chitons) (f) echinodermata (brittlestars) Error bars represent +/- one standard error of the mean (n = 5).
Figure 3.16. Principal coordinates (metric MDS) ordination (PCO) of seaweed simulators within four macroalgal communities over four sampling days. 21/9/2009 (green triangle), 16/11/2009 (blue plus), 7/1/2010 (black circle) and 23/4/2010 (red cross). The PCO axes given on the plot explain percentage variability.

Figure 3.17. Principal coordinates (metric MDS) ordination of coralline cobble simulators within four macroalgal communities over four sampling days. 21/9/2009 (green triangle), 16/11/2009 (blue plus), 7/1/2010 (black circle) and 23/4/2010 (red cross). Line = average point each sampling date. The PCO axes given on the plot explain percentage variability.
Figure 3.18. Mean abundance per replicate of epifaunal taxonomic groups found in coralline cobble and seaweed simulators over the sampling period (early spring 21/9/09, late spring 16/11/09, summer 7/1/10 and autumn 23/4/10) for (a) Tripterygiidae (triplefins), (b) Gobiesocidae (clingfish). Error bars represent +/- one standard error of the mean (n = 5).
**Figure 3.19.** Mean abundance per macroalgal community (*Carpophyllum/Cystophora, Macrocytis pyrifera* and *Ecklonia radiata*) from seaweed and coralline cobble simulators. Of (a) *Gobiesocidae* (clingfish) and (b) *Tripterygiidae* (triplefin species). Error bars are +/- one standard error of the mean (n = 5).

**Figure 3.20** Mean density per 100g wet weights of epifaunal species found upon four macroalgal species (*Carpophyllum flexuosum, Cystophora retroflexa, Macrocytis pyrifera* and *Ecklonia radiata*). Sampled on the 22/4/10 from Butterfly Bay. Error bar represent +/- one standard error of the mean.
Table 3.1. Comparisons of the taxonomic groups found within macroalgal communities, presence/absence (+/-) information for seaweed simulators, coralline cobble simulators and seaweed species. 0m= *Macrocrystis pyrifera* canopy, 3m= *Carpophyllum/Cystophora* bed, 6m= *Macrocrystis pyrifera* kelp forest, 12m= *Ecklonia radiata* bed, C.f= *Carpophyllum flexuosum*, C.r= *Cystophora retroflexa*, M.p= *Macrocrystis pyrifera* and E.r= *Ecklonia radiata*.

<table>
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<th>Seaweed Species</th>
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<td>Bivalves</td>
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<td>Trichopteran</td>
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3.4 Discussion

The high abundance of epifauna observed in this study indicates that epifauna are potentially important links in rocky reef food webs. Studies have found that epifauna, such as amphipods play important roles in the intertidal as well as subtidal communities, influencing among other processes, succession of macroalgae and recruitment of sessile invertebrates and fishes (Taylor 1998, Arrontes 1999, Cowles et al. 2009).

3.4.1 Coralline cobble and seaweed simulators

This study to my knowledge was the first within New Zealand’s South Island to characterize epifaunal communities using standard monitoring units within three distinct macroalgal communities that simulate coralline cobbles and seaweeds. These simulator units successfully captured epifauna and small reef fish from four macroalgal habitats and enabled differences in abundance and diversity over a 6 month time period to be asserted. The epifauna community found in this study is taxonomically similar to that found within other studies within New Zealand and the rest of the world. However, due to various methods used to capture and process samples and different mesh sizes used to sample epifauna it would be difficult quantitatively to compare to these studies. Studies within northern New Zealand (Taylor 1994, Taylor 1998, Taylor et al. 1998 and Cowles et al. 2009), Tasmania (Edgar 1983), South Africa (Allen and Griffiths 1981), California USA (Coyer 1984), Canada (Schmidt and Scheibling 2006), Cyprus (Russo 1997) and Japan (Mukai 1971) all found that gammarid amphipods, isopods, mysid shrimp, gastropods and polychaetes dominate epifaunal species captured within subtidal littoral environments. These epifaunal species are similar to those observed in this study, which were dominated by gammarid amphipods and gastropods.

Differences were observed in the abundance and diversity of epifauna caught within the simulators. Overall, coralline cobble simulators had greater abundances of epifauna compared to seaweed simulators. Within seaweed simulators gammarid amphipods dominated samples. Gammarid amphipods are the dominant animal that reside upon macroalgal in the subtidal environment and are commonly found upon brown species such as *Carpophyllum* spp., *Cystophora* spp., *Ecklonia radiata* (Taylor and Cole 1994, Cowles et al. 2009) and *Macrocystis pyrifera* (Russ 1980, Hepburn and Hurd 2005, Davenport and Anderson 2007).

Within coralline cobble simulators a greater diversity of epifauna were observed; gastropods as a taxonomic group were found in greatest abundance followed by gammarid amphipods and other arthropods such as crabs. Benthic rocky reef habitats usually have a greater diversity of fauna found both on top and below macroalgal and coralline covered
boulders, rocks and cobbles (Choat and Kingett 1982). Furthermore the study by Maughan and Barnes (2000) found that areas of moderate water motion and low sedimentation have far greater diversity and abundance of fauna upon and below cobbles and rocks compared to surrounding areas with high sedimentation and low water movement. Epifauna on coralline cobble simulators epifauna were dominated by less mobile species such as gastropods and crabs compared to the seaweed simulators (which were dominated by mobile swimming amphipods and polychaetes). Most species found within the coralline cobble simulators were found within other studies upon or below cobbles and rocks in other studies (Bruno and Bertness 2001).

Within seaweed simulators, epifaunal species observed were similar to those found upon macroalgal species sampled from the same area (Table 3.1). Taylor (1998) observed that epifaunal species collected from Cystophora spp. and Ecklonia radiata in northern New Zealand were predominantly gammarid amphipods, polychaetes and small gastropod snails. Ricciardi and Bourget (1999) also noted macrofaunal biomass and diversity to be greater on rocky shores (which are generally more structurally complex) than sediment and sand dominated shores in a global survey. The trend of less mobile epifaunal invertebrates to be more abundant in coralline cobble simulators than seaweed simulators may be due to the less stressful stable physical environment of coralline cobbles and rocks, which are usually fairly stable. Macroalgal habitats are generally ephemeral in nature being highly flexible and mobile structure; exposed to wave action and currents, which can damage or remove the macroalgae thus dislodging or removing sessile epifauna from macroalgal surfaces and within habitats.

3.4.2 Macroalgal communities

Noticeable differences were observed between *Macrocystis pyrifera* kelp forest canopy and the other macroalgal communities sampled. Canopy seaweed simulators were dominated by the highly mobile gammarid amphipod in great abundances (over 900 per simulator in spring). Kelp forests are known to be extremely productive releasing most of their biomass as detritus (Mann 1973); allowing for much of the food available from kelp to be a major food source for epifauna (Taylor 1998). *Macrocystis pyrifera* kelp forest is also a major structuring component in the water column providing habitat complexity and attachment substrate for amphipods to reside (Hepburn and Hurd 2005). *Macrocystis pyrifera* also provides protection from predators, as few predatory fishes reside in the canopy and only clingfish species and small pelagic fish such as yellow-eyed mullet (*Aldrichetta fosteri*) (pers obs.). Furthermore Choat and Kingett (1982) found that triplefins are the most influential predator upon epifauna within turfing and sub-canopy macroalgae habitats. As these fish
species were not captured within the *M. pyrifera* kelp canopy simulators; but can be found within the sub-canopy simulators, this could contribute to the greater abundance of epifauna in the canopy. Thus *M. pyrifera* canopies would be considered refugia from triplefin predation.

The *Macrocystis pyrifera* kelp forest canopy could also provide ample attachment points for epifauna resting during the day. Epifaunal species such as gammarid amphipods are thought move into the water column at night (Alldredge and King 1985). *Macrocystis pyrifera* kelp canopy simulators were usually deployed on the outer edges of the kelp forest at Butterfly Bay and would allow easy access to the water column to feed upon planktonic species. A study by Alldredge and King (1985) found that macroalgae were the ideal resting place for epifaunal species before leaving at night to enter the water column to feed. Taylor (1998) also noted a decrease in mobile epifauna abundance at night compared to the day. Furthermore the habitat forming properties and productivity associated with the *Macrocystis pyrifera* kelp forest canopies (Hepburn & Hurd 2005) enable this community to support the high abundances of epifauna encountered in this study.

Within the shallow *Carpophyllum flexuosum* and *Cystophora* spp. beds a number of abundant species were observed, characterised by mobile gammarid amphipods in seaweed simulators and less mobile gastropods (snails) and crabs in coralline cobble simulators. Epifauna on simulators in this habitat were different to other habitats due to high numbers of amphipods and snails. The abundance of gammarid amphipods between the seaweed and coralline cobble simulators were remarkable similar in this habitat, which did not occur within the other macroalgal communities sampled.

Differences in macroalgal morphology may account for the differences seen in epifaunal abundance between this shallow community and deeper habitats. Taylor and Cole (1994) observed that algal species with finely structured blades such as *Carpophyllum* and *Cystophora* spp. tended to support higher epifauna densities than coarsely structured (wide flat bladed) macroalgae such as *Ecklonia radiata*. This is observed in the comparison of macroalgal species and simulators in this study; where finely structured *Carpophyllum flexuosum* and *Cystophora scalaris* had significantly greater abundances of epifauna compared to *Macrocystis pyrifera* kelp forest and *Ecklonia radiata*. Furthermore Taylor and Cole (1994) suggested several ways in which macroalgal morphology could affect epifaunal density, (1) finely structured plants provide a greater surface area for food items such as epiphytic algae to grow; (2) finely structured algae provide more surfaces to hide allowing better refugia from predators and (3) finely structure macroalgae provide better attachment
points to rest and not be washed off by water motion. Edgar and Moore (1986) also noted that in finely structured macroalgal habitats epifaunal and mesograzer species were the most productive in shallow rocky reefs due to abundant food sources and protection from predators and increased wave action in shallow waters.

Of the three-macroalgal habitats sampled that had benthically attached seaweed simulators *Macrocystis pyrifera* kelp forest had the greatest abundance of gammarid amphipods. Thus the greatest abundances of amphipods were found within the canopy (top) and benthic (bottom) attached seaweed simulators. A possible explanation (as discussed previously) for greater abundance within the *M. pyrifera* kelp forest is that many epifauna (especially amphipods and isopods) are demersal zooplankters, and spend time in the water column at night feeding before resettling on various substrata before daybreak (Taylor et al. 1998). Kelp forests usually occupy a zone from around 5-15 m depth on the Karitane coastline. By occupying this area within the canopy and sub canopy, amphipods would have easy access to food sources within and outside the kelp forest at night, returning at daybreak from feeding and settling in this case upon the seaweed simulators. Furthermore the extent to which epifauna graze tissues of their host plants (such as *M. pyrifera*) is contentious, with most epifauna found to be generalists feeding upon items other than their host macroalgae such as periphyton, epiphytic macroalgal, other epifauna and plankton (Russo 1988, Edgar 1991, Bell 1991).

Simulators within the deep (10-15 m) *Ecklonia radiata* habitat generally had lower abundances of epifaunal species in comparison to shallower habitats. Gastropods were the most abundant in the coralline cobble simulators with very few gammarid amphipods found in either type of simulator. More crabs and polychaetes were found within *E. radiata* than any other macroalgal habitat. Possible reasons for epifaunal lower abundances could be increased predation pressure from small fishes such as triplefin species; which were found in greater abundances within the simulators at the deeper depth. Triplefins are known to be predators of epifauna on rocks shores, being highly territorial and voracious predators of epifauna (Willis et al. 2003, Feary et al. 2009). Furthermore, it has been observed that epifaunal abundance is often affected by variation in light intensity along depth and turbidity gradients. This is thought mainly due to the impact of lower macroalgal biomass and ease of access to planktonic food sources for herbivorous amphipods and gastropods (Edgar and Aoki 1993). Within the study site, water clarity is a major factor influencing macroalgal growth on the East Otago Coast. Pritchard et al. (unpublished data) found that periods of low water clarity due to suspended sediment within Butterfly Bay, with less than 1% of ambient light reaching
12 m depths. Furthermore at the depth range (10-15m) in which *E. radiata* is found at Karitane, water movement is low except when large storm events occur. Studies have found that exposure to water movement can significantly decrease abundances of epifauna upon exposed shores (Edgar 1990). Wave action or currents can support high densities of suspension-feeding amphipods (Fenwick 1976, Edgar 1983).

3.4.3 Seasonality

Seasonality of coralline cobble and seaweed simulators was intriguing. Coralline cobble simulators showed a distinct pattern of epifaunal abundance; many species were observed to increase over the sampling period. Seaweed simulators on the other hand showed a pattern of highly variable abundance for most taxonomic groups. This is similar to what has been seen in previous studies of epifauna upon macroalgal species (Taylor 1998, Cowles *et al.* 2009).

Coralline cobble simulators had patterns of abundance, similar to those seen in a succession of macroalgae upon a recently disturbed or artificial substrate introduced to the marine environment (Sousa 1979). Taxonomic groups such as decapod crustaceans (crabs), gastropods (snails), echinoderms (sea stars), polychaetes, sea squirts, triplefins and clingfish species all follow a pattern of increasing abundance with length of time within the water. These species culminate in the greatest abundances being found in autumn; this result could also be due to the sampling method of the last autumn sampling where the baskets were deconstructed back at the lab. There is still a pattern of increase seen in these species with the least mean abundance of epifauna found in early spring when the cages were first sampled. Coralline algae also encrusted both the inside and outside of the coralline cobble simulators, and the trawl netting also became heavily coated in diatom films. Studies have found experimentally that distinct patterns exist within the rocky reef environment after a disturbance event where macroalgae (Sousa 1979, Richards 2010) and epifaunal invertebrates (Keough 1984) colonise recently disturbed rocks and artificial substrates over time. Early colonization of a substrate moves from a diatom film to larger adventitious macroalgal species such as *Ulva* to more perennial species such as *Macrocystis pyrifera* (Sousa 1979). These macroalgal habitats are in turn colonized by less mobile epifauna such as snails, with predatory fish and invertebrate species such as triplefins and large starfish (Dean and Connell 1987).

The epifaunal assemblages on the seaweed simulators show no successional changes in abundance but followed a varied cycle of peaks and troughs. Species that show this pattern
included gammarid amphipods, which were found in the greatest abundance in summer, but did not vary considerably. Isopod and caprellid amphipods had a peak in the late spring, but were found in low abundances. Polychaetes were found in the greatest abundance during autumn. These patterns are similar to what has been found within other studies during spring summer and autumn in New Zealand, but it is unknown whether these patterns would persist throughout the year. Taylor and Cole (1994) found in Northern New Zealand, that the peak abundance of epifauna on brown macroalgae was found in roughly similar abundances throughout the year. Furthermore Fincham (1974) found that amphipod species within Wellington Harbour, New Zealand were sporadically caught within light traps, with seasonal peaks in late winter, spring and early autumn. Edgar (1983) found in Tasmania, Australia, peak abundances of epifauna upon macroalgae were present in summer and early autumn. In a study by Choat and Kingett (1982) epifaunal invertebrates in a perennial algal turf habitat showed marked seasonal fluctuations in abundance. These were characterised by a summer peak in December of gammarid amphipods. Epifaunal abundance was lowest during February to March and coincided with an influx of young of the year sparid fish *Pagrus auratus* (Snapper).

### 3.4.4 Diversity

Over 70 different species of epifauna and fish were found within the coralline cobble and seaweed simulators with many only identified to family level. A significantly greater diversity of epifauna was found within the coralline cobble simulators compared to seaweed simulators. There were also significant differences between all sampling events with increases in diversity of species, with the greatest diversity found in autumn. Also significant differences in species diversity were found between macroalgal communities.

The greatest diversity was seen in the shallow *Carpophyllum/Cystophora* simulators. The least diverse communities were found in simulators in the *Macroystis pyrifera* kelp canopy. These differences could be attributed to the type of environment they are found. *Macroystis pyrifera* kelp forest canopy is a monospecific ephemeral environment in which epifaunal species need to be highly motile to exist. Shallow *Carpophyllum/Cystophora* and benthic subcanopy *M. pyrifera* kelp forest contain a diverse assemblage of macroalgal species with better access to light and detrital food sources. Deep *Ecklonia radiata* is an area that is light limited with low water movement, which is also limited by algae species morphology and increased predator density compared to other macroalgal habitats. This is observed within this study where the greatest number of triplefins captured was in the deep coralline cobble simulators. Furthermore Edgar and Moore (1986) found that epifaunal communities were
typically diverse and collectively consume a wide variety of living and detrital algae matter that is found in the shallower macroalgal communities. There was however no difference found in the diversity of benthic *M. pyrifera* kelp forest and *Ecklonia radiata* seaweed and coralline cobble simulators. Deeper epifaunal species would not be as competitive within *E. radiata* beds, which are also found inside and on the outer edge of the *M. pyrifera* kelp forest habitats.

### 3.4.5 Predators

Epifauna within rocky shore macroalgal habitats are not thought to be food limited, however it is thought that predation plays a critical role in epifauna and mesograzer abundance (Arrontes 1999). Thus predator prey interactions may be an important factor influencing epifaunal abundance within differing macroalgal communities seasonally. The prevalence of triplefin and clingfish species within coralline cobble simulators would have some influence on abundance and type of species present. Triplefin species were found in greatest abundance within the *Ecklonia radiata* coralline cobble simulators and clingfish species were found within the *Carpophyllum/Cystophora* coralline cobble simulators. There was however no identifiable interaction where the abundance of small fish predators increased and epifaunal species abundance decreased.

The three most abundant taxonomic groups sampled were arthropods (crabs), gastropods and polychaetes in the coralline cobble simulators and gammarid amphipods in seaweed simulators, which dominate the diets of small benthic and demersal fishes such as *Noto labrus celidotus* (spotty) (Russell 1983, Jones 1988, Holbrook et al. 1990, Edgar and Shaw 1995). Within New Zealand amphipods are the major dietary items of juvenile reef fish (Jones 1988) and epifaunal gastropods occur in the diet of many adult reef fishes (Russell 1983). Most New Zealand reef fish species are carnivorous, with only a few species feeding directly on macroalgae (Choat and Schiel 1982, Russell 1983, Clements and Choat 1993). Evaluating the effects of fish predation on epifauna is difficult to quantify due to the highly mobile nature of most epifaunal species (Edgar and Aoki 1993). However, predation by fish is not thought to affect abundance of epifauna but affect the size structure of the assemblage, where larger individuals are consumed over smaller individuals within controlled lab tests (Edgar and Shaw 1995). Small fishes such as triplefins are almost certainly the major predators of epifauna on temperate reefs (Taylor 1998). Decapods such as crabs are the only other potentially important predators (Howard 1982) but are not abundant upon seaweeds and are found more under cobbles and rocks in this study.
The macroalgal habitat preferences of reef fish obtained in the fish surveys from chapter two, where greatest abundances of fish were found in the *Macrocystis pyrifera* kelp forest and *Ecklonia radiata* beds. A few adult reef fish are known to consume epifaunal invertebrates such as amphipods, snail and crabs etc as primary food sources (Russell 1983). The patterns of epifaunal abundance where high abundances were found within both the *M. pyrifera* kelp canopy and subcanopy with the kelp forest as well as in *Carpophyllum/Cystophora* spp. habitat; and low epifaunal abundance in *Ecklonia radiata* bed suggests the reef fish are important predators possibly influencing populations of epifauna through predation pressure.

### 3.4.6 Comparisons to seaweeds

Epifaunal species found upon the dominant habitat forming macroalgae were found in both the seaweed and coralline cobble simulators. No new species were found upon the macroalgae that the seaweed and coralline cobble simulators had not already captured. Abundances found upon the seaweed are not really comparable but there seem to be fewer amphipods upon the macroalgal species compared to what has been found in other studies in New Zealand (Taylor and Cole 1994, Taylor 1998, Taylor *et al.* 1998, Cowles *et al.* 2009). These studies found greater mean abundances on comparable species. This could be due to the sampling date, which was in late autumn when other studies have found decreased numbers of epifauna (Choat and Kingett 1982).

### 3.4.7 Conclusions

The results of this study confirm that there are differences in the epifaunal abundance, species composition and diversity between coralline cobble and seaweed simulators. The communities found within the two types of simulators are different and are similar to that found upon seaweed and under rocks. The macroalgal community assemblages of epifauna with the greatest numbers of fauna found within the *Macrocystis pyrifera* kelp forest communities (benthic and canopy) as well as *Carpophyllum/Cystophora* habitats dominated by gammarid amphipods and small gastropods.
Depth and complexity of habitat affects the abundance of epifauna but not necessarily the number of taxa found. There were significant differences found in the diversity of species found among macroalgal habitats except benthic *Macrocystis pyrifera* kelp forest and *Ecklonia radiata* simulators. Seasonality of epifauna between sampling dates were shown to differ greatly. Coralline cobble simulators showed a successional type increase in epifaunal abundances through time as simulators improve as a habitat for epifauna. Seaweed simulators reflected that highly variable nature of macroalgae with only a few peaks of differing species of epifauna. Predation by small predatory fish was not seen to be a major factor influencing the abundances of epifauna, there were however patterns of increased number of predator of reef fish with depth of habitat (found in chapter 2), which corresponds to decreases in epifaunal abundances. It is thought other aspects may also play a part in controlling the epifaunal distribution, such as access to food sources and water motion.

Coralline cobble and seaweed simulators would be a good way to gain a better understanding of epifaunal abundance through time as they sampled a fair representation of the epifauna present in the seaweed and under rocks. Thus allowing the better understanding of food availability of epifauna to new recruits and small fishes on temperate coasts.
CHAPTER FOUR

Macroalgal Primary Productivity Supporting Coastal Food Webs of the East Otago Coastline

The East Otago Taiāpure, looking northwards from Brinns Point.
4.1 Introduction

4.1.1 Importance of primary production in coastal food webs

Advances in community and food web ecology around the world have made it possible for studies to highlight the importance of key primary producers and the flux of energy, organic matter and nutrients through food webs to higher trophic levels (Griffiths and Wilke 1998). Coastal marine ecosystems are affected by both oceanic and terrestrial sources and are connected by a series of complex interactions that have downstream effects upon an organism’s productivity (Fry 2008). These factors can either enhance or negatively impact coastal marine ecosystems by increasing the amounts of nutrients for macroalgal and planktonic primary productivity (Michener and Lajtha 2007). To understand coastal processes (specifically the cycling of nutrients and food sources) it is important to understand how source primary productivity moves from one trophic level to the next through food webs. By relating coastal productivity to specific primary producers through the use of stable isotope and stomach content analysis it is possible to determine sources of macroalgal and phytoplankton productivity, which will enable a better understanding of the drivers of productivity and identify coastal habitats which are important for protection.

Food webs in coastal continental shelf areas are dominated by planktonic production; however, in coastal areas where large stands of macroalgae, primary production is driven by macroalgae (Mann 1988, Duggins et al. 1989, Kaehler et al. 2000, Fredriksen 2003). This productivity leads to a diverse and highly productive ecosystem (Peterson and Howarth 1987, Thompson et al. 2005, Michener and Lajtha 2007, Fry 2008). Macroalgae are vitally important within coastal areas as they offer crucial habitats and food sources for grazers, epifauna and fish. Macroalgal consumers such as gastropods, bivalves and amphipods are important prey for reef fish in New Zealand (Russell 1983). Fredriksen (2003) found that coastal production within a kelp forest community in Norway is almost entirely driven by macroalgal carbons sources; large predatory fish caught offshore from the macroalgal zone were found to have a significant proportion of diet associated with carbon source pools of macroalgae and to a lesser extent planktonic sources. Alfaro et al. (2006) found in a northern New Zealand estuary that a variety of primary organic carbon sources were available to primary consumers. Large brown macroalgal species while only present in small quantities compared to other sources, contributed an unexpectedly high proportion of carbon to these estuarine associated organisms.
4.1.2 Stable isotopes, a useful tool in food web studies

Stable isotope analysis has proven to be a valuable tool in understanding food webs as a complement to other traditional approaches such as gut content analyses, faecal analyses, direct behavioural observation, radiotracers, immunological and fatty acid applications (e.g. Choat and Kingett 1982, Russell 1983, Quammen 1984, Rowan and Rasmussen 1996, McLeod and Wing 2007). By using a combination of techniques involving stable isotopes and gut analysis, a better understanding of food webs can be achieved. Stable isotopes have been used extensively in food web studies to assess the importance of primary producers in supporting secondary production in the terrestrial (Gannes et al. 1997, Ruess et al. 2004), freshwater (Fry 1991), estuarine (Coffin et al. 1994) and coastal marine environments (e.g. Peterson and Fry 1985, Michener and Schell 1994, Hansson et al. 1997, Fredrickson 2003, Deudero et al. 2004, McLeod and Wing 2007). The heavier isotopes of carbon ($^{13}$C), nitrogen ($^{15}$N) and sulphur ($^{34}$S) naturally occur in lower abundance than the lighter isotopes ($^{12}$C, $^{14}$N and $^{32}$S) (Fry 2008). Among primary producers there are natural discrepancies in the amounts of the heavier isotopes fixed during biological fixation (uptake), leading to characteristic isotope signatures for many primary producers from different environments (e.g. terrestrial plants, marine macroalgae and phytoplankton). As energy is incorporated into higher trophic levels, carbon, nitrogen and sulphur from primary producers is passed through the food web and their specific isotopic ratios are passed to consumers with predictable stepwise fractionation of these ratios occurring between different trophic levels (DeNiro and Epstein 1978, McCutchan et al. 2003). Thus the isotopic signature of an animal’s tissue can reflect its diet (Fry 2008). Stable isotopes record both the source and trophic level information of the organism, with sulphur and carbon isotopes providing the strongest information regarding organic matter source and nitrogen isotopes recording information on trophic level.

Isotopic signatures have their own specific symbol and are illustrated by the δ notation, which signifies a difference between isotopes from the measured sample compared to known isotopic standards. Isotopic standards have a known composition against which all samples are compared (Fry 2008). A standard for carbon $^{13}$C/$^{12}$C is PeeDee Belemnite (PDB) and nitrogen $^{15}$N/$^{14}$N AIR and are used in the calculation of δ values by this equation.

$$\delta^HX = \left(\frac{R_{SAMPLE}}{R_{STANDARD}} - 1\right) \times 1000.$$ 

In this equation the δ notation is specified for a particular element (e.g. $X = \text{C, N, S}$) and the superscript $H$ gives the heavy isotope mass of that element (e.g. $^{13}$C, $^{15}$N, $^{34}$S) and $R$ is the ratio of the heavy isotope to the light isotope (e.g. $^{13}$C/$^{12}$C, $^{15}$N/$^{14}$N, $^{34}$S/$^{32}$S). By also
multiplying the equation by 1000 it in affect amplifies very small differences measured between samples and standards (Fry 2008).

**Carbon cycles and isotopic signatures**

The carbon cycle involves the direct interchange of carbon sources between the atmosphere, ocean surfaces and terrestrial ecosystems. The exchange of carbon dioxide ($CO_2$) between the atmosphere and the surface of oceans is driven by the fractionation of a chemical equilibrium reaction between carbon dioxide ($CO_2$) and bicarbonate ($HCO_3$) (Michener and Lajtha 2007). Within the terrestrial environment the withdrawal of carbon from the atmosphere to form carbohydrates involves small fractionations of carbon whereas within the aquatic environment the uptake of dissolved inorganic carbon in marine planktonic photosynthesis involves larger kinetic fractionations. This results in isotopic values for organic inputs of near shore systems of C3 terrestrial plant material of $\delta^{13}C$ (-23 to -30 ‰) seagrasses and macroalgae (-2.7 to -35.3 ‰) and phytoplankton (-18 to -24 ‰) (Fry and Sherr 1984, Raven et al. 2002, Fry 2008). This fractionation involved in photosynthesis is one of the most important processes governing carbon isotopic circulation in the biosphere, and controls the carbon cycle (Fry 2008).

**Nitrogen cycles and isotopic signatures**

Most nitrogen on earth is available as nitrogen (N$_2$) gas in the atmosphere. This huge reservoir is well mixed isotopically and is essentially constant at 0 ‰, with most other sources of nitrogen in the biosphere ranging from -10 to +10 ‰, primarily due the amount of nitrogen available to plants often limits growth. Nitrification and denitrification in the ocean leads to substantial isotopic effects (0 to 40 ‰) by primary producers such as phytoplankton and macroalgae (Michener & Lajtha 2007). A common problem of coastal areas is terrigenous runoff due to industrial, farm and human wastewater discharges into rivers and groundwater leading to eutrophication (Cabana and Rasmussen 1996, Michaels et al. 1996, Galloway 1998). Areas with high anthropogenic pollution can lead to more negative nitrogen values (0 to -20 ‰) of signatures (Fry 2008). Terrestrial organic matter is often depleted in $^{15}N$ with values from -1 to 3 ‰ relative to marine nitrogen, although dissolved inorganic nitrogen derived from sewage and farm wastes may be significantly enriched in $^{15}N$ as a result of volatilization and microbial processing of the nitrogen in solution (Sweeney et al. 1980, Heaton 1986, Van Dover et al. 1992).
4.1.3 Drivers of variability in isotopic signatures between primary production sources

Fractionation of isotope atoms occurs during uptake due to the differences in the amount of energy required to break bonds of heavy and light isotopes. Fractionation also occurs during assimilation of primary producers by consumers, as there are isotopic differences between assimilated and respired carbon as carbon dioxide (CO$_2$) and excreted nitrogen as nitrogenous waste (McCutchan et al. 2003). It is important to consider fractionation when studying isotopes when inferring an organism’s diet, as there are many pathways through which photosynthesis and nutrient uptake can occur. Also the amount of fractionation of $\delta^{13}C$, $\delta^{15}N$ differs among primary producers, leading to distinct isotopic signature of C3 and C4 plants, macroalgae and phytoplankton (McCutchan et al. 2003, Fry 2008). Fractionation usually occurs in a stepwise fashion among trophic levels, with higher trophic level organisms having isotopic signatures that are more enriched with heavy isotopes than those at lower trophic positions (DeNiro and Epstein 1978). Typically fractionation of $\delta^{13}C$ is relatively small between trophic levels (<1 ‰), and thus it is usually used to infer the use of basal source of primary production. Values for fractionation of $\delta^{15}N$ on the other hand are relatively large from (3 to 6 ‰) making this value good for understanding the relative trophic position of the organism in a food web (Fry 2008). Also the biological processes that move nitrogen in and out of the ocean play a key role in determining the natural abundance of $\delta^{15}N$ in marine systems.

4.1.4 Species used in stable isotope analysis

A total of 11 fish species were taken for stable isotope analysis on the East Otago Coast within Blueskin Bay (Figure 4.1). Six were reef-associated and 5 were soft sediment associated and pelagic species. Also epifaunal amphipods were sampled as an important prey item value. Data from other unpublished data were used to give values for planktonic (SPOM) and macroalgal source pools.

Reef associated fish species

Stable isotope samples were taken from blue cod (Parapercis colias), blue moki (Latridopsis ciliaris), spotty (Notolabrus celidotus), banded wrasse (Notolabrus fucicola), greenbone (Odax pullus) and variable triplefin (Forsterygion varium). A brief description of these species habitat preferences, distributions, life histories and feeding preferences are given in chapter two introduction.
**Soft sediment and pelagic associated fish species**

Stable isotope samples were taken from five species of fish that are commonly thought to be associated with either soft sediment or pelagic habitats. These species include pelagic associated barracouta (*Thyrsites atun*) and school shark (*Galeorhinus galeus*). Soft sediment associated red gurnard (*Chelidonichthys kumu*), sand flounder (*Rhombosolea plebeia*) and sole (*Peltorhamphus novaeeelandiae*). Brief descriptions of these species habitat preferences, distribution, life histories and feeding preferences are given below.

**Barracouta (*Thyrsites atun*) Māori name: Manga**

Barracouta belong to the snake mackerel family Gemphylidae and are a slender pelagic species with large teeth that are used to hunt pelagic fish species (Ayling and Cox 1987). *Thyrsites atun* are a pelagic schooling fish that feed on a wide range of small pelagic fishes including sprats, anchovies, yellow-eyed mullet and smaller individuals of their own species. They are widespread throughout New Zealand and are most abundant south of Cook Strait. They are also found off southern Australia, South Africa and South America (Hurst and Bagley 1989). The life history of this species is relatively poorly known but spawning is thought to occur in late winter to spring over the continental shelf especially on the west coast of the south island. They are a slow growing species with larger individuals aged to ~30 years and can grow to 1.5 m length, weighing over 7 kg and occupy depths up to 200 m (Ayling and Cox 1987). This species TAC set by the Ministry of Fisheries for the whole of New Zealand is 32,672.461 t and for the southeast coast 162.732 t (MFish info website 2010).

**Red gurnard (*Chelidonichthys kumu*) Māori name: Kumukumu**

Red Gurnard are found upon the continental shelf over sand and mud bottomed areas at depths from 20 to 150 m. These fish are known to walk upon the bottom using their sensory feelers of their pectoral fins. These feelers scare prey out into the open, where they are engulfed whole by a large mouth. Crabs, shrimp and worms are common prey items, but small fishes are also consumed. *Chelidonichthys kumu* life history is relatively poorly known with spawning occurring in spring to summer. Juveniles grow quickly and mature at around 2 years. Females are found to grow faster than males maturing at ~33 cm whereas males mature at ~26 cm. Few fish live longer than 10 years reaching 65 cm maximum length (Francis 2001). This species is widespread throughout New Zealand from the Three Kings Islands to Stewart Island and Chatham Islands. The species is also found in Australia, South Africa and Japan (Ayling and Cox 1987). The commercial fishery TAC set by the Ministry of Fisheries
for the whole of New Zealand 5181.187 t and for southeast coast 900 t of fish (MFish info website 2010).

**Common sole** (*Peltorhamphus novaezeelandiae*) Māori name: *Pātiki rori*

Common sole are endemic to New Zealand and are found upon a sand or mud bottom or in estuaries, harbours and the inner continental shelf. They are usually hidden within the sand, relying on excellent camouflage for protection from predators (Francis 2001). *Peltorhamphus novaezeelandiae* feed from dusk till dawn on worms, crustaceans and small shellfish that live on or in sand and mud bottoms. They are very mobile when searching for food, and may swim in mid-water. The life history is poorly known with spawning occurring in shallow waters during winter and spring, with activity peaking in August to September. Growth is rapid with maturity reached in the first 2 years (Francis 2001). Maximum length obtained ~68 cm and are prefer depths up to 100 m (Ayling and Cox 1987. Their distribution is widespread throughout New Zealand from Cape Reinga to Foveaux Strait and Chatham Islands; but individuals are most abundant and larger in the south (Francis 2001). The TAC for combined flatfish species is set at for the whole of New Zealand 5,418.8 t of fish (MFish info website 2010).

**Sand flounder** (*Rhombosolea plebeia*) Māori name: *Pātiki*

Sand flounder are endemic to New Zealand and are usually found during the day partially or fully covered in sand on the bottom. Their camouflage colours provide good protection from predators. Colours and patterns can change dramatically to suit surroundings. Feeding occurs at night consuming a wide range of crustaceans, worms, brittlestars and small shellfish that live on or near sand and mud bottoms; large amounts of seaweed and mud can be ingested while feeding (Francis 2001). Life history of this species is relatively well known with spawning occurring in the north over a long time period from March to December; in the south breeding usually occurs during spring (Ayling and Cox 1987). After a larval stage up to 6 months, juveniles will migrate to mudflats, bays, harbours and estuaries where they will remain until maturity at around 2 years old. Migration then takes place to spawning grounds in deeper waters of 30 to 50m (Francis 2001). Migrations between shallow and deeper water occurs yearly to feed and spawn. The maximum age of flounder is usually 4 years, with maximum length ~46 cm. They are found throughout New Zealand from Cape Reinga to Stewart Island and the Chatham Islands. The TAC for combined flatfish species is set at for the whole of New Zealand 5,418.8 t of fish (MFish info website 2010).
4.1.5 Objectives

Very few studies have looked at the roles of primary producers as driving factors upon coastal areas in New Zealand (McLeod and Wing 2008). For this study stable isotopes are the primary tools to determine the sources and relative importance of primary production driving the food web on the East Otago coastline. The purpose of this chapter is to resolve the sources of $\delta^{15}N$ and $\delta^{13}C$ to rocky reef, benthic soft sediment and pelagic associated fish guilds to determine the relative importance of macroalgal and planktonic productivity to each.

It was predicted that reef fish would have signatures indicating food sources reliant upon macroalgal productivity as reef fish inhabit macroalgal-dominated reef areas (refer Chapter 2) and guts would contain prey species found within *Macrocystis pyrifera* kelp forests. It was also predicted that soft sediment associated and pelagic fish species have isotope signatures closer to planktonic productivity than macroalgae, as they inhabit areas where planktonic productivity is all above them and usually are not found upon macroalgal dominated reefs. This would suggest the planktonic primary production is driving the soft sediment associated food webs. It was predicted that some change in isotope signatures would occur from winter to summer due to natural fluctuation in isotopic source pools (Fry 2008).

Source pools of organic matter isotopic signature are thought to change seasonally due to the isotopic fluctuations in the makeup of seawater seasonally, with isotopes such as nitrogen becoming depleted in the water column during summer and carbon becoming isotopically heavier during winter due to lower macroalgal productivity in summer. (Michener and Lajtha 2007).

4.2 Methods

4.2.1 Collection sites of samples from fish and amphipods

Muscle tissue samples were taken for stable isotope analysis from six rocky reef and five soft sediment or pelagic associated fish species during summer 2009 (Table 4.1) upon the East Otago coast (Figure 4.1). Three species of reef fish were also sampled in winter 2009 including wrasse *Notolabrus fucicola*, *Notolabrus celidotus* and blue cod (*Parapercis colias*).

All reef fish samples were collected by shore based fishing either by rod and reel or spear. Winter samples from the 3 reef associated species were captured at Big Rock and Pincers Rock (Figure 4.1). Summer reef fish species samples from *Notolabrus fucicola*,
Latridopsis ciliaris and Odax pullus were taken from Puketeraki and summer samples from Parapercis colias and Notolabrus celidotus were taken from Butterfly Bay. Samples from the soft sediment and pelagic fish were taken from a variety of areas within or close to the East Otago Taiāpure (Figure 4.1). Barracouta (Thyrsites atun) adults were caught by lure trawled behind a boat along the Seacliff coastline. The commercial trawler Kaitiki based at Port Chalmers caught red gurnard (Chelidonichthys kumu) and sand flounder (Rhombosolea plebeia). Sole (Peltorhamphus novaezeelandiae) and Thyrsites atun juveniles were caught by otter trawl close to Pincers rock. School shark (Galeorhinus galeus) were caught off Haywood Point. At least three replicate fish were taken per species.

Amphipods and variable triplefins (Forsterygion varium) samples were taken from seaweed and coralline cobble simulators within Butterfly Bay, Karitane (refer methods chapter 3) in spring 2009. Amphipod samples were taken from canopy seaweed simulators within the Macrocystis pyrifera kelp forest. Amphipod samples were taken in micro-centrifuge tubes, which were a homogenised sample of herbivorous (approximately 50) individuals. Forsterygion varium samples were caught within coralline cobble simulators upon the bottom from 3-10 m depths.

4.2.2 Macroalgae and Planktonic (SPOM) source pools

Macroalgal signatures were obtained during both summer and winter of 2008, which were kindly given to me by Hepburn et al. (unpublished data). Samples were taken from tissue situated in the apical meristem (growing tips) from the species Cystophora retroflexa (n=9), Carpophyllum flexuosum (n=9), Macrocystis pyrifera (n=9) and Ecklonia radiata (n=3) from three depths and two seasons on a wave-exposed coast near Huriawa Peninsula, Karitane (Figure 4.1). Planktonic suspended particulate organic matter (SPOM) signatures were obtained from Van-Hale et al. (unpublished data) and were sampled during summer and winter on a standardised transect during each year from 1997 to 2000. Signatures obtained were from within 5 km of Taiaroa Head at the entrance of the Otago Harbour. Seasonal signatures were averaged to give a multi year planktonic signature value within the neritic zone waters of the Otago coastline (Figure 4.1).
4.2.3. Sample preparation and stable isotope ($\delta^{13}C$ and $\delta^{15}N$) sample analyses

Dorsal white muscle tissue was dissected from just behind the head for all fish species. White muscle has been shown to be much less variable in $^{15}N$ and $^{13}C$ than other fish tissues, largely as a result of its comparatively low lipid content (Deudero et al. 2004). Samples were then placed in sealed (2ml) centrifuge tubes and frozen for later drying. Total and standard lengths as well as sex and weight were also noted.

All fish tissue and amphipods samples were freeze dried and ground to a fine powder using a 10% HCL washed mortar and pestle (washed with purified water between samples) then placed in sealed (2 ml) tubes for storage prior to analyses. Stable isotope analyses were performed by Iso-trace New Zealand Ltd. (University of Otago). Subsamples of all dried, ground samples (1 to 1.5 mg) were analysed for $\delta^{13}C$ and $\delta^{15}N$ on a Europa Hydra 20-20 continuous update stable isotope mass spectrometer (Europa scientific, Crewe, U.K) interfaced to a Carlo Erba (NC 2500) elemental analyser (Carlo Erba, Milan Italy) in continuous flow mode (precision: 0.2‰ for $\delta^{13}C$ and 0.3‰ for $\delta^{15}N$). Analysis was calibrated to EDTA laboratory standards (IAEACH-6) for carbon, IAEAN1 and IAEAN2 for nitrogen). Ratios of $^{15}N$: $^{14}N$ and $^{13}C$: $^{12}C$ are expressed in standard $\delta$ notation following the aforementioned calculation from the introduction.

4.2.6 Stomach contents analysis

During sampling of muscle tissue, fish stomachs were extracted and frozen for later dissection. To analyse gut contents the stomachs were first defrosted and dissected to extract all food items within the gastrointestinal tract. Once the gut contents were extracted prey items were sorted into major taxonomic groups. Fullness of stomachs was observed as a percentage of gastrointestinal tracts with prey items present and largest gut diameter was also noted.
Figure 4.1. Map of the sampling sites for reef, soft sediment and pelagic fish species (black circles), macroalgal species and planktonic SPOM (white circle) taken from within the East Otago Taiāpure and surrounding areas.
Table 4.1. Summary of samples collected for analyses of $\delta^{15}$N and $\delta^{13}$C from along the East Otago coastline.

<table>
<thead>
<tr>
<th>Species</th>
<th>Season</th>
<th>N</th>
<th>Location</th>
<th>Size (mm)</th>
<th>Date of collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reef fish</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Parapercis colias</em></td>
<td>Winter</td>
<td>4</td>
<td>Warrington</td>
<td>250-350</td>
<td>June 2009</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>3</td>
<td>Butterfly Bay</td>
<td>240-290</td>
<td>Nov. 2009</td>
</tr>
<tr>
<td><em>Latridopsis ciliaris</em></td>
<td>Summer</td>
<td>3</td>
<td>Puketeraki</td>
<td>265-530</td>
<td>Nov. 2009</td>
</tr>
<tr>
<td><em>Notolabrus celdotus</em></td>
<td>Winter</td>
<td>5</td>
<td>Pincers</td>
<td>240-255</td>
<td>June 22, 2009</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>2</td>
<td>Butterfly Bay</td>
<td>225-276</td>
<td>Nov. 2009</td>
</tr>
<tr>
<td><em>Notolabrus fucicola</em></td>
<td>Winter</td>
<td>3</td>
<td>Big Rock</td>
<td>310-350</td>
<td>June 22, 2009</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>3</td>
<td>Puketeraki</td>
<td>260-400</td>
<td>Nov. 2009</td>
</tr>
<tr>
<td><em>Odax pullus</em></td>
<td>Summer</td>
<td>3</td>
<td>Puketeraki</td>
<td>315-345</td>
<td>Nov. 2009</td>
</tr>
<tr>
<td><em>Forsterygion varium</em></td>
<td>Summer</td>
<td>4</td>
<td>Butterfly Bay</td>
<td>21.5-81.6</td>
<td>Nov. 2009</td>
</tr>
<tr>
<td>Sediment/pelagic fish</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Thyrsites atun</em></td>
<td>Summer</td>
<td>3</td>
<td>Sea Cliff</td>
<td>750-825</td>
<td>Feb. 2010</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>3</td>
<td>Warrington</td>
<td>85-95</td>
<td>Feb. 2010</td>
</tr>
<tr>
<td><em>Chelidonichthys kumu</em></td>
<td>Summer</td>
<td>3</td>
<td>Sea Cliff</td>
<td>87-460</td>
<td>Feb. 2010</td>
</tr>
<tr>
<td><em>Rhombosolea plebeia</em></td>
<td>Summer</td>
<td>2</td>
<td>Sea Cliff</td>
<td>340-346</td>
<td>Feb. 2010</td>
</tr>
<tr>
<td><em>Peltorkamphus novaezeelandiae</em></td>
<td>Summer</td>
<td>3</td>
<td>Sea Cliff</td>
<td>50-93</td>
<td>Feb. 2010</td>
</tr>
<tr>
<td><em>Galeorhinus galeus</em></td>
<td>Summer</td>
<td>3</td>
<td>Harrington</td>
<td>320-490</td>
<td>Feb. 2010</td>
</tr>
<tr>
<td>Epifauna</td>
<td>Amphipod spp.</td>
<td>Summer</td>
<td>4</td>
<td>Butterfly Bay</td>
<td>5+</td>
</tr>
<tr>
<td>Macroalgal species</td>
<td><em>Carpophyllum flexuosum</em></td>
<td>Summer/ winter</td>
<td>9</td>
<td>Butterfly</td>
<td>N/a</td>
</tr>
<tr>
<td></td>
<td><em>Cystophora retroflexa</em></td>
<td>Summer/ winter</td>
<td>9</td>
<td>Butterfly</td>
<td>N/a</td>
</tr>
<tr>
<td></td>
<td><em>Macrocystis pyrifera</em></td>
<td>Summer/ winter</td>
<td>9</td>
<td>Butterfly</td>
<td>N/a</td>
</tr>
<tr>
<td></td>
<td><em>Ecklonia radiata</em></td>
<td>Summer/ winter</td>
<td>3</td>
<td>Butterfly</td>
<td>N/a</td>
</tr>
</tbody>
</table>
4.2.5 Data treatment

To assess the trophic level of fish species from winter and summer the mean values of carbon $\delta^{13}$C and nitrogen $\delta^{15}$N from all 11 fish species were plotted in relation to the values obtained for basal carbon and nitrogen sources of macroalgae and plankton from the East Otago coastline. Trophic levels were then added (5 or 6 values for each) by plotting a line upwards which was corrected for their fractionation. The mean fractionation values were taken from McCutchan et al. (2003) for aquatic animals; the values for carbon ($\delta^{13}$C) and nitrogen ($\delta^{15}$N) were $+0.4$ and $+2.3$ respectively. Trophic levels was placed in respect to where the average values for the fish species lay. To solve the actual trophic level of each species an equation was calculated in Excel for the slope between the mean values of planktonic and macroalgae source pools and then solved using the equation for the slope in DataGraph to obtain the actual number of trophic levels that each fish species.

To test for differences in isotope values between fish species and seasons a PERMANOVA on raw data using a Euclidean distance similarity index was performed individually on carbon ($\delta^{13}$C) and nitrogen ($\delta^{15}$N) values. Pairwise comparisons were then applied if a significant difference was found to get a PERMANOVA t-statistic and P-value. To test for differences in trophic levels between fish species (reef, soft sediment and pelagic associated) and seasons a PERMANOVA on raw data with a Euclidean distance similarity index was completed. PERMANOVA analysis is also sensitive to differences in the dispersion of values so a test of homogeneity of dispersion (PERMDISP) (Anderson et al. 2005) was performed for each analysis. Functionally PERMANOVA with a Euclidean distance similarity index is an ANOVA of individual values from their area of centroid to quantify differences in multivariate space.

In order to quantify the relative importance of carbon source pools (phytoplankton and macroalgae) in fish muscle tissue for all fish species a two source mixing model (IsoError) was applied (Phillips and Gregg 2001) to determine the average contribution of the two carbon sources pools to the diets of different fish species on the East Otago coastline. Firstly the average and standard deviation were calculated for each fish species sampled. Trophic levels were then determined for phytoplankton and macroalgae as described previously and enriched according to McCutchan et al. (2003).

Sensitivity analysis on the isotope values obtained from a common, territorial generalist reef fish species blue cod (Parapercis colias) was carried out for isotope fractionation within the IsoError two source mixing model to test the model’s sensitivity to
the amount of fractionation due to trophic shift of nitrogen (δ\textsuperscript{15}N) and carbon (δ\textsuperscript{13}C). This is the result of the assumed fractionation of isotopes as you move up trophic levels. Nitrogen fractionation has been observed to change widely between organisms in the marine environment (1 to 4%), whereas carbon is generally accepted to be stable, changing <1% on average as moves through trophic levels in the food chain (Fry 2008). To address the range of fractionation reported in McCutchan et al. (2003), data was corrected with fractionation factors between 1.4 to 4% for δ\textsuperscript{15}N and 0.4 to 1.6% for δ\textsuperscript{13}C in steps of 0.2% (Leakey et al. 2008).

4.3 Results

The results from the stable isotope analysis of fish from the East Otago coastline showed high variability of carbon (δ\textsuperscript{13}C) and nitrogen (δ\textsuperscript{15}N) signatures for reef and soft sediment/pelagic associated fish species (Figure 4.2). There were no significant differences found in the isotopic signatures between the reef and soft sediment associated and pelagic fish species for carbon (δ\textsuperscript{13}C) (PERMANOVA Pseudo F\textsubscript{1, 49} = 0.95975 P (perm) = 0.323) or nitrogen (δ\textsuperscript{15}N) (Pseudo F\textsubscript{1, 49} = 0.50937 P (perm) = 0.457).

4.3.1 Values for δ\textsuperscript{13}C and δ\textsuperscript{15}N in summer fish species

The values obtained for δ\textsuperscript{13}C and δ\textsuperscript{15}N in reef fish species in summer are spread between the two source pools of the average values for macroalgal species and phytoplankton (Figure 4.3). Variable triplefin (Forsterygion varium) a small reef fish was most enriched (+16) in δ\textsuperscript{15}N, which indicates a high trophic level of prey items. The herbivorous reef fish and the greenbone (Odax pullus) had the lowest δ\textsuperscript{15}N value. Blue cod (Parapercis colias) was most enriched in δ\textsuperscript{13}C (-17) and the wrasses Notolabrus fucicola and Notolabrus celidotus were most depleted in δ\textsuperscript{13}C. Blue moki (Latridopsis ciliaris) values fall in the middle for both δ\textsuperscript{15}N (trophic level) and δ\textsuperscript{13}C (source pool).

The two-source IsoError mixing model (Figure 4.4) predicted that macroalgal productivity comprised the largest proportion of prey diets of the reef fish blue cod (Parapercis colias) (81%), greenbone (Odax pullus) (66%) and triplefin (Forsterygion varium) (65%). The model also predicted that planktonic SPOM productivity made the largest contribution to wrasses Notolabrus fucicola (72%), Notolabrus celidotus (65%) and the blue moki (Latridopsis ciliaris) (56%) diets. Statistical analyses using PERMANOVA found
significant differences in $\delta^{13}$C isotopic signatures between reef fish species. (Pseudo $F_{12, 38} = 6.2968$ P (perm) = 0.001) Pairwise comparisons indicated significant differences between *Odx pullus* and *Parapercis colias, Notolabrus fucicola* and *Notolabrus celidotus* ($t = 2.6938$ P (perm) = 0.03, $t = 2.9971$ P (perm) = 0.024 and $t = 2.8819$ P (perm) = 0.03). Between *Forsterygion varium* and *P. colias, N. fucicola* and *N. celidotus* ($t = 3.5757$ P (perm) = 0.016, $t = 3.8194$ P (perm) = 0.004 and $t = 3.8077$ P (perm) = 0.008). No differences were found in the dispersion or homogeneity of $\delta^{13}$C signatures (PERMDISP $F_{12, 38} = 1.925$ P (perm) = 0.29).

The values obtained for $\delta^{13}$C and $\delta^{15}$N from soft sediment and pelagic associated fish species in summer indicate a close association to macroalgal productivity source pools (Figure 4.5). The sole (*Peltorhamphus novaezeelandiae*) are found to be most enriched in $\delta^{15}$N (+16) and barracouta (*Thyrsites atun*) juveniles were found to be the most depleted (+13). School shark (*Galeorhinus galeus*) are most enriched in $\delta^{13}$C (-15.5) and *T. atun* adults most depleted (-17.5). The two-source IsoError mixing model (Figure 4.6) predicted that macroalgal productivity comprised the largest proportion of the diets of all soft sediment and pelagic fish species, with *T. atun* adults having the greatest percentage of planktonic derived production in their diets (27%). The 5 other species had less than 16% of planktonic productivity in their diet; with *G. galeus* proportions for plankton were negative indicating a separate source of productivity for this species.

Statistical analyses using PERMANOVA found statistically significant differences in $\delta^{13}$C isotopic signatures (Pseudo $F_{5, 11} = 5.4309$ P (perm) = 0.019) between soft sediment and pelagic associated fish species. Pairwise comparisons reveal significant differences between individual soft sediment and pelagic species using a Monte Carlo test for small sample sizes between *Rhombosolea plebeia* and *Thyrsites atun* adult and juvenile ($t = 5.134$ P (perm) = 0.013 P (MC) = 0.016 and $t = 4.723$ P (perm) = 0.011 P (MC) = 0.014); *Peltorhamphus novaezeelandiae* and *T. atun* adult and juvenile ($t = 3.6455$ P (perm) = 0.098 P (MC) = 0.016 and $t = 4.1244$ P (perm) = 0.103 P (MC) = 0.014).

Reef and soft sediment/pelagic fish species $\delta^{13}$C and $\delta^{15}$N isotopic signature (Figure 4.2) are fairly similar reef fish with slightly more positive $\delta^{15}$N values on and more negative $\delta^{13}$C values on average. Reef fish also have greater planktonic derived productivity in their diets compared to pelagic and soft sediment associated fish which are shown to be derive over 90% organic matter sources from macroalgal productivity.
4.3.2 Comparisons of summer and winter reef fish species $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values

The results obtained from seasonal isotope analysis for three reef fish species (*Parapercis colias*, *Notolabrus fucicola* and *Notolabrus celidotus*), macroalgal species (*Carpophyllum flexuosum*, *Cystophora retroflexa*, *Macrocystis pyrifera* and *Ecklonia radiata*) and planktonic suspended particulate organic matter (SPOM) show clear shifts in isotopic signature of carbon $\delta^{13}\text{C}$ and nitrogen $\delta^{15}\text{N}$ between winter and summer (Figure 4.2). Reef fish and basal organic sources for macroalgal and planktonic productivity are seen to shift by +2 in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for fish species; by +1 in $\delta^{13}\text{C}$ and +2 in $\delta^{15}\text{N}$ for planktonic and up to +3 in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for macroalgal signatures.

The values obtained in winter for macroalgal and planktonic source pools show some clear associations between fish species and their source pools (Figure 4.7). *Notolabrus celidotus* and *Parapercis colias* are shown to be closely associated to macroalgae and *Notolabrus fucicola* to planktonic SPOM organic matter source pools. The two-source IsoError mixing model (Figure 4.8) predicted that macroalgal productivity comprised the largest proportion of diet by a small amount to planktonic SPOM productivity for *N. celidotus* (52 to 48%) and *P. colias* (57 to 43%). *Notolabrus fucicola* proportion of diets fell outside the models parameters with 130% proportion of planktonic productivity in its diet suggesting another source of productivity or flaws in the models source pools.

4.3.3 Trophic levels

The trophic level values $\delta^{15}\text{N}$ obtained from the mixing model of fish species in summer were fairly similar between species (Figure 4.9). Statistical analyses using PERMANOVA reveal significant differences in nitrogen $\delta^{15}\text{N}$ isotopic signatures (Pseudo F$_{12, 38}$ = 11.384 P (perm) = 0.001) (refer to table 4.2 for pairwise comparisons). Comparisons of trophic levels between winter and summer fish samples from the two source-mixing model (Figure 4.10) show that blue cod (*Parapercis colias*) and spotty (*Notolabrus celidotus*) decrease slightly in feeding trophic level during summer compared to winter. Banded wrasse (*Notolabrus fucicola*) increased in trophic level between winter and summer.
4.3.4 Analysis of stomach contents

The contents of the fish stomachs from the species used for stable isotope analysis revealed that a total of 15 taxonomic groups were represented within the stomach contents (table 4.3 and 4.4). The prey items within the fish diets were fairly similar between winter and summer for reef fish. Furthermore soft sediment and pelagic associated fish species consumed prey items found on the outer edges of rocky reefs upon the sand (Figure 4.3). The most dominant taxonomic group found in almost all species gut contents were crabs, gastropods (snails), bivalves (mussels), gammarid amphipods and euphausiid shrimp. *Thrysites atun* (barracouta) gut contents were dominated by whale krill (*Munida gregaria*) and euphausiid shrimps. *Galeorhinus galeus* (school shark) contained a number of small cuttlefish (*Sepia* spp.); cuttlefish were also caught in the otter trawls when we were fishing for flatfish close to Warrington Beach (Figure 4.1).

4.3.5 Sensitivity of mixing model

The sensitivity models of carbon $\delta^{13}$C (Figure 4.11) and nitrogen $\delta^{15}$N (Figure 4.12) for blue cod (*Parapercis colias*) show how the mixing models were dependent on the assumed fractionation of both $\delta^{13}$C (0.4%) and $\delta^{15}$N (2.3%). The change in $\delta^{13}$C from 0.4% to 1.4% resulted in an almost 100% difference in input of either macroalgae to planktonic organic matter source. The same can be said for the change in $\delta^{15}$N from 1.4 to 4% fractionation, which resulted in a 30% increase in macroalgae contribution. These ranges of change in fractionation are enough to reverse the dominant source pool for from either macroalgae to plankton according to the model output.
Figure 4.2. Average values of $\delta^{15}$N and $\delta^{13}$C ($\%\pm 1$ SE) of muscle tissue sampled during winter (a) and summer (b) 2009-10 from reef fish species (black circles): *Notolabrus celidotus*, *Notolabrus fucicola*, *Parapercis colias*, *Latridopsis ciliaris*, *Forsterygion varium* and *Odax pullus* and soft sediment and pelagic associated fish species (white circles): *Thyrsites atun* (adult and juvenile), *Chelidonichthys kumu*, *Rhombosolea plebeia*, *Peltorhamphus novaezeelandiae* and *Galeorhinus galeus*. As well as gammarid amphipods (diamond), macroalgal species (triangle): *Macrocystis pyrifera*, *Ecklonia radiata*, *Carpophyllum flexuosum*, *Cystophora retroflexa* and Planktonic SPOM (suspended particulate organic matter) (square). Values for each are averaged between replicates ($n = 3$).
Figure 4.3. Mean values of $\delta^{15}$N and $\delta^{13}$C (%$^\circ$+/− 1 SE) of muscle tissue sampled from reef fish species Notolabrus celidotus, Notolabrus fucicola, Parapercis colias, Latridopsis ciliaris, Forsterygion varium and Odax pullus along the East Otago coastline during summer 2009-10. Also illustrating the number of trophic levels up fish are against the mean values of potential organic sources (+/− 1 SE) SPOM (planktonic productivity and habitat forming macroalgal species). Fractionation values per trophic level were 2.3 for $\delta^{15}$N and 0.4 for $\delta^{13}$C. (n = 3).

Figure 4.4. Results from the mixing model of proportions of macroalgal and planktonic source pools of organic matter from all reef fish species sampled on the East Otago coastline during summer 2009-10. Error bars represent +/- SE (n = 3).
Figure 4.5. Mean values of $\delta^{15}$N and $\delta^{13}$C (%$^{\circ}$± 1 SE) of muscle tissue sampled from soft sediment and pelagic associated fish species *Thyrsites atun* (adult and juvenile), *Chelidonichthys kumu*, *Rhombosolea plebeia*, *Peltorhamphus novaeseelandiae* and *Galeorhinus galeus* along the East Otago coastline during summer 2010. Also illustrating the number of trophic levels up fish is against the mean values of potential organic sources (+/- 1 SE) planktonic and habitat forming macroalgal species. Fractionation values per trophic level were 2.3 for $\delta^{15}$N and 0.4 for $\delta^{13}$C. (n = 3).

Figure 4.6. Results from the mixing model of proportions of macroalgal and planktonic source pools from all soft sediment and pelagic associated fish species sampled on the East Otago coastline during summer 2010. Error bars represent +/- SE. “X” denotes an unfeasible solution (n = 3).
Figure 4.7. Mean values of $\delta^{15}$N and $\delta^{13}$C (%$^\circ$ +/- 1 SE) of muscle tissue sampled from reef fish *Notolabrus celidotus*, *Notolabrus fucicola* and *Parapercis colias*, species along the East Otago coastline during winter 2009. Also illustrating the number of trophic levels up fish is against the mean values of potential organic sources (+/- 1 SE) planktonic and habitat forming macroalgal species. Fractionation values per trophic level were 2.3 for $\delta^{15}$N and 0.4 for $\delta^{13}$C. ($n = 3$).

Figure 4.8. Results from the mixing model of proportions of macroalgal and planktonic source pools from reef fish species *Parapercis colias*, *Notolabrus fucicola* and *Notolabrus celidotus* sampled on the East Otago coastline during winter 2009. Error bars represent +/- SE. “X” denotes an unfeasible solution ($n = 3$).
Table 4.2 PERMANOVA pairwise comparison results from nitrogen $\delta^{15}$N isotope results for differences between species as a factor of tropic level. # Bold numbers denote significant differences.

<table>
<thead>
<tr>
<th>Group</th>
<th>D.f</th>
<th>T</th>
<th>P (perm)</th>
<th>Unique Perms</th>
</tr>
</thead>
<tbody>
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<td>Odax pullus and Parapercis colias</td>
<td>1, 8</td>
<td>5.746</td>
<td><strong>0.01</strong></td>
<td>120</td>
</tr>
<tr>
<td>Odax pullus and Notolabrus celidotes</td>
<td>1, 8</td>
<td>4.5657</td>
<td><strong>0.012</strong></td>
<td>84</td>
</tr>
<tr>
<td>Odax pullus and Notolabrus fucicola</td>
<td>1, 7</td>
<td>5.6121</td>
<td><strong>0.004</strong></td>
<td>120</td>
</tr>
<tr>
<td>Odax pullus and Forsterygion varium</td>
<td>1, 5</td>
<td>3.0082</td>
<td><strong>0.05</strong></td>
<td>35</td>
</tr>
<tr>
<td>Parapercis colias and Galeorhinus galeus</td>
<td>1, 7</td>
<td>2.7924</td>
<td><strong>0.05</strong></td>
<td>120</td>
</tr>
<tr>
<td>Parapercis colias and Thyrsites atun (adult)</td>
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<td>4.1183</td>
<td><strong>0.006</strong></td>
<td>120</td>
</tr>
<tr>
<td>Parapercis colias and Thyrsites atun (juv.)</td>
<td>1, 8</td>
<td>3.6312</td>
<td><strong>0.013</strong></td>
<td>120</td>
</tr>
<tr>
<td>Notolabrus fucicola and Thyrsites atun (adult)</td>
<td>1, 7</td>
<td>3.1933</td>
<td><strong>0.039</strong></td>
<td>84</td>
</tr>
<tr>
<td>Notolabrus celidotus and Galeorhinus galeus</td>
<td>1, 7</td>
<td>3.4717</td>
<td><strong>0.013</strong></td>
<td>120</td>
</tr>
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<td>Notolabrus celidotus and Thyrsites atun (adult)</td>
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<td>4.4224</td>
<td><strong>0.008</strong></td>
<td>120</td>
</tr>
<tr>
<td>Notolabrus celidotus and Thyrsites atun (juv.)</td>
<td>1, 8</td>
<td>4.1433</td>
<td><strong>0.012</strong></td>
<td>120</td>
</tr>
<tr>
<td>Amphipod and Parapercis colias</td>
<td>1, 8</td>
<td>8.9239</td>
<td><strong>0.009</strong></td>
<td>314</td>
</tr>
<tr>
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<td>10.394</td>
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<td>7.3388</td>
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<td>48.3634</td>
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<td>312</td>
</tr>
<tr>
<td>Amphipod and Odax pullus</td>
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<td>3.213</td>
<td><strong>0.039</strong></td>
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<tr>
<td>Amphipod and Chelidonichthys kumu</td>
<td>1, 4</td>
<td>10.207</td>
<td><strong>0.03</strong></td>
<td>15</td>
</tr>
<tr>
<td>Amphipod and Galeorhinus galeus</td>
<td>1, 5</td>
<td>7.1407</td>
<td><strong>0.025</strong></td>
<td>35</td>
</tr>
<tr>
<td>Amphipod and Peltorhamphus novaezeelandiae</td>
<td>1, 5</td>
<td>12.021</td>
<td><strong>0.022</strong></td>
<td>35</td>
</tr>
<tr>
<td>Amphipod and Thyrsites atun (adult)</td>
<td>1, 5</td>
<td>5.5932</td>
<td><strong>0.035</strong></td>
<td>35</td>
</tr>
<tr>
<td>Amphipod and Thyrsites atun (juv.)</td>
<td>1, 5</td>
<td>3.6034</td>
<td><strong>0.026</strong></td>
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</tr>
<tr>
<td>Amphipod and Forsterygion varium</td>
<td>1, 6</td>
<td>4.6808</td>
<td><strong>0.034</strong></td>
<td>35</td>
</tr>
</tbody>
</table>
Figure 4.9. Estimated trophic levels up from source macroalgal and planktonic source pools of reef and soft sediment and pelagic associated fish and gammarid amphipod species taken from the East Otago coastline in summer 2009-10.

Figure 4.10. Estimated trophic levels up from source macroalgal and planktonic source pools of reef fish species Parapercis colias, Notolabrus fucicola and Notolabrus celidotus taken from the East Otago coastline in summer 2009-10 and winter 2009.
Figure 4.11. Sensitivity of IsoError two source mixing model to the assumed fractionation of δ\textsuperscript{13}C in the diet of *Parapercis colias* from summer samples.

Figure 4.12. Sensitivity of IsoError two source mixing model to the assumed fractionation of δ\textsuperscript{15}N in the diet of *Parapercis colias* from summer samples.
Table 4.3. Winter reef fish stomach contents presented as presence (+) absence (-) of prey items put into broad taxonomic groupings. Fullness of stomach is given as a percentage.

<table>
<thead>
<tr>
<th>Winter Reef fish species</th>
<th>Taxonomic group</th>
<th>Parapercis colias</th>
<th>Notolabrus fucicola</th>
<th>Notolabrus celidotus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crab species</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Gastropod (snails)</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Bivalves</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Gammarid amphipod</td>
<td>+</td>
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<td></td>
</tr>
<tr>
<td>Isopods</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Euphausiid shrimp</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Polychaeta</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Echinoderm</td>
<td>-</td>
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<tr>
<td>Macroalgae</td>
<td>+</td>
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<td></td>
</tr>
<tr>
<td>Ascidians</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Fullness of gut</strong></td>
<td><strong>50%</strong></td>
<td><strong>25%</strong></td>
<td><strong>25%</strong></td>
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</table>
**Table 4.4.** Summer fish stomach contents presented as presences (+) absence (-) of prey items put into broad taxonomic groupings. Fullness of stomach is given as a percentage.

<table>
<thead>
<tr>
<th>Summer</th>
<th>Fish species</th>
<th>P. colias</th>
<th>N. fucicola</th>
<th>N. celidotus</th>
<th>L. ciliaris</th>
<th>O. pullus</th>
<th>C. kumu</th>
<th>G. galeus</th>
<th>T. atun</th>
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</thead>
<tbody>
<tr>
<td>Crabs</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Gastropod</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>(snails)</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Bivalves</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>(mussels)</td>
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<td>+</td>
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<td>+</td>
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<td>-</td>
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<td>amphipod</td>
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<td>Euphausiid</td>
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<td>-</td>
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</tr>
<tr>
<td>Polychaeta</td>
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</tr>
<tr>
<td>Fish (Flesh,</td>
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<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>skeletons)</td>
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<td>+</td>
</tr>
<tr>
<td>(seagrass)</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Munida gregaria</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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<td>Cephalopods</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
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</tr>
<tr>
<td>(cuttlefish)</td>
<td></td>
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4.4 Discussion

4.4.1 Macroalgal productivity driving coastal food webs

The results of this study show that fish species upon the East Otago coastline gain most of their productivity from macroalgae. Isotopic signature of nitrogen $\delta^{15}$N and carbon $\delta^{13}$C gathered from reef and soft sediment and pelagic associated fish species show tight associations between source organic matter pools and the fish species. This data combined with analysis of stomach contents suggest that fish species upon the East Otago coast and associated food webs are driven by macroalgal productivity. Some unexpected results were obtained in which reef associated fish were dependent on both macroalgal and planktonic production with wrasse species more reliant on planktonic than macroalgal production for sources of organic matter. Soft sediment and pelagic associated fish species were very closely associated to macroalgal productivity for prey sources with all species falling close to the line drawn by macroalgae (Figure 4.5). Results from other studies have found that productivity in coastal areas is driven by planktonic productivity especially in the oceanic and island environments (Kaehler et al. 2000, Takai et al. 2002). The unique hydrographical conditions of East Otago make it a fascinating system to study. Inputs of estuarine productivity and the abundance of dense macroalgal beds including *Macrocystis pyrifera* kelp forests (Fyfe et al. 1999) make it a highly productive system that is driven primarily by macroalgal productivity with very little input from oceanic planktonic productivity.

4.4.2 Reef and soft sediment/pelagic fish species isotopic signatures

The fish species collected in this study have a wide variety of feeding mechanisms and specific prey preferences. Some possible explanations for the values obtained from isotopic analysis in relation to feeding preferences follow.

**Reef fish species:** The wrasse species *Notolabrus fucicola* (banded wrasse) and *Notolabrus celidotus* (spotty) have values for carbon $\delta^{13}$C (Figure 4.3) that fall close to planktonic (SPOM) sources of productivity with results from the mixing model confirming this (72% for banded and 65% for spotty) (Figure 4.4). These values are possibly due to feeding preferences for suspension feeders especially mussels (*Perna canaliculus, Modiolarca impacta, Aulacomya atra maoriana*). This was confirmed by the analysis of stomach content analysis, with all fish containing mussel shell fragments (Table 4.3). Jones (1984c) and Russell (1983) found that spotty consumed a wide range of small animals and was the most indiscriminant feeder of the wrasses and found that the greatest proportion of
their diets consisted of bivalves (especially mussels) and hermit crabs. Graham (1973) found that *N. celidotus* around Otago consumed many species of bivalves, brachiopods and crab species. Banded wrasse (*Notolabrus fucicola*) was found by Denny and Schiel (2001) to feed predominantly on bivalves such as ribbed mussels (*Aulacomya atra maoriana*) with over 50% of occurrence in their stomach contents being mussel fragment from all species around Kaikoura. Russell (1983) found banded wrasse are a selective forager with a preference for small hard-shelled animals such as gastropods, crabs and bivalves in northern New Zealand. Graham (1973) found feeding preferences for any hard-shelled mollusc it came across in foraging, with a specific preference for bivalves. The evidence offered by published literature of feeding preferences for suspension feeders especially mussels, which are filter feeders of planktonic organisms (Kasper *et al.* 1985); These explain the isotopic signature of *N. celidotus* and *N. fucicola* and results from the mixing model that show a close association to planktonic (SPOM) as well as macroalgal productivity.

The position of blue moki (*Latridopsis ciliaris*) means the isotopic signature is between (Figure 4.3) the two carbon sources (macroalgae and plankton), with the results from the mixing model confirming this (56% planktonic and 44% macroalgal productivity). Stomach contents analysis revealed a diverse number of species such as crabs, gastropods, bivalves, gammarid amphipods, euphausiid shrimp, isopods, polychaetes and chitons. The dominant proportion of their diet was amphipods and crabs in this study (over 50%). Russell (1983) found that moki fed predominantly on gastropods, chitons, bivalves, crabs, polychaetes, amphipods and echinoids in northern New Zealand. Graham (1973) found *L. ciliaris* in Otago waters feed predominantly on a wide range of species of gastropods, bivalves, crabs, amphipods, isopods, krill, euphausiid shrimp and polychaetes. This diverse diet of moki, which has been described as a generalist picker within kelp forests and macroalgal beds (Francis 2001), could lead to the proportion of productivity to be dominated neither by macroalgal productivity or planktonic productivity.

The common blue cod (*Parapercis colias*) δ¹³C values are shown to be most closely associated to macroalgal productivity of all reef fish species. The proportion obtained from the mixing model (19% planktonic and 81% macroalgae) indicate a tight association. Taxonomic groups present within the stomach contents confirm that this species is reliant upon macroalgal productivity and prey species such as gastropod snail grazers. Beer *et al.* (unpublished data) found that blue cod upon Fiordland’s outer-coastline were primarily feeding on benthic invertebrates consisting of small crustaceans (crabs, mysid shrimp) and salps in summer with the major organic matter source of δ¹³C values derived from macroalgal
productivity. Rodgers and Wing (2008) also in Fiordland found *P. colias* diets consisted of molluscs, small fish and crustaceans. Jiang (2002) found that blue cod in Foveaux Strait fed predominately on crustaceans, molluscs, polychaetes and small fish, with crustaceans found to be the most preferred prey source. Graham (1973) found that around the Otago coastline *P. colias* consumed a wide variety of benthic and pelagic organisms, especially fish (pilchard, sprats, pipefish, red cod spotties etc), bivalves, gastropods, crabs and other crustaceans (crayfish, euphausiid shrimp, krill) and polychaetes. The majority of these prey items could be thought to be reliant on macroalgal productivity, which has been found in Fiordland (Rodgers and Wing 2008).

The herbivorous fish species greenbone (*Odax pullus*) isotopic values suggest a tight association to macroalgal productivity. The proportions of productivity obtained from the mixing model (66% macroalgae to 34% planktonic) indicate a close association to macroalgal production. Greenbone feed predominantly on species such as *Marginariella urvilliana*, *Macrocystis pyrifera*, *Ecklonia radiata* and *Durvillaea* spp. in the South Island of New Zealand (Taylor and Schiel 2010) and *Ecklonia radiata* and *Carpophyllum* spp. in northern New Zealand, with small proportions of hydroids, bryozoans, amphipods and gastropods found in some stomachs (Clements and Choat 1993). Diets of *O. pullus* from the Otago coastline looked to be mainly comprised of *M. pyrifera* and *E. radiata* with a mixture of reds macroalgae species. Furthermore only macroalgal fragments were encountered with no animals. It would be hard to say what exact species of macroalgae *O. pullus* are feeding on from the gut contents as most algae in the gut masticated into small pieces. This was also found by Clements and Choat (1993).

The small carnivorous triplefin species *Forsterygion varium* (variable triplefin) isotopic values fall between those of blue cod and blue moki but with a slightly higher $\delta^{15}$N value (trophic level). The results from the mixing model indicate 65% of organic matter is derived from macroalgal and 35% planktonic productivity. This species has been recorded feeding upon gammarid amphipods, euphausiid shrimp, crabs, hermit crabs, bivalves and small fishes (Paulin and Roberts 1992; Francis 2001). Feary *et al.* (2009) found that small crustacea was its main prey, with gammarid amphipods the dominant component in northern New Zealand. The isotopic signature of amphipods was more enriched in $\delta^{13}$C than all fish species, suggesting although amphipods are a major component of its diet other planktonic (planktonic) derived organic matter is also important to *F. varium*. 
**Soft sediment and pelagic fish species**: Soft sediment and pelagic species were also closely associated to macroalgal productivity (Figure 4.5). The diet of these fish species is poorly known but based on the data obtained from the stomach analysis in this study, the taxonomic group that these fish species were feeding upon are similar to that of the reef fish (Table 4.3).

The pelagic predatory barracouta (*Thyrsites atun*) adults and juveniles had very similar $\delta^{13}$C isotopic signatures (Figure 4.5). Results from the mixing model reveal that this species was least reliant upon macroalgal productivity of all soft sediment and pelagic fish species (Figure 4.4) (73% and juveniles 84%). This result was unexpected as *T. atun* is known to predate small fishes, crustaceans and squid (Mehl 1970, Russell 1983). In this study *T. atun* were observed to have consumed only a few differing taxonomic groups consisting of whale krill (*Munida gregaria*), euphausiid shrimp and small fish. Graham (1973) observed that adults barracouta prey species were predominantly small fish (sprats, pilchards and ahuru), whale krill (*M. gregaria*) and squid. Juveniles on the Otago coastline have been observed feeding on small crustaceans such as amphipods and larval yellow-eyed mullet (<3 cm).

The red gurnard (*Chelidonichthys kumu*) isotopic $\delta^{13}$C values were the same as barracouta but at a higher trophic level. The mixing model suggests that 82% of organic matter is derived from macroalgal productivity. *Chelidonichthys kumu* is thought to feed predominantly on crabs, euphausiid shrimp, small fish and polychaetes (Francis 2001). Graham (1973) examined over 250 stomachs from the Otago coastline and observed several fish species (pilchards, sprats, garfish, red cod etc); seven species of shellfish, octopus, squid and polychaete worms. Shrimp and other crustaceans were also observed as well as nine species of crab, which were the most abundant taxonomic group consumed. The stomach analysis of the gurnard in this study found crabs, gastropods and bivalves. Most gut contents however were well digested with few fish having much more than fragments of prey items.

The flat fish species flounder (*Rhombosolea plebeia*) and sole (*Peltorhamphus novaezeelandiae*) has very similar $\delta^{13}$C values, but sole’s trophic level was higher (Figure 4.5). The results from the mixing model suggest that 98% (flounder) and 95% (sole) of organic matter comes from macroalgal productivity (Figure 4.6). These percentages reveal that these two species are the most closely associated to macroalgal productivity of all fish in this study. These species are thought to feed predominantly upon polychaete worms, crabs, shrimps, amphipods, brittlestars and small shellfish (Francis 2001). Graham (1973) observed that these species within Blueskin Bay consume small fish (ahuru (*Auchenoceros punctatus*)) and pilchards (*Sardinops neopichardus*), several species of bivalves (cockle (*Austrovenus*...
stuchburyi)) squid, octopus crabs, whale krill (*Munida gregaria*) as well as amphipods, isopods and brittlestars. Polychaetes were also a major part of diets making up the greatest part, with crustaceans and bivalves. Also within all stomach contents the macroalgal species *Ulva* and *Zostera* were found, suggesting foraging within estuarine areas. These prey items suggest that the foraging behaviour of these species is related strongly to macroalgal productivity from the *Ulva* and *Zostera* found in the estuaries in which these fish are known to forage and be caught at certain times of the year (Francis 2001). Within the Blueskin Bay area estuaries with extensive beds of *Zostera* and *Ulva* (especially in late winter and spring for *Ulva* when it blooms) exist. Macroalgae are then washed out of the estuaries and are carried along the coast settling upon soft sediments and rocky reef areas (Hepburn *et al.* (unpublished data)). The size of the sole caught could have also have had an impact on the isotopic signatures obtained as all were of a small size (>15 cm) and could be feeding upon small crustacean such as amphipods which are shown to be closely associated to macroalgal productivity (Figure 4.2).

The highly transient pelagic school shark (*Galeorhinus galeus*) isotopic values were the most enriched in δ¹³C of all species caught in this study (Figure 4.5). The mixing model indicates that over 100% of productivity is associated with macroalgae (Figure 4.6). As this cannot be a true value this suggests that school shark has other sources of productivity that are not accounted for by sources in this study as mentioned by McCutchan *et al.* (2003). School shark are thought to be highly migratory within New Zealand waters with tagged individuals recaptured in Australasian and South American waters (Olsen 1954, Peres and Vooren 1991, Punt and Walker 1998). Gut contents within this study were fairly consistent with what was found by Graham (1973) with small pelagic and flatfish, squid, octopus and whale krill (*Munida gregaria*), found which suggested to Graham (1973) that they feed at any depth. School shark are not thought to be present in Blueskin Bay year round with breeding individuals moving in during summer and leaving during winter. The isotopic values suggest that they are closely associated to macroalgal productivity, but the mixing model results suggest possible oceanic productivity from offshore waters where enrichment of δ¹³C can reach -28% (Degens *et al.* 1968).

The reliance of reef, soft sediment and pelagic species of fish suggests macroalgal productivity is an important source of organic matter for food webs associated to rocky reefs and surrounding soft sediment areas. The net transport of macroalgae in the form of detrital drift provides usable energy as a driving force in food webs close to the reefs. Temperate reefs other than providing critical habitats for reef fish, benthic invertebrates (chapter 2) and
epifauna (chapter 3) also transport productivity to surrounding areas. Oceanic planktonic productivity along the north Otago coast is only a minor component of this coastal food web according to my results. Planktonic production is thought to be an important component driving coastal food webs, especially for islands. Kaehler et al. (2000) found that on the Sub-Antarctic Prince Edward Islands the majority of productivity for higher trophic level consumers came from planktonic productivity. An important system within the coastal zone that is driven by macroalgal productivity is estuaries, where a significant portion of organic matter is derived from macroalgae and terrestrial plants (Kwak and Zedler 1997, Melville and Connolly 2005, Alfero et al. 2006). In a study by McLeod and Wing (2008) found that terrestrial organic matter drives the inner fjords in Fiordland due to chemoautotrophic productivity. However on the outer Fiordland coastline, it has been shown that macroalgae are the primary driver for fish species such as Parapercis colias (Rodgers and Wing 2008) and similar proportions of macroalgae and planktonic productivity for wrasse species spotty (Notolabrus celidotus), banded wrasse (Notolabrus fucicola) and scarlet wrasse (Pseudolabrus miles) (Davis 2010 in prep).

Coastal macroalgal beds and kelp forests through detrital pathways are known to subsidise and fuel intense secondary productivity in offshore soft sediment and coastal habitats (Duggins et al. 1989, Vetter 1995, Harrold et al. 1998, Vanderklift and Wernberg 2008). This is thought to occur through the net offshore transport through coastal currents and eddies of detrital macroalgae, which accumulates in seafloor depressions and submarine canons (Harrold 1998). Vetter (1995) found that a submarine canyon off California within dense detrital accumulations of detrital macroalgae harbors an assemblage of leptostracan and amphipod crustaceans whose density and productivity are extremely large supporting communities of fish and invertebrates. It is thought that this process could be occurring on the Otago coast where detrital macroalgae especially Macrocystis pyrifera, detached during storms settles out onto sandflats of the north Otago coast and supports secondary production there. This drift algae would likely support amphipods and other epifaunal species, which are fed upon by the soft sediment and pelagic species of fish sampled in this study.

4.4.3 Seasonality of carbon $\delta^{13}C$ and $\delta^{15}N$ signatures

The variability of stable isotope signatures between seasons was obvious from the plot of winter and summer values for $\delta^{13}C$ and $\delta^{15}N$ (Figure 4.3). The spotty (Notolabrus celidotus) shifted down an entire trophic level from winter to summer, suggesting a possible prey shift between the two seasons from mussels and crabs to a diet of amphipods and
euphausiid shrimps etc. The other two reef fish species banded wrasse (*Notolabrus fucicola*) and blue cod (*Parapercis colias*) only varied a small amount, with small changes in $\delta^{13}C$ and $\delta^{15}N$ signatures observed. A possible explanation for these shifts observed could be due the prey sources isotopic makeup of $\delta^{13}C$ and $\delta^{15}N$, which are thought to differ between seasons (Hepburn *et al.* unpublished data). This has been found by (Fredrikson 2003) by which grazers within a *Laminaria hyperborea* kelp forest were relatively isotopically depleted during spring compared to autumn. Many reef fish species are known to be opportunistic predators, which will feed upon any suitable prey source if it is available (Choat and Kingett 1982, Russell 1983). Furthermore shifts were observed in planktonic and macroalgal source pools, where large shifts are found from winter to summer. Planktonic (SPOM) values for $\delta^{13}C$ and $\delta^{15}N$ were relatively stable compared to macroalgae. All macroalgal species used as source values showed marked shifts in both $\delta^{13}C$ and $\delta^{15}N$ from winter to summer (Hepburn *et al.* (in press)). Within the macroalgae source pools this shift is most pronounced in the species *Carpophyllum flexuosum*, which shifted from $-18$ to $-15 \%$ in $\delta^{13}C$ and $4.5$ to $7.5 \%$ in $\delta^{15}N$ values from winter to summer. The other species *Cystophora retroflexa* and *Ecklonia radiata* underwent a shift from around $-19$ to $-17 \%$ for $\delta^{13}C$ and a shift in $\delta^{15}N$ of around one. *Macrocystis pyrifera* did not change very much between the seasons (Figure 4.2). These changes in source pool are due to changes in seawater chemistry, which is thought to be carbon $\delta^{13}C$ light during winter and nitrogen switching from nitrate (NO$_3^-$) in winter to ammonium (NH$_4^+$), which is isotopically enriched (Hepburn *et al.* (in press)).

**4.4.4 Trophic levels of fish**

The relative trophic levels for fish species in this study were fairly similar between reef and soft sediment/pelagic associated species. These assumed feeding trophic levels should be however treated with caution. The trophic level shown for greenbone (*Odax pullus*) is rather high for a species that feeds predominantly on macroalgae. Barracouta (*Thyrsites atun*), which are known to feed at high trophic levels upon other small fishes is rather low. The wrasse species spotty (*Notolabrus celidotus*) and banded wrasse (*Notolabrus fucicola*) are at a relatively high trophic level and are known to feed upon mussels (which consume suspended organic matter either planktonically derived or slothed off macroalgae) and small gastropods (which are assumed to graze directly upon macroalgae). Another surprising result was the high trophic level of variable triplefin (*Forsterygion varium*), which was one of the highest of all fish. This species is a small benthically feeding species, feeding upon small epifaunal species of a low trophic level and this level suggests trophic level two levels higher than where it was assumed it would lie as a lower trophic level feeding fish species. Possible
explanations for the lack of good trophic information is that the assumed fractionation between trophic levels is be highly variable as found by McCutchan et al. (2003). The assumed fractionation between trophic levels in the marine environment can vary from 0.2 to 3.5 per trophic level.

4.4.5 Stomach analysis supporting isotopes

The results obtained from stomach contents analysis support values obtained from the mixing models, which suggest fish gain a high proportion of primary productivity from macroalgae. Most consumed species found in the stomachs of reef fish are either found benthically upon rocky reefs or found within the water column or upon the macroalgae itself (Taylor 1998, Richards 2010). For the soft sediment and pelagic associated fish species, prey species found within their stomachs seem to have their origin along the edges of the macroalgae beds. These fish species were predominantly caught over sand on the edge of the *Macrocystis pyrifera* kelp forest and suggest that most of these species during summer reside close to rocky reef areas feeding on organisms, that gain organic matter from macroalgal productivity, which through detrital processes is available to soft sediment associated prey species (Duggins et al 1989). Furthermore there is a significant bottom trawler fishery within Blueskin Bay and during most of the year it is common to observe fishing boats with nets down fishing close to the rocky reefs over sand. No difference was observed between winter and summer stomach samples. The only observable difference was that winter fish stomachs were either empty or contained small amounts of prey compared to summer, which were usually full. The results should also be treated with caution as they are based on a very small sample size (5 per species) that lack repetition overtime and between sites. It was also not possible to identify many species past broad taxonomic groups, as most soft body species were partly digested. An example of this would be the soft bodied gammarid amphipods, euphausiid shrimp and polychaete worms which in most cases only remnants could be found and make a haphazard guess to actual groupings.

4.4.6 Caveats

Stable isotope analysis provides a powerful tool in food web studies allowing the importance of organic matter source pools to be elucidated providing that the source pools of organic matter have distinct isotopic signatures and do not change considerably over time (Fry 2008). The importance of a good baseline that is relatively stable is important as you cannot trust the basal sources if large variation exists and fractionation is not known (Bearhop et al. 2006). The values for basal carbon from macroalgae were taken in 2008 for macroalgae
and 1997 to 2000 for planktonic and ideally should have been reevaluated in this study. Furthermore, within this study the macroalgal species used for this source pool isotopic signature for both carbon and nitrogen were diverse between species and between winter and summer. Planktonic productivity (SPOM) as a source pool also changed considerably from summer to winter. Replication of samples from fish species within this study was low (3 per fish species) and results should be treated with caution. This study is a good pilot study for further investigation, with greater replication of fish species and sources of organic matter. It would also be helpful to gather prey species such as macroalgal grazers and suspension feeders.

The assumed fractionation values through the food web from aquatic animals obtained from McCutchan et al. 2003 were based on an average for aquatic organisms mainly from the northern hemisphere so the real fractionation for the food in this study could be very different to that used. The sensitivity analysis of the mixing model for Parapercis colias (Figure 4.11 and 4.12) show that this model is sensitive to changes in fractionation values. Also though it is known that nitrogen δ¹⁵N is enriched in tissues through foods webs from the primary producers to consumers and predators, the actual trophic enrichment may vary as a result of both physiological and environmental factors making the need to gather community isotopic information essential to understand these enrichment processes for the communities (McCutchan et al 2006)

The results from the mixing model used only two sources (macroalgae and plankton) to assess the sources of productivity. The results from the fish samples indicated some other sources could also play a role (negative values obtained for planktonic productivity in Galeorhinus galeus (Figure 4.6) and Notolabrus fucicola in winter (Figure 4.8). The results from the mixing model must also be interpreted with caution as they are very vulnerable to natural variability of isotopic signature and consider the other sources of carbon within the community even though they may not be directly incorporated into the food web. To make the model robust the collection of site-specific isotopic signatures for each source of organic matter is essential. Studies have demonstrated large gradients of signatures due to variability in the environmental characteristics (Cornelison et al. 2007). Furthermore the mean value used for basal macroalgae was an average of all species isotopic signatures and should instead have been a proportion of actual production in biomass of the four species with Macrocystis pyrifera and Ecklonia radiata having that greatest biomass and associated productivity associated with them, however this was not possible to quantify accurately at the time of this study.
4.4.7 Conclusions

Macroalgal primary production in coastal food webs has been shown to be important subsidising soft sediment and pelagic associated fish. These results are surprising as it was assumed that reef fish would be tightly coupled to macroalgal productivity and soft sediment/pelagic species would be more closely aligned with planktonic productivity. The mechanism for this to occur involves large amounts of detrital macroalgae settling upon soft sediment areas and supporting secondary productivity there.

The signatures obtained for carbon $\delta^{13}$C and nitrogen $\delta^{15}$N for reef fish species show that wrasse species are reliant upon both macroalgae and planktonic production, while blue moki and blue cod were more tightly aligned to organic matter derived from macroalgae. Each fish species has isotopic signatures that relate to prey choices and feeding preferences.

Soft sediment and pelagic fish species were expected to gain most productivity from planktonic origins, but were subsided by macroalgal primary productivity to a high degree. It would be assumed that these species would feed upon species upon the continental shelf, which would gain most of their productivity from planktonic sources from the water column above.

Natural fluctuation seasonally was observed between winter and summer isotopic signatures for all fish species and source pools (macroalgae and planktonic (SPOM)). This result was expected as most species fluctuate seasonally in isotopic signature due to natural changes in diet for fish and in availability of carbon and nitrogen in coastal waters.

All fish species seemed to occupy a similar trophic level with very little difference found between the species from the mixing models. Greenbone and barracouta occupy a lower trophic level, which was expected for greenbone feeding upon macroalgae directly, but not for barracouta, which are known to be a pelagic schooling fish, feeding predominantly on fish.
CHAPTER FIVE

General discussion and conclusions

A wide range of factors influence the habitat associations of fish and epifauna on the East Otago coastline, including macroalgal habitat, depth, seasons and quality and quantity of reef habitat. The abundance and diversity of reef fish were greatest within *Macrocystis pyrifera* kelp forests and *Ecklonia radiata* beds. The purpose of this chapter is to briefly review the results obtained during this study, discuss the implications in relation to threats posed to the East Otago Taiāpure and make recommendations on how to better protect these habitats from degradation. Macroalgal habitats are highly important within this area as they provide primary productivity, crucial habitats and abundant food sources. This productivity was found to be the primary source of organic matter driving the local rocky reef and soft sediment food webs.

5.1 Relationships of reef dwelling animals to macroalgal habitats

The results obtained in this study indicate reef fish have clear macroalgal habitat preferences for the deeper *Macrocystis pyrifera* and *Ecklonia radiata*. Very few fish were observed in shallow *Carpophyllum flexuosum* and *Cystophora* spp. beds with 91% of fish being found within the two deeper habitats. The mid-depth *M. pyrifera* kelp forest is flanked on its outer edge by *Ecklonia radiata* beds. Reef fish species found in the greatest abundance in this habitat included blue moki (*Latridopsis ciliaris*), spotties (*Notolabrus celidotus*) and banded wrasse (*Notolabrus fucicola*). The only species found in greater abundance in the shallow habitat was greenbone (*Odax pullus*), a herbivorous species that feeds upon *Durvillaea* spp. and *Marginariella* spp. in shallow wave exposed areas (Clements and Choat 1993). The important predator blue cod (*Parapercis colias*) were predominately found on the deeper sections of the reef within the *E. radiata* beds. Close associations of these fish species indicate that *M. pyrifera* kelp forest and the adjacent deeper *E. radiata* beds would be considered to be crucial habitat. *Macrocystis pyrifera* and *Ecklonia radiata* provide habitat complexity but also food sources and protection for fish and invertebrate species.

Among seasons, the abundance and diversity of fish was greatest during summer and least during winter. Marked decreases in abundance within all macroalgal habitats were observed for all fish species. This was most pronounced in blue cod, decreasing from an average of around 1.5 fish per survey replicate in summer to 0.5 in winter. This pattern of reef fish abundance is thought to be due to seasonal migrations to spawning grounds and offshore
movement to deeper warmer waters due to low prey density on reefs during the winter. The wrasse species *Notolabrus celidotus*, *Notolabrus fucicola* and immature blue moki (*Latridopsis ciliaris*) however were found to be resident throughout the year only decreasing slightly in abundance during winter.

Differences in abundance and diversity of fish existed between survey sites within the East Otago Taiāpure. The greatest fish abundance and diversity were found at Matainaka, Brinns Point and Puketeraki sites. These sites are all points with high water movement, sticking out from the coast into deeper waters. They also contain complex reef topography with large guts, overhangs and caves. On these reefs large dense *Macrocystis pyrifera* kelp forests can be found. These results indicate that not just the presence of macroalgae increases fish abundance, but also reef topography can increase the quality of macroalgal habitats to reef fish species.

The epifaunal invertebrate community associated with macroalgal habitats on the East Otago coastline was shown to be tightly associated to specific habitat forming macroalgal species. Within each macroalgal habitat, specific taxon of epifauna dominated the community. The taxon found in highest abundance throughout all habitats were gammarid amphipods, which were found to dominate seaweed simulators deployed in both the *Macrocystis pyrifera* canopy, shallow *Carpophyllum/Cystophora* and benthically within the *M. pyrifera* kelp forest. Gastropods (snails) and crabs dominated coralline cobble simulator epifaunal assemblages within each macroalgal habitat sampled, but were found in greatest abundance within the *M. pyrifera* kelp forest. Small predatory triplefin species were found in greatest abundance within deeper coralline cobble simulators with very few found in shallow habitats. The specificity of epifaunal species to particular macroalgal species such as *Macrocystis pyrifera* indicates a tight relationship, which would be vulnerable to habitat degradation. Loss of habitat would likely lead to decreased numbers of epifauna. These tight relationships between epifauna and habitat indicate an innate link between epifauna and macroalgae and rocky reef habitats. Epifauna lack mobility, due to the small size and sessile nature of most species, making them highly vulnerable to habitat change and degradation associated with large storm events, sedimentation and harvest of macroalgae. If decreases in the extent and biomass of *M. pyrifera* occur on the East Otago coast, this could lead to the reduction of large numbers of epifauna either attached to their surfaces or reliant upon it as a food source through the detrital food web (Duggins *et al.* 1989).
The seasonal abundance of epifauna was observed to be greatest during late spring and summer within seaweed simulators and least during early spring and autumn. Within the coralline cobble simulators, epifauna were observed to increase in abundance the longer the simulators were in the water. The seasonality for mobile epifauna such as amphipods can potentially be explained by the productivity associated to kelp forests being greatest in early spring (Kain 1982, Brown et al. 1997) and population increases during winter due to lower fish predation due to lower fish abundance. Within the coralline cobble simulators, successional colonisation occurred whereby the greatest diversity and abundance of epifauna was found during the autumn sampling as the simulators became more and more heavily encrusted in corallines, diatom films and macroalgae (Sousa 1979).

The trends observed in this study indicate that reef fish species are less tightly associated to specific macroalgal species when compared to epifauna; but are associated with the entire habitat types of the deeper macroalgal reef environments of *Macrocystis pyrifera* kelp forests and associated species. Epifaunal invertebrate communities on the other hand are tightly associated to particular macroalgal species such as *M. pyrifera* canopies. This is thought to be due to the greater mobility of fish, which are able to move between habitat types and reef areas. Epifaunal movement is largely limited due to their small size, limited mobility and inability to move large distances. Specialization of ecological niches and feeding preferences within habitat types are more pronounced in epifauna. Reef fish are highly mobile and less specialized for specific habitats, moving between suitable areas of habitat with abundant food sources on daily and seasonal timeframes (McCormick 1989, Ebeling et al. 1990, Holbrook et al. 1994).

### 5.2 Food webs on the Otago coastline

It has been noted by Fry (2008) that oceanic food webs are influenced primarily by phytoplankton, whereas inshore coastal systems reflect benthic macroalgal productivity. Motile organisms usually do not have isotopic values corresponding to just one primary producer, reflecting access to multiple food sources (Fry et al. 1983). These factors can influence food webs greatly, making elucidation of primary organic matter sources difficult. The possible food web associations along East Otago coastline would start with the primary productivity associated with both macroalgae and phytoplankton. Macroalgae are localised to the reefs close to shore and through movement offshore and settlement entering the detritus; while planktonic productivity is likely entrained by the Blueskin gyre which could move planktonic productivity shoreward (Jillett 1969). Planktonic productivity is likely utilized by the detrital food web and by bivalves (mussels e.g. *Perna canaliculus, Aulacomya maoriana*)
and zooplankton (euphausiid shrimp, whale krill (*Munida gregaria*) etc). The macroalgal productivity and associated biomass would likely to be fed upon directly or indirectly within a detrital food web; with *Macrocystis pyrifera* kelp forest being the major component of drift observed on the East Otago coastline (McLeod and Hepburn (unpublished data)). Macroalgal organic matter sources would be consumed by gastropod grazers such as paua (*Haliotis iris*), cook’s turban (*Cookia sulcata*), cat’s eye (*Turbo smaragdus*), duck’s billed limpet (*Scutus brevicus*) etc and epifauna gammarid amphipods, top shells (*Cantharidus purpureus, Trochus viridis*) etc. These would be likely then preyed upon by predatory invertebrates such as starfish (*Astrostole scabra*), crayfish (*Jasus edwardsii*) crabs (*Ovalipes cantharus*) and reef fish. As macroalgae play an important role as a source of organic matter, therefore it is possible that soft sediment and pelagic associated fish species prey on species associated with macroalgal dominated reefs; as indicated in the simplified schematic on the next page.
**Figure 5.1** Schematic of the possible coastal food web in the East Otago Taiāpure. Starting at the top with two primary productivity sources phytoplankton (left), macroalgae (right). Macroalgal productivity becomes detrital material consumed directly by grazers and epifauna. Phytoplankton would be consumed by bivalves, zooplankton and epifauna. All consumers are likely preyed upon by invertebrate predators and by soft sediment and pelagic and reef associated fish predators. Arrows indicate flow of organic matter through food web. Arrow colours indicate initial organic matter source: blue = planktonic, orange = macroalgal, red = combination and black = possible pathways. Large arrows = major pathway and small arrows = minor pathways of organic matter through the food web.
5.4 Identification of critical habitats for use in future East Otago Taiāpure management decisions

The results from the fish surveys indicate that for reef fish *Macrocystis pyrifera* kelp forests and *Ecklonia radiata* beds are highly important habitats. The results from the simulator suggest that *M. pyrifera* canopies and coralline cobble rocky areas are important habitats as they harbour a large biomass of epifauna found upon rocky coastal areas. *Macrocystis pyrifera* kelp forests thus would be considered a key habitat forming species within the East Otago Taiāpure, which provides abundant food sources, protection from predators, shelter from waves and habitat for many species of fish and invertebrates and epifauna (Dayton 1985, Hepburn *et al.* 2006).

Macroalgal habitats are under threat on the East Otago coastline and two threats of concern are sedimentation and harvest. A proposed deepening of the Otago harbour is currently under consultation, which will dump over 7 million tonnes of sediment in the area (Port Otago website 2010). This sediment will likely be entrained by the Blueskin gyre bringing it back onto the reefs along the north Otago coastline. *Macrocystis pyrifera* kelp forests are very sensitive to sedimentation (Devlinny and Volse 1978). Long-term data from studies in the North Pacific suggests that sedimentation is a key factor in the loss of *M. pyrifera* kelp forests (Foster and Schiel 2010) and anecdotal evidence from within New Zealand supports this. Dense *M. pyrifera* kelp forest existed at the Taieri River mouth south of Dunedin in the past, but due to increased riverine sediment inputs they have disappeared (C. Hepburn (pers. comm.)). High sediment loads within the Taiāpure would lead to loss of rocky reef habitats due to smothering of reefs in the long term. The direct effects upon macroalgae are loss of water clarity and inhibition of growth for new kelp recruits (Devlinny and Volse 1978). The growth of *Macrocystis pyrifera* is largely light limited on the East Otago coastline (Brown *et al.* 1997, Hepburn *et al.* 2005). Increases in sediment load will lead to lower water clarity near rocky reefs (related to dumping of dredge spoil), which will reduce the light levels reaching macroalgae, thereby reducing levels of photosynthesis. These effects will decrease the productivity of associated macroalgae resulting in flow on affects to local fisheries.

Recently the Ministry of Fisheries introduced *Macrocystis pyrifera* into the quota management system. The harvest of this crucial habitat for fish and epifauna will lead to decreased productivity in Taiāpure due to loss of associated biomass, which will be removed through the harvest of *Macrocystis* kelp forests (MFish info website 2010). The effects of this harvesting upon southern New Zealand kelp forests are largely unknown, with little
information available on the impact of harvesting kelp and affects on associated reef fish life histories. Foster and Barilotti (1990) found that harvesting of kelp affects productivity and natural growth patterns. McClenehan and Houk (1985) found that the removal of kelp canopies leads to lower growth and fewer divisions of haptera (new apical meristems) after harvest thus reducing productivity. Furthermore, the effect of kelp harvesting on the productivity of communities adjacent to macroalgal habitat may be substantial. Macroalgae have been shown to provide significant detrital biomass that is utilized by animals within soft sediment habitats (Vetter 1995). This was found in this study in which primary productivity for reef, soft sediment and pelagic fish species was provided by macroalgae.

5.5 Future research

Future research within this area would involve yearly fish surveys to understand the longer temporal scales of reef fish changes in abundance. Monitoring of reef fish populations should also be carried out to see if reduced bag limits for recreational fishermen, which were established in October of 2010, are successful in increasing fish stocks within the East Otago Taiāpure.

Future research upon epifaunal communities is needed to further characterize habitat preferences and associated biomasses. This could involve sampling throughout a year and replication of simulators at several sites within differing habitats.

With the threat of sedimentation and harvest of kelp forests, a useful future study could involve looking at the effects of increased sedimentation on *Macrocystis pyrifera* kelp forests. Also, experiments could be done looking at the effects of harvest and the removal of kelp biomass from the system. This would lead to a better understanding of the accumulative effects upon macroalgal beds due to current and future threats and how to manage them. Another possible future study related to modification of kelp forests would look at the effects of kelp loss on epifaunal species and reef fish populations, observing the affects of decreased and modified areas of kelp forest to the productivity of the area.

A study currently in progress relates to food webs of the East Otago coastline, which will expand on the study carried out in chapter four. This study will involve greater replication of fish species from different areas and site-specific sampling of source pools for both macroalgae and phytoplankton. To gain a better understanding of the feeding trophic levels of fish, sampling of key prey items such as grazers and other reef-associated invertebrates will be completed. This study is important as it will enable a better understanding of the food webs associated to macroalgal productivity and the mechanism
behind kelp forests subsidising pelagic and soft sediment associated fish species. By gaining this understanding this will enable informed advocates for better protection and management of coastal macroalgal beds and forests.

5.6 Conclusions

- High quality macroalgal habitat is vitally important to reef fish and epifaunal species especially *Macrocystis pyrifera* kelp forests and *Ecklonia radiata* beds.
- Macroalgal productivity drives food webs on the East Otago coastline providing a great proportion of organic matter to reef, soft sediment and pelagic finfish species.
- Reef fish species use both planktonic and macroalgal driven organic matter but a significant proportion comes from macroalgal productivity.
- Soft sediment and pelagic associated fish species derive over 90% of their primary productivity from macroalgal carbon sources according to mixing models. This could be due to export of macroalgae as detrital materials to offshore to soft sediment habitats.
LITERATURE CITED


Taiōpure guiding principals Document. (2010). Contact admin@puketeraki.co.nz.


APPENDIX I

Chapter Two fish surveys PERMANOVA pairwise comparisons for all significant results

Pairwise comparisons of reef fish differences between seasons from the PERMANOVA analysis.

<table>
<thead>
<tr>
<th>Groups</th>
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Pairwise comparisons of reef fish differences between sites from the PERMANOVA analysis.

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Pairwise comparisons of reef fish differences in diversity between macroalgal habitats from the PERMANOVA analysis.

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Pairwise comparisons of reef fish differences in diversity between macroalgal habitats from the PERMANOVA analysis.

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Pairwise comparisons of reef fish differences in diversity between seasons from the PERMANOVA analysis.

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Pairwise comparisons of reef fish differences in diversity between survey sites from the PERMANOVA analysis.

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Pairwise comparisons of macroalgal species differences in assemblage between macroalgal habitats from PERMANOVA analysis.

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Pairwise comparisons of macroalgal species differences in community between seasons from PERMANOVA analysis.

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Pairwise comparisons of macroalgal species differences in assemblage between survey sites from the PERMANOVA analysis.

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Pairwise comparisons of benthic invertebrate species differences in assemblage between macroalgal habitats from the PERMANOVA analysis.

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Pairwise comparisons of benthic invertebrate species differences in assemblage between seasons from the PERMANOVA analysis.

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Pairwise comparisons of benthic invertebrate species differences in assemblage between survey sites from the PERMANOVA analysis.

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<td>Matainaka, Butterfly Bay</td>
<td>1.2543</td>
<td>0.132</td>
<td>999</td>
</tr>
<tr>
<td>Matainaka, Puketeraki</td>
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<tr>
<td>Matainaka, Brinns point</td>
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<td>Matainaka, Omimi</td>
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<tr>
<td>Butterfly Bay, Puketeraki</td>
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<tr>
<td>Butterfly Bay, Brinns point</td>
<td>1.2062</td>
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<tr>
<td>Butterfly Bay, Omimi</td>
<td>2.1217</td>
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<td>998</td>
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<tr>
<td>Puketeraki, Brinns point</td>
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<td>0.031</td>
<td>999</td>
</tr>
<tr>
<td>Puketeraki, Omimi</td>
<td>2.2435</td>
<td>0.002</td>
<td>998</td>
</tr>
<tr>
<td>Brinns point, Omimi</td>
<td>2.0999</td>
<td>0.004</td>
<td>999</td>
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</tbody>
</table>
APPENDIX II

Chapter Three simulators PERMANOVA pairwise comparisons for all significant results

Pairwise comparisons of seaweed simulators epifaunal assemblage differences between macroalgal habitats from the PERMANOVA analysis.

<table>
<thead>
<tr>
<th>Groups</th>
<th>T</th>
<th>P (perm)</th>
<th>Perms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cystophora/Carpophyllum, Macrocystis</td>
<td>1.5659</td>
<td>0.019</td>
<td>999</td>
</tr>
<tr>
<td>Cystophora/Carpophyllum, Ecklonia</td>
<td>2.3491</td>
<td>0.001</td>
<td>999</td>
</tr>
<tr>
<td>Cystophora/Carpophyllum, Macrocystis canopy</td>
<td>2.635</td>
<td>0.001</td>
<td>998</td>
</tr>
<tr>
<td>Macrocystis, Ecklonia</td>
<td>2.7957</td>
<td>0.001</td>
<td>999</td>
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<tr>
<td>Macrocystis, Macrocystis canopy</td>
<td>2.6429</td>
<td>0.001</td>
<td>999</td>
</tr>
<tr>
<td>Ecklonia, Macrocystis canopy</td>
<td>4.2977</td>
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<td>999</td>
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</table>

Pairwise comparisons of seaweed simulators epifaunal assemblage’s differences between sampling dates from the PERMANOVA analysis.

<table>
<thead>
<tr>
<th>Groups</th>
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<th>P (perm)</th>
<th>Perms</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.001</td>
<td>997</td>
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<tr>
<td>16/11/2009, 7/1/2010</td>
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<tr>
<td>16/11/2009, 23/4/2010</td>
<td>2.5094</td>
<td>0.001</td>
<td>996</td>
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<tr>
<td>7/1/2010, 23/4/2010</td>
<td>2.3745</td>
<td>0.001</td>
<td>999</td>
</tr>
</tbody>
</table>

Pairwise comparisons of coralline cobble simulators epifaunal assemblage differences between macroalgal habitats from the PERMANOVA analysis.

<table>
<thead>
<tr>
<th>Groups</th>
<th>T</th>
<th>P (perm)</th>
<th>Perms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cystophora/Carpophyllum, Macrocystis</td>
<td>1.5829</td>
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<tr>
<td>Cystophora/Carpophyllum, Ecklonia</td>
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<td>0.065</td>
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<tr>
<td>Cystophora/Carpophyllum, Macrocystis canopy</td>
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<td>0.001</td>
<td>997</td>
</tr>
<tr>
<td>Macrocystis, Ecklonia</td>
<td>4.2955</td>
<td>0.001</td>
<td>998</td>
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<tr>
<td>Macrocystis, Macrocystis canopy</td>
<td>4.6567</td>
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<tr>
<td>Ecklonia, Macrocystis canopy</td>
<td>9.8792</td>
<td>0.001</td>
<td>993</td>
</tr>
</tbody>
</table>

Pairwise comparisons of coralline cobble simulators epifaunal assemblage differences between sampling dates from the PERMANOVA analysis.

<table>
<thead>
<tr>
<th>Groups</th>
<th>T</th>
<th>P (perm)</th>
<th>Perms</th>
</tr>
</thead>
<tbody>
<tr>
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<td>21/9/2009, 7/1/2010</td>
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<td>16/11/2009, 7/1/2010</td>
<td>3.2549</td>
<td>0.005</td>
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<tr>
<td>16/11/2009, 23/4/2010</td>
<td>7.2671</td>
<td>0.001</td>
<td>995</td>
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<tr>
<td>7/1/2010, 23/4/2010</td>
<td>4.3294</td>
<td>0.002</td>
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</tbody>
</table>