A sampling programme to construct and quantify fish food-webs on the Chatham Rise

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7. Executive Summary

The energetics and trophic interactions of fish and invertebrates are not well studied in New Zealand, particularly in offshore fish communities. This report presents the rationale for determining the diet of hoki and other species that form 95% of the middle depth fish biomass on the Chatham Rise, an area of relatively high commercial fishing activity, rich biodiversity and high productivity.

The ontogenetic, seasonal, annual, and spatial variation in predator-prey relationships will be investigated through the reconstruction of fish diet compositions and daily consumption for major predators, based primarily on stomach contents of fish on the Chatham Rise. The resulting information will provide baseline biological information on the feeding habits and annual consumption rates of the more abundant fish species found in middle depths (200-800 m) on the Chatham Rise. This diet composition and consumption information will be used to estimate dietary overlap and potential competition between predators. It will also be used as input to ecosystem models that describe temporal and spatial variation in energy fluxes on the Chatham Rise. The feasibility of using the new data to calibrate historical stomach content records from the Chatham Rise should be also assessed.

The proposed work is seen as a first step to directly improve our knowledge and understanding of feeding interrelationships in an important New Zealand marine ecosystem, and provide a baseline on which to assess the indirect effects of fishing on the Chatham Rise. Future work will need to incorporate predator-prey relations from species found at depths greater than 800 m.

8. Objectives:

To design a sampling programme to collect relevant data for the construction and quantification of food-webs supporting important fish and invertebrate species. (MFish Project Code ENV2002/07, Objective 1).

Specific Objective

1 To design a sampling programme to collect relevant data for the construction and quantification of food-webs supporting important fish species on the Chatham Rise.

9. Methods: See attached report.

10. Results: See attached report.

11 Conclusions: See attached report.

12. Publications: None.

13. Data storage: This work did not generate any new data.

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1. INTRODUCTION

There is currently a worldwide sense of urgency to re-evaluate fisheries management and stock assessment procedures within an ecological context. Growing evidence on the anthropogenic degradation of marine ecosystems (e.g., Pauly et al. 1998; Caddy 2000, Clark 2001; Pitcher 2001 Caddy 2002; Pauly et al. 2002) has resulted in a call for substantial improvement on the understanding of ecosystem structure and functioning to develop useful conceptual and analytical tools that will broaden the approach taken in fisheries management (Sainsbury et al. 2000). Within New Zealand, fish harvesting levels have risen rapidly since 1975 (Figure 1) in all depths, and fishing mortality on some stocks has been extremely high in recent years. For example, fishing mortality on the western hoki stock has risen to over 70% in recent years (Figure 2). In fisheries such as hoki where the population dominates the fish community so extensively in areas such as the Chatham Rise (Bull et al 2000), and fishing is on such a wide-scale, one might expect there to be some direct and indirect effects of fishing.

An ecosystem approach to fisheries (EAF) requires taking into account several important classes of interactions that are not valuated by species-by-species stock assessments or fishery-based management programs. One of the indirect effects of harvesting on ecosystems involves alterations of feeding relationships and energy flows between trophic levels (Sissenwine & Murawski 2004). Hollowed et al. (2000) emphasized the need for data to support research on the fundamental processes that regulate populations, in particular, competition (food limitation), predation and environmental variability so as to tease out natural changes from the effects of fishing which can substantially alter predator-prey relations within a fish community. Understanding and quantifying marine food-web structures are integral parts of this research.

Although significant advances in understanding marine food-webs have been made, it is clear that the task is complex. Thousands of predator-prey interactions may exist within an ecosystem. Further, most predators in marine ecosystems are generalist rather than specialist in their dietary intake, and can switch between different prey species from a number of trophic levels (Link 2002). This switching depends on the preferences of the predator, and on the relative abundances of different acceptable prey species. This “feeding omnivory” (terminology used to describe feeding from more than one trophic level, Link 2002) means that food-webs in marine ecosystems are complex, with many, relatively weak predator-prey linkages, rather than dominant trophic chains seen in more closed systems. The complexity and flexibility of marine food-webs adds to the range of possible indirect effects of fishing on marine ecosystems, and means that a simple picture of “who-eats-who” is insufficient to understand ecosystem functioning. Instead, quantified sampling which allows the determination of dietary overlap at species level and trophic guild level, and ultimately quantify how energy is transferred though the ecosystem by estimating consumption rates of key species, is more appropriate. Ultimately, ecotrophic modeling can be used to explore the the ‘interplay of fishing and predation’ on ecosystems (Bundy 2001).

Many feeding studies, based on stomach contents of fish, have been carried out in localized areas of New Zealand (Table 1.). Some relate to inshore commercial species such as snapper or barracouta, and a few to deeper offshore species (Table 1). Most of these studies are the results from MSc or PhD studies and are not broad-scale ecosystem studies. The most extensive data has been collected for species such as orange roughy and oreos living at depths greater than 800 m from several areas of New Zealand (Clark et al 1989, Rosecchi et al 1988). Another study examined the feeding habits and dietary overlap of 8 species in the Sub-

Antarctic and was able to identify feeding guilds in middle depths (200-800 m) and potential competitive interactions (Clark 1985). These data were used as inputs for the fish component in an ecotrophic model developed for the Sub-Antarctic, but were described as seriously limited in terms of determining competition between pisciverous fish and other fish feeders such as squid, seabirds and mammals (Bradford-Grieve et al. 2003).

The recording of stomach contents from commercial species during trawl surveys has been routine practice by sea-going science staff on research vessels, and charter vessels since the mid-eighties. Several species have been 'biologically sampled' for information on gonad condition and length-weight relationships, and also the fullness of the stomach, the state of digestion and identification of prey items, with a by-eye assessment of the relative volume of each prey item from almost every station occupied during such surveys (Appendix 1). This potentially provides a huge stomach content database for examining longterm trends in the diet of key species (Table 2). A major shortcoming in this stomach content data is, however, the highly variable taxonomic resolution in the identification of prey items. This has been a combination of the degree of digestion, the experience of individuals examining the stomachs, and not least, conflicting priorities for time at sea. Another important shortcoming is the absence of weight measurements of the stomach contents. This is largely because of the difficulty of measuring weights less than 1 gram with any degree of accuracy at sea. By assessing the fullness of the stomachs without weighing them, annual consumption rates required for ecotrophic modeling cannot be estimated. An extensive piece of work to summarise the stomach content data from New Zealand waters generally, including trawl surveys, drew up tables describing the importance of prey items in diets in terms of percent occurrence, but did not attempt to make any firm conclusions about the proportional dietary content for individual fish species (Stevens et al. in prep.). Livingston (2004) attempted to draw up food-webs using the information presented by Stevens et al. characterizing the percent occurrence of 6 principle prey groups (mesopelagic fish, bottom dwelling fish, midwater crustaceans, benthic crustaceans, tunicates, squids and benthic molluscs) in the diets of the 25 species listed in Table 2. Quantification of dietary overlap, however, was not possible. Also there is no information available on consumption rates, nor gastric evacuation.

Table 1. Published feeding studies of fish in New Zealand

Fish studied	Reference	Fish studied	Reference
Barracouta	O'Driscoll 1998	Plankton & predators*	Fenwick 1978
Blue cod	Rapson 1956	Red cod	Habib 1975
Coastal fishes	Graham, 1938	Red gurnard	Ingerson 1996
Deepwater species*	Clark & King 1989	Rig	King & Clark 1984
Estuarine fishes	Webb 1973	Silver roughy	Kerstan 1989
Flatfishes*	Livingston 1987	Slender smoothhound	Yano 1993
Groper	Johnston 1983	Snapper	Colman 1972
Hoki	Kuo & Tanaka 1984	Snapper*	Godfriaux 1970
Kahawai	Baker 1971	Southern blue whiting,	Schpak 1976
Lemon sole	Rapson 1940	Spiny dogfish	Hanchet 1991
Ling	Mitchell 1984	Tarakihi	Godfriaux 1974a
Mid-depth species*	Clark 1985a,b	Trevally	James 1972
Orange roughy	Rosecchi et al. 1988	Warehous	Gavrilov & Markina 1979
Oreos*	Clark et al. 1989		

Much can be gained from quantitative characterization of the diet of fish species, including identification of guild levels and potential competitive interaction between them (Goldsworthy et al. 2001). By focusing on abundant and high biomass species it is possible to

construct realistic models of mid- to upper level trophic interactions that influence total mass and energy flows within a system. Combining such work with quantified primary production and lower trophic processes makes it possible to develop both stationary and dynamic models of trophic relationships within an ecosystem.

There has been some development of trophic modeling of New Zealand inshore and offshore marine ecosystems but this approach has only been applied to the Sub-Antarctic (Bradford-Grieve et al 2003). Work is underway at the time of writing to determine the rates of carbon transfer within the shelf system off the northeast coast of the North Island (Dr. Janet Grieve, NIWA pers. com.), and the Chatham Rise (Dr. Matt Pinkerton, pers. com.). As already stressed, a lack of quantitative data on the diets of fishes in New Zealand limits understanding of the ecology of fish assemblages in New Zealand (Bull et al. 2000, Francis et al. 2001), and the trophic structure of our marine ecosystems (Bradford-Grieve et al. 2003).

A review to identify possible ecosystems (Appendix 2) suitable for ecotrophic studies that maximizes the use of existing research programmes (MFish and PGSF funded projects) and other sampling opportunities through Observer Programmes, identified the Chatham Rise and the Sub-Antarctic as two areas of important fisheries as useful starting points (Livingston 2004). The two areas are oceanographically quite different, with contrasting biodiversity and productivity levels. There is an ongoing commitment to monitor these areas with fisheries based and fisheries independent data collection for stock assessment purposes, and there has already been a lot of work already published on lower trophic levels, particularly on the Chatham Rise (see Livingston 2004). The Chatham Rise is also seen as an important area for ongoing ecosystem research and funding is being sought elsewhere by NIWA to carry out baseline research in this area. In consultation with the Ministry of Fisheries, a sampling program to focus on the feeding dynamics within the middle depths fish community on the Chatham Rise has been developed and is presented here as the first step towards collecting baseline, quantitative dietary information for use in determining the trophic interactions within the Chatham Rise fish community. The programme is designed to characterise and identify variability in the diets of the top 30 species, primarily from stomach samples, over a 3 year period.

Table 2. Total number of stomachs examined from trawl surveys of 25 commercial species in different areas of New Zealand (after Stevens et al. in prep.).

Species	Median depth (m)	Chatham Rise	Sub-Antarctic	East Coast South Island	North Island	Challenger, West Coast South Island	Total number stomachs examined	Number of stomachs containing food	Proportion of stomachs containing food
Alfonsino	400	61	0	0	304	0	365	162	0.44
Banded stargazer	250	0	406	0	0	0	406	370	0.91
Blue cod	50	0	39	92	0	0	131	60	0.46
Blue warehou	100	0	974	0	0	0	974	844	0.87
Bluenose	450	52	3	0	165	4	224	62	0.28
Dark ghostshark	400	50	175	0	0	1	226	91	0.40
Gurnard	80	0	1	986	0	0	987	299	0.30
Hapuku	250	52	267	0	0	0	319	149	0.47
Lookdown dory	500	20	0	0	509	3	549	206	0.38
Peruvian mackerel	250	52	362	0	0	0	414	200	0.48
Pale ghostshark	600	45	47	0	0	17	109	77	0.71
Seaperch	400	28	0	266	0	2	296	124	0.42
White warehou	400	204	58	0	0	0	262	179	0.68
Black oreo	1 000	4 944	1 338	0	0	0	6 282	872	0.14
Gemfish	300	6	1 103	0	0	0	1109	581	0.52
Giant stargazer	300	78	1 917	1 475	0	0	3 470	2 734	0.79
Hake	600	3492	2 684	0	11	1 265	7 452	2 315	0.31
Red cod	400	20	263	3 420	0	0	3 703	1 864	0.50
Silver warehou	400	1279	714	0	28	1	2 022	1824	0.90
Smooth oreo	1 200	6 271	1 639	0	194	21	8 125	2 557	0.31
Southern blue whiting	550	43	5 814	0	0	0	5 857	2 358	0.40
Barracouta	200	2 678	4 879	3 594	1 487	2 904	15 542	7 505	0.48
Ling	500	6 386	11 004	0	374	238	18 002	7 189	0.40
Hoki	600	11 267	18 078	0	3 202	1 198	33 745	14 170	0.42
Orange roughy	900	52 881	6 067	0	24 006	23 034	105 988	30 498	0.29
Total		89 909	57 832	9 833	30 280	28 688	216 559	77 290	

2. THE CHATHAM RISE: BACKGROUND

The Chatham Rise is a prominent bathymetric ridge that projects about 500 nautical miles (n. miles) east from Banks Peninsula on the east coast of the South Island to the Chatham Islands (Figure 3). It is characterized by the Subtropical Front (STF), an area of convergence between two major water masses, Subtropical water (STW) to the north and Sub-antarctic water (SAW) to the south (Figure 4). Primary productivity is relatively high along the Chatham Rise compared with other offshore areas (Bradford-Grieve et al. 1997, 1998, 1999, Chang & Gall 1998, Murphy et al. 2001). Zooplankton productivity may also be high (Bradford 1980, McClatchie et al. 2004) and mesopelagic biomass has been reported as high (McClatchie & Dunford 2003). The high productivity is widely believed to be the underlying reason why the Chatham Rise supports major fisheries such as barracouta (*Thyrsites atun)*, jack mackerel (*Trachurus spp.*), hoki (*Macruronus novaezelandiae*), hake (*Merluccius australis*), ling (*Genypterus blacodes*), and silver warehou (*Seriolella punctata*), to depths of about 800 m, and orange roughy (*Hoplostethus atlanticus*) and oreos (black oreo, *Allocyttus niger,* smooth oreo, *Pseudocyttus maculatus,*spiky oreo, *Neocyttus rhomboidalis*) in deeper waters (Annala et al. 2004). It may also be the reason for the presence of hotspots in demersal fish diversity (McClatchie et al. 1997) and high benthic biomass and diversity in the area (Nodder et al. 2003, Probert & McKnight 1993, Probert et al. 1996). The links between primary productivity and high fish biomass have not however been proved, and as a result a lot of studies are currently underway or are being proposed, to determine how energy is transferred through the food web within the Chatham Rise ecosystem. The study to determine feeding interactions among fish on the Chatham Rise proposed here will therefore mesh into a broader programme investigating food-webs and energy transfer in the Chatham Rise ecosystem as a whole.

Most of the increase in commercial catches from the Chatham Rise in the past 15 years has come from the hoki fishery. In 1986, the quota for hoki was increased from 60 000 t to 250 000 t, but 80–90% of the catch at that time was taken from spawning aggregations off the west coast of the South Island rather than bottom trawl fisheries in other parts of New Zealand. In 1992, the catch on the Chatham Rise rose to over 40 000 t as a new, year-round fillet fishery was developed in the area. This peaked in 1998 and 1999 at 74 000 t, and there has been concern that the increased fishing effort on the Chatham Rise may have impacted on the abundance of species caught incidentally when fishing for hoki as well as on the fish community infrastructure since hoki is the dominant species in the Chatham Rise demersal fish community in depths of 200–800 m (Bull et al. 2001, Livingston et al. 2003).

Despite the high abundance of hoki on the Chatham Rise, little is known of its feeding habits or interactions with other species, or how these might have changed in relation to increased fishing effort. Kuo & Tanaka (1984) used percent occurrence to determine principle prey items in the diet of hoki during the mid-seventies. They were described as feeding principally on small shrimps (20% occurrence) and myctophids (20% occurrence), but taxonomic resolution was low and no indication of species composition was reported. Data collected from the mid-eighties through the nineties summarized by Stevens et al. (In prep.) gave slightly higher resolution of the hoki diet with fish occurring in 37% of stomachs, of which myctophids were the dominant group. Euphausiids and natant decapods also occurred in 20% or more of stomachs. Although identification of fish prey to species level was rare, *Maurolicus australis Photichthys argenteus* and *Lampanyctodes hectoris* were the most commonly identified fish species in hoki stomachs from Chatham Rise trawl surveys (Stevens et al. In prep.). Off Tasmania, hoki feed primarily on *Lampanyctodes hectoris*, *Lepidorhynchus denticulatus* and *Diaphus danae* (Bulman & Blaber 1986). Bulman and Blaber also reported cannibalism, something not reported among hoki in New Zealand waters.

The proposed feeding study will obtain data from the stomach contents of hoki and other important fish species caught in middle-depths on the Chatham Rise with the initial aim of characterizing and quantifying the current feeding habits of 30 important species in the

system. It is also proposed that the quantitative methodology be run in conjuction with the way data has been collected historically to establish correlations between stomach content weights and stomach fullness for as many fish as possible, for a given length. Then, once feeding guilds have been identified and major prey groupings associated with them are known, it may be feasible to convert the historical stomach content data into a semi-quantitative data set. If this is successful, it will be possible to determine the extent of any broad-scale changes in diet of these species over the past 15 years. By combining with the ongoing trawl survey programme and meshing in with trophic studies underway and planned on other parts of the ecosystem, the proposed work constitutes an extremely cost-effective opportunity to measure important trophic model parameters for the trawlable populations of fish species in this major fishing ground. If it proves feasibile to convert historical stomach content records (i.e., the data summarized by Stevens et al. in prep.) from qualitative to quantitative data, we will also have a powerful tool for assessing trophic changes over the past fifteen years in relation to intense fishing activity (Annala et al. 2004).

2.1. Project Objective

1. To design a sampling programme to collect relevant data for the construction and quantification of food-webs supporting important fish and invertebrate species. (MFish Project Code ENV2002/07, Objective 1).

2.2. Specific Objective

1 To design a sampling programme to collect relevant data for the construction and quantification of food-webs supporting important fish species on the Chatham Rise.

3. METHODS

Analysis of stomach contents has been shown to be one of the most efficient and effective methods for determining trophic interactions on an ecosystem scale (Link 1998). Quantitative data (e.g., percentage by weight for each prey item) is essential to determine guild structures, and estimate dietary overlap among species. Quantitative data that allow estimation of annual consumption rates are a requirement for estimating carbon content and therefore energy flows through food webs for trophic modeling. It is proposed therefore that fish stomach samples will be collected to determine spatial and seasonal variation in the diets of fish on the Chatham Rise. The samples will also be collected to ensure that all sizes of fish are sampled to detect ontogenetic shifts in the diets of larger species such as hoki, hake, and ling.

Stable isotopes (see Appendix 3) can be particularly useful for elucidating both the nutritional components and the trophic levels within fish communities. We propose that stable isotopes be used to complement the results from stomach analyses of fish in this study.

3.1. Sampling in the field

We propose to collect stomach samples in three ways:

- January survey, Tangaroa
- Commercial sampling by observers (MFish)
- Commercial sampling by observers (HFMC)

Middle depth trawl surveys on the Chatham Rise are conducted in January each year, and sample a wide range of fish species with the trawl during daylight hours (e.g., Livingston et al 2004). We propose adding a scientific crew of at least 2 staff during these surveys to collect stomach samples from as many species as possible during the hours of dark and early morning. The rationale for this is that many of the species feed from dusk to dawn and so stomach contents taken during the night and early morning will be fresh and much easier to identify (Blaber & Bulman 1987). In addition, the time can be used to obtain samples of mesopelagic prey using a fine-mesh midwater trawl to determine relative prey proportions compared with those observed in the stomachs. Mesh selectivity will need to be considered. Sampling will be carried out from replicate random stations (after Francis 1984) within strata currently used for the trawl survey (Figure 5). All depths (200–800 m), habitat types (north and south of the Subtropical Front) and water masses will therefore be sampled across the Chatham Rise.

In addition to the daytime trawling that takes place for the trawl survey, we would propose to conduct some fine-mesh midwater trawls at night to ground truth the mesopelagic fish component during these trawl surveys and obtain proportional estimates of relative abundance from the species mix caught in midwater, since we know that at least hoki tend to feed on midwater species, primarily at night (Blaber & Bulman 1987). This may give some indication about the electivity (prey selectivity) of fish diets.

To improve understanding of seasonal variability, we would propose to use the Observer Programme and industry observers to sample fish stomachs on a seasonal basis. We propose to collect the stomach contents at sea by excising the entire stomach from the study species, freezing them, and transporting the frozen stomachs back to the laboratory for processing.

We would not propose to sample the benthic community during the trawl survey. To determine the relative biomass of species within benthic assemblages would require a different sampling methodology (e.g., sediment mapping, and sampling using cameras and sleds). This would require a separate research programme that is beyond the scope of the work proposed here.

3.2 Selection of fish at sea

January survey, Tangaroa

The species recommended for study are listed in Table 3, and include the 30 most abundant species taken out of a total of more than 100 sampled by the trawl, within the depth range of the survey, 200-800 m. Species that are widespread will be sampled across all strata to ensure full spatial coverage. Less abundant and less widespread species will be sampled opportunistically wherever they occur. If stomach samples exceed the total required, they will be sub-sampled. Sampling intensity for each species will reflect abundance (i.e., higher sampling targets for high biomass species) and species asymptotic size (i.e., higher sampling size for larger growing species to enable detection of ontogenetic shifts in diet).

The number of samples to be collected is a compromise between ensuring that adequate data is gained for the development of food-webs and trophic modeling, costs, and project timing. It has been shown that the number of different prey items consumed by fishes generally asymptotes between 500 and 1000 stomachs (with food in), for a given species (Link 2002). The trawl survey database indicates that many fish caught have empty stomachs. For example, on average only about 50% of hoki have food in their stomachs (Stevens et al. in prep.). To ensure that adequate samples of stomachs containing food are obtained, it will be necessary to collect more than the target number of stomachs. We recommend that a target of 500 stomachs from each of the top 15 species, and up to 100 of the remaining 15 species, be

analysed from the trawl survey. In total then we expect that a sample of 9 000 stomachs (i.e., $500_{stomachs}$ X $15_{species}$ plus 100 $_{stomachs}$ X $15_{species}$) will yield about 5 000 stomachs that will have food remains in.

Some fish species will require much less sampling than others. This will depend on the diversity of food types consumed, and also the size range of fish species sampled. For example, wide size range species such as hoki, hake, and ling, which have diverse diets, will require more intense sampling than fish such as javelin fish which tend to fall in a narrow size range, or silver warehou which have low dietary diversity.

Commercial sampling by observers (MFish)

Seasonal variation will be derived from a smaller number of stomachs that should be collected at sea by Observers or Company Vessels as possible. We propose that MFish Observers obtain stomach samples from all 30 species, but with higher priority on target species such as hoki, hake and ling. Other species such as javelin fish, dark ghost shark, big-eye rattail, silver warehou, sea perch, spiny dogfish, lookdown dory, pale ghostshark, shovelnose dogfish, white warehou, giant stargazer will also be important.

The aim will be to select species of fish from each tow that are (1) commercially important (i.e. quota species, dominant species in the catch); (2) ecologically important on the Chatham Rise throughout the year. For each tow, we recommend selecting 3 individual fish of 10 different species (total 30). These species will be the 5 most common species in the catch, and 5 others taken in order from a list. We anticipate that this will take about 2 hours of observer time to complete per day. Once a species on the list has been measured, it should not be sampled again until all others on the list have been sampled. This approach will focus sampling on the major fishery target species, but allow us to gain some information on other species that are important in terms of biomass and community composition.

The three individuals of each sampled species should be 1 large, 1 mid-size, 1 small. The aim will be to mix location, time of day, depth of tow. This procedure would be continued throughout each month until the target of 100 fish from each of the species listed is reached each month. Observer samples will result in a maximum of 36 000 stomachs from a 1-year period (i.e., $100_{stomachs}$ X $30_{species}$ X 12_{months}). It is very likely however, that some of the less abundant species will not reach the target of 100 stomachs. This number will contain proportion of empty stomachs that will need minimal processing ashore.

Commercial sampling by observers (HFMC)

We recommend that HFMC vessels sample hoki hake and ling as the three most commonly targeted species in these depths. Three fish of each species should be sampled from a given tow (1 large, medium and small). If the HFMC collected 200 stomachs per month, per species for one year, this would provide an additional 7 200 stomachs (i.e., $200_{stomachs}$ X $3_{species}$ X 12_{months}). of key species. There should be no more than a maximum of 10 fish of any species per tow.

Including the trawl survey samples, this comes to an annual total of fish stomachs of 52 200, of which we anticipate more than half will be empty. At the end of the first year, the data should be reviewed to refine any sampling protocols or sample sizes before repeating the exercise for two more years.

Table 3. The 30 most abundant species from the Chatham Rise trawl survey (200–800 m depths) in 2003. *, coefficient of variation usually high and species distribution outside depth range sampled. (Feeding habits from Stevens et al. in prep; Clark et al. 1989.)

Common name	Latin name	No. samples	Biomass (t)	Occurrence (%)	Feeding habit
Hoki	*Macruronus novaezelandiae*	17 000	52531	97	meso-pelagic fish, euphausiids, prawns
Black oreo*	*Allocyttus niger*	760	31489	10	amphipods, prawns,
Javelinfish	*Lepidorhynchus denticulatus*	8500	13175	90	amphipods, prawns
Dark ghost shark	*Hydrolagus novaezealandiae*	5 500	10431	47	crabs, prawns, starfish, polychaetes
Big-eye rattail	*Caelorinchus bollonsi*	2811	8186	88	unknown
Silver warehou	*Seriolella punctata*	700	7815	46	salps
Ling	*Genypterus blacodes*	1500	7261	93	prawns, galatheids, fish (esp. hoki and rattails)
Sea perch	*Helicolenus* spp.	4800	6904	88	salps, crustacea, rattails
Spiny dogfish	*Squalus acanthias*	1500	6191	57	crustacea, fish
Lookdown dory	*Cyttus traversi*	4300	5904	93	euphausiid, mysid, scampi, krill, javelinfish
Pale ghost shark	*Hydrolagus* sp B2	1000	4653	68	crabs, metanephrops, salps, echinoderms, bivalves
Shovelnose spiny dogfish	*Deania calcea*	1500	3781	32	myctophids, squid
Barracouta*	*Thyrsites atun*	500	3696	12	euphausiids, pelagic fish
White warehou	*Seriolella caerulea*	1200	3685	42	salps
Giant stargazer	*Kathetostoma giganteum*	600	2178	62	rattails, hoki, squids, bivalves
Ray's bream*	*Brama brama*	30	1746	27	nil
Baxter's lantern dogfish*	*Etmopterus baxteri*	500	1398	15	fish, squids
Smooth skate	*Dipturus innominatus*	60	1355	43	rattails, bivalves
Orange perch	*Lepidoperca aurantia*	600	1313	14	unknown
Oliver's rattail	*Caelorinchus oliverianus*	700	1187	53	amphipods, copepods
Spiky oreo*	*Neocyttus rhomboidalis*	500	1180	18	prawn, salps
Alfonsino*	*Beryx splendens*	800	1151	32	mesopelagic fish, squids
Banded bellowsfish	*Centriscops humerosus*	3000	1148	56	unknown
Longnose velvet dogfish*	*Centroscymnus crepidater*	350	1065	7	unknown
Long-nosed chimaera	*Harriotta raleighana*	300	937	38	unknown
Hake	*Merluccius australis*	100	888	68	rattails, hoki, prawns, squids
Oblique banded rattail	*Caelorinchus aspercephalus*	1000	857	51	unknown
Silver dory	*Cyttus novaezealandiae*	100	832	14	unknown
Red cod	*Pseudophycis bachus*	600	809	25	galatheids, fish, bivalves, squid
Arrow squid	*Nototodarus sloanii*	500	245	63	unknown

Collection procedure at sea

Details of each fish will be recorded at sea (see procedure outlined below), but all stomachs will be excised, frozen and transported to the laboratory for subsequent identification and quantification. This will ensure that the sampling will not be biased towards over full stomachs, as it can be difficult to ascertain fullness externally. On *Tangaroa* an attempt to estimate digestion rates by sampling over 24 hours and fitting sigmoidal curves to stomach fullness and digestion state will be made.

1. Record location, time, date, depth
2. Select fish from sample (details)
3. Identify species, sex
4. Measure length (±0.5 mm), weight (±0.3g)
5. Record everted stomachs, and note presence/absence of food around mouth or gill rakers. Indicate digestion state if possible.
6. Remove stomach
7. Blot to remove excess moisture
8. Measure wet weight of stomach (±0.3g*)
9. Place stomach in pottle or jar with concentrated seawater (salt added to seawater to minimize further digestion) and freeze to -20º C
10. Transport to lab for analysis

* Stomach weights less than 1g may prove difficult to do at sea, and will have to be repeated at the laboratory.

This procedure should be followed for all stomach samples collected during middle depth surveys on *Tangaroa*

Samples collected by Observers or HFMC will omit tasks 4 and 8 as scales are not available at sea.

3.3 Stomach content prey identification and procedure (all samples)

1. Thaw and weigh stomach with contents.
2. Remove from brine by washing through a fine mesh sieve for identification
3. Weigh contents once washed through sieve (±0.1 g)
4. Identify contents to the lowest possible taxon using appropriate keys of, for example: Taw (1975), Tafe (1979) for copepods; Kirkwood (1982) for euphausiids; Bowman & Gruner (1973) for amphipods; otoliths for fish
5. Measure total length of whole prey using ocular micrometer (±0.1 mm)
6. Measure number and wet weight of each prey taxon
7. Dry prey to constant weight at 60°C
8. Record dry weight (±0.01 mg)
9. For selected samples, use bomb calorimetry to determine energy values (kJ g^{-1})
10. Homogenise wet samples in blender, dry to constant weight at 60°C
11. Pulverise and make into pellets (approx 10 individuals of a species per pellet)
12. Use adiabatic bomb calorimeter
13. For selected samples, use stable isotope analysis

3.4. Stomach Content Database

In view of the potentially large amount of information that will be collected during the course of this project, and from historical data, we recommend that a new database be set up with

appropriate automation to calculate different measures and indicators. We recommend the approach adopted by Laurinolli et al (2004), Bundy et al. (2000) and Bundy (2004).

3.5. Quantifying stomach contents

Stevens et al. (in prep.) reviewed the methods commonly used in New Zealand feeding studies, or New Zealand species that have been studied elsewhere:

- **F, percentage of frequency of occurrence:** the number of stomachs containing one or more individuals of each prey category expressed as a percentage of the total number of stomachs containing food (Rapson 1956, Godfriaux 1969, 1974, Rosecchi et al. 1988, Hanchet 1991).

- **N, percentage of number:** the total number of individuals of each food category expressed as percentage of the total number of individuals in all food categories (Godfriaux 1974, Rosecchi et al. 1988).

- **I, number of individual prey in a prey category:** Clarke (1980, 1982) studied feeding in mesopelagic fishes. He divided the species into planktivores and nekton-eating fishes. For the nekton-eating fishes he only provided quantitative data for relatively intact fish or crustacean prey. Remains of prey items were simply recorded as present.

- **W, percentage of weight:** the total weight of each food category expressed as a percentage of total weight of all stomach contents (Rapson 1956, Rosecchi et al. 1988).

- **M, percentage of body mass:** total mass of each food category expressed as a percentage of the total mass of all stomach contents (Paya 1992).

In the laboratory, we propose a "prey-by-weight approach" to quantifying the stomach contents. In this method, the stomach contents are separated into prey items, and the wet-weight of each prey item are then measured. Identification of prey items would involve the use of on-campus expertise, existing otolith collections, and protein and DNA analyses to identify digested fragments, but only if required. A description of how DNA analysis has been used successfully on identifying digested remains from seabird stomachs is given in Appendix 4. The prey-by-weight approach would result in data that can be used on many levels, and allow grouping of similar prey items into "prey-type categories" or treat prey items separately to higher taxonomic resolution, as required. We strongly favour measuring the weight of each prey item in each stomach rather than just frequency of occurrence, or other index of diet composition. As Bulman and Blaber (1986) noted: "using percentage frequency [of occurrence] alone can be misleading and inaccurate, and even more so when combined with volumetric or numerical methods in an index". There is no reliable relationship between frequency of occurrence and diet proportion.

Frequency of occurrence of prey items will be calculated for comparison of the results with previous studies (e.g., Stevens et al. in prep). It is also intended that trophic levels of different species be compared with values for New Zealand species currently on the Fishbase website (Appendix 5, Froese et al. 2003). The typical weights of different kinds of prey items in the fish stomachs would also be investigated. This type of data can be used to determine the predator-prey linkages between species, by using dietary overlap at species level. The data can also be used to quantify energy intake in terms of an amount of organic carbon for trophic modeling. Measurements of the wet-weight of each prey type present in the stomach can be converted into the quantity of organic carbon by using a conversion factor that is specific to a particular type of prey material (e.g., carbon per gram wet weight of crustaceans as a group).

The prey categories can then be amalgamated to give total energy consumption. In the first instance, carbon:wet-weight ratios could be taken from the scientific literature (Bowen 1966, Gaedke 1992, Leidy& Jenkins 1977) The study could however, be usefully extended by measuring these factors directly from a small subset of the data using bomb calorimetry if desired.

All 30 fish species and size-class categories sampled for stomach contents should also be analysed for stable isotopes. Tissue samples from slow turnover tissue such as bone should be sampled.

3.6. Data analysis

The data collected in this program will be analysed to provide answers to the following key questions:

For each species individually:

1. *What are the main prey items?*
2. *What are their relative contribution to the energy requirements of the species?*
3. *What does the diet tell us about where the fish is feeding (e.g. surface benthos, benthic infauna, water column)?*
4. *How does the prey change with body size?*

Some species take the same mix of prey items throughout their lives, though the proportions may change with body length of predator. Conversely, some fish have a marked change in diet as their body size increases, e.g. from epibenthic to benthopelagic. Knowledge of diet with body size will elucidate changes in feeding location with age.

5. *What is the prey breadth? i.e., does the species have a specialist feeding ecology or is it a generalist/opportunistic feeder?*

"Normalised diet breadth" (Levins 1975; Hespenheide 1975) is typically used to assess the degree of specialisation, and this is calculated from the proportions of different prey items in the diet of a predator. Note that prey breadth cannot be calculated from percent occurrence of prey items. Identifying prey breadth will first allow us to identify the significance of various prey items to important fisheries. Species with greater prey breadth may be more resilient to environmental variability than more specialist feeders.

6. *Variability: how do the prey characteristics change with: time (diel patterns); month-to-month (season); year to year (annual)?*

Diel patterns of diet will be more easily determined from the trawl survey samples than observer samples because of the short tow lengths during trawl surveys (commercial vessels often tow for 4 hours). Commercial samples may also be biased in terms of spatial variation simply because the vessels target aggregations of fish rather than covering the full range of a species, particularly non-commercial species. It will be important therefore to compare frequency of occurrence and spatial distributions of as many species as possible from trawl survey and all observer datasets for an indication of potential bias.

Variations in diet with time of day help to determine whether the species has a pronounced vertical migration pattern. Variations in diet from year to year may be sensitive indicators of ecosystem changes, and monitoring diets may be a useful management tool. Marked changes in feeding habit of slope fishes off Tasmania were found from month to month in some studies (Young and Blaber 1986) but not in others

(Blaber and Bulman 1987). Estimating seasonal variations in diet will be important for setting up a strategy for the ongoing monitoring of fish diets in New Zealand.

7. How much material do species need to consume to survive?

The dietary information obtained from this programme will be used in an ecotrophic model. To run an ecotrophic model, the following information is required for each trophic compartment (species, group of species, or trophic guild):

a. Biomass (in tonnes of carbon for the ecosystem being considered as a whole).
b. Total production over the time period considered (usually annual) in tonnes of carbon. This is often estimated using a Production/Biomass (P/B) ratio, and assuming variations in biomass and P/B are independent.
c. Total consumption over the time period considered (usually annual) in tonnes of carbon. This is often estimated using a Consumption/Biomass (Q/B) ratio, and assuming variations in biomass and Q/B are independent.
d. Proportion of consumption from each prey trophic compartment (diet information).

In the trophic modeling work underway at NIWA, we propose to estimate biomass and production (a, b) for major fish species from stock assessment models. The work proposed here will provide information on consumption by fish (Q), and their diet (c, d).

Consumption rates of fish are difficult to measure, and vary considerably depending on the metabolic energy requirement of the fish (how much energy the fish needs to survive) and the type of prey (which determines the energy obtained per gram of organic matter consumed by the fish). Metabolic energy requirement varies with fish species, individual size, behaviour, and habitat (water temperature, currents, depth). Offshore species at the depths to be sampled do not survive tank conditions and it is not possible to carry out experiments. Many ecotrophic models in other countries estimate metabolic energy requirements empirically from observations and experiments on other species in controlled environments (e.g., Palomares & Pauly 1989). These relationships are often based on data from tropical or sub-tropical water and their accuracy as applied to New Zealand species is unknown. Also, empirical relationships such as Palomares & Pauly (1989) often consider the whole stock together. Energy requirements of a particular fish species will vary considerably between individuals of different age and size. As the size structure of a stock changes (e.g., due to fishing pressure) its overall food requirement will change, and should be considered within a trophic model.

We propose to estimate the amount of material consumed by key fish species in New Zealand waters by measuring the average mass of material in the stomach at different times, and using published information on the digestion rates of different prey items. This method is not expected to be extremely accurate, but will allow us to investigate whether the consumption values estimated from literature regressions are appropriate to New Zealand. By sampling for different sizes of fish, particularly larger species such as ling, hake and hoki, dietary change with individual fish size will be accounted for. We note that a proportion of fish will be expected to have everted stomachs caused by the change in pressure during hauling, and that this will make it difficult to ascertain if the stomach contained food or not. Recording the presence of food material in the mouth, teeth or gill rakers can be a useful indicator of the magnitude of the problem.

Metabolic energy requirement is converted to mass of prey consumed using knowledge of the mass-specific calorific content of prey material. Where widely different types of prey are consumed, this calculation must take into account the relative amounts of different types of prey consumed because different prey items have different food qualities. For example, an omnivorous fish must consume a greater mass of crustaceans each day than if

it fed on fish because crustaceans have a lower specific energy content than fish. Bomb calorimetry should be used on a small subset of prey samples to determine the potential calorific yield of common New Zealand prey items (e.g., Blaber & Bulman 1987, Tierney et al. 2002). We will measure the weight-energy relationship of key prey items for input to the trophic model.

8. What are the effects of changing prey abundance?

Knowledge of the variations in diet with location, season and year-to-year does not tell us why these changes occur. The extra information needed to understand reasons for diet changes is the abundance of prey items. For example, if the diet of a species suddenly changes, is this because the old prey item is no longer there, or because a preferred prey item has suddenly become more abundant? In the former case, the species may now grow slower or have higher natural mortality than before. In the latter case, the productivity of the species may increase. Dynamic trophic models (e.g. EcoSim) which aim to predict changes in the abundance of one species from knowledge of ecological and environmental "forcing" factors (e.g. prey availability, fishing pressure, biomass of other species etc) rely on knowledge of "prey electivity" for each prey item of each predator. Calculation of electivity requires knowledge of diet compositions and the concurrent prey abundances.

Prey abundance is often difficult to measure. The main prey items of many fish species are not routinely measured, despite the fact that technology exists to do so. We recommend identify the potential for measurement of the following prey items during diet studies:

1. Mesopelagic fish – acoustic methods, mid-water fine trawl, target-strength calibrations
2. Epipelagic fish - acoustic methods, mid-water fine trawl, target-strength calibrations
3. Macrozooplankton - acoustic methods, zooplankton nets, continuous plankton recorder
4. Gelatinous plankton (salps, jellyfish etc) - zooplankton nets
5. Squid (including juvenile squid) - mid-water fine trawl
6. Benthic epifauna – benthic sampling

Sampling to determine prey abundance of these groups is beyond the scope of the proposed project, but analysis of existing acoustic records to obtain ball-park estimates of abundance should be explored. Further, same data will be obtained during voyages funded elsewhere to explore other aspects of the food web. (i.e., FRST work)

Predator prey interactions

Interactions between species can occur in two main ways: by competition for resources (due to having common prey items), and by direct feeding of one species on another.

1. Dietary overlap between pairs of species is typically measured using the Sorygin percentage similarity of diet (Ivlev 1961; Blaber and Bulman 1987). This measure is calculated from the proportions of different prey items within the diets of each species, and cannot be calculated from percentage occurrence. In combination with prey breadth, dietary overlap can help to investigate vulnerabilities of species. For example, if two species have high dietary overlap, and neither have broad diets, then if one is fished heavily, we might expect the second to grow faster or have lower natural mortality. Of course, if the abundance

of prey items is not a limiting factor, competition for resources between species will be less important.

2. Niche overlap (Levins 1968; Macpherson 1979) is similar to dietary overlap except that it is takes into account diet breadth and is hence directional i.e., species A and species B have a single *dietary* overlap, but the *niche* overlap of A on B is not the same as the niche overlap of B on A, unless A and B have the same diet breadths. The niche of a generalist feeder always overlaps the niche of a specialist feeder more than the reverse (Cody 1974).

Knowledge of diets will allow us to identify whether feeding of one species on another should be taken into account in management. For example, if we find that a target species has a narrow prey breadth (i.e. is a specialist feeder) with preferred prey items that are also fished, then we might predict that reducing prey biomass through fishing will negatively impact stock levels. Alternatively, generating large quantities of fishing discards it may positively impact scavenging species (e.g., bottom feeders, dogfish species, seabirds).

This work will also identify interactions between different ages of the same species, i.e. identifying the extent of cannibalism within target species. It is known that hoki in Chile and Tasmania tend to be cannibalistic i.e. adult hoki consume juvenile hoki, whereas this does not seem to occur in New Zealand. Cannibalism can affect the resilience of a stock to environmental variability. This could be positive (adults reduce the number of juveniles entering the stock in boom years, and do not consume juveniles in years with poorer spawning success), or negative (as numbers of adults increase, more juveniles are consumed and recruitment is reduced). Knowledge of cannibalism may improve our ability to manage risk to a fishery.

Ecosystem Indicators

The mean trophic level of an ecosystem is increasingly being used internationally to measure the impact of fishing on the environment. For example, mean trophic level is required by the Convention on Biological Diversity to assess ecological "health". A decline in mean trophic level is a typical consequence of fishing and can be used to compare the effects of fishing on ecosystems in different regions of the world. Mean trophic level is calculated by assigning a trophic level to each species, and this process relies fundamentally on knowledge of the diets of each species. An ecosystem that is very "flat" (i.e. with a large number of species feeding on lower trophic levels) tends to naturally have a lower mean trophic level than one which contains a higher proportion of piscivorous species. Data obtained by the proposed diet study will allow us to determine the trophic level of each species in the Chatham Rise ecosystem, and produce a mean trophic level value for assessment of ecosystem state. If indeed the programme is successful in converting historical stomach content data into a comparable database extending back in time, gross changes in mean trophic levels will provide an indication of changes during the period of intensified fishing.

Trophic Modelling

Diet data will allow species to be grouped into trophic guilds. These are: "groupings of species without regard to taxonomic positions, that overlap significantly in their niche requirement" (Bulman et al. 2001). Trophic guilds could include individual species and groups of species (e.g. "small fish", "other large fish", "mesopelagics", "rays": Bulman et al. 2001). Trophic guilds can be chosen subjectively (e.g. on the basis of commercial importance, or amount of knowledge on the stock), or identified objectively by a variety of statistical methods (e.g., cluster analysis).

Species can be grouped more coarsely based entirely on diet type using cluster-type analysis. For example, Blaber and Bulman (1987) identified 4 descriptive diet groupings: (1) pelagic piscivores; (2) epibenthic piscivores; (3) epibenthic invertebrate feeders; (4) benthopelagic omnivores. Bulman et al. (2001) found 9 diet groupings: (1) pyrosome feeders; (2) invertebrate feeders/dominant unidentified prey; (3) benthopelagic omnivores specializing on megabenthos and small crustaceans; (4) benthic invertebrate feeders specializing on polychates; (5) epibenthic invertebrate feeders; (6) benthic piscivores; (7) bentho-pelagic piscivores; (8) pelagic piscivores; (9) pelagic omnivores. This kind of diet analysis provides a method of determining coarse guilds for trophic modeling.

Others have used more sophisticated clustering techniques involving bootstrap methods (Jaksic & Medel 1990) to statistically define trophic guilds (e.g., Garrison & Link 2000, Bulman et al. 2001, Gaskett at al. 2001, Goldsworthy et al. 2001,)

Diet characterization and temporal variability

Annual and seasonal diet for each species (or size grouping within species) expressed as

- Percent frequency of occurrence of prey items
- Proportion by weight of prey items
- Total stomach content weight

Factors to be calculated

- Adjusted proportion by weight for digestibility of prey items estimated from literature.
- Assignment of trophic level

Predator prey interactions

- Similarity index (degree of overlap of prey) (e.g., Schoener 1970)
- Ordination of groupings using ordination techniques such as principal component analysis or MDS techniques (e.g., Garrison & Link 2000)
- Cluster analysis to determine trophic guilds (e.g., Pielou 1984, Jaksic & Medel 1990)
- Diet breadth (e.g., Levins 1968)
- Dietary diversity using Shannon-Weiner species richness index
- Level of omnivory
- Selectivity of prey by comparing proportional occurrence of prey in the water compared with stomach contents
- Numerical response (determine how predator numbers change with prey density)
- Functional response (determine how the rate of consumption varies with density of prey)

Consumption rates

- Diel variation and fitting of sigmoidal function to stomach fullness to estimate evacuation rates.
- Mean weight of prey consumed taking into account proportion of everted and empty stomachs
- Daily, seasonal and annual consumption rates of prey groupings for each species expressed in terms of grams of carbon using published conversion formulae (e.g., Ikeda 1996, Parsons 1984, McLusky 1981, Cohen & Grosslein 1987, Vlieg 1988).
- Consumption rates by trophic guild

- Energy consumption rates will be obtained by using literature conversion rates. It may however be prudent to carry out bomb calorimetry experiments on some of the principle prey items if these are not available. This can be assessed at the end of the first year

Spatial variation

- Variation in diet by station across the Chatham Rise in relation to physical and biological variables, including latitude and longitude, depth, water mass, temperature at depth of capture, and species distribution, using redundancy analysis or linear regression modeling
- The extent of co-occurrence between fish in the same trophic guild will be examined from trawl survey records to ascertain spatial competitive exclusion.

Biomass from January surveys

- Biomass of predators will be estimated through the trawl survey biomass program.
- Biomass of prey will be estimated from proportional occurrence of prey in the mid-water trawl and calibrated to acoustic scatter collected during midwater tows.

Functional changes to fish community

- Determine feasibility of using a calibration technique to convert historical data to quantitative format by using linear regression techniques to convert % volume to % weight (e.g., Garrison & Link 2000)
- Track changes in dietary composition within time series and compare with changes in abundance and fishing effort.

Ecotrophic modeling

- Develop appropriate number of categories for inclusion in Chatham Rise ecotrophic model, including fishing
- Use time-varying ecotrophic model to identify changes to predatory-prey pathways within time series

Review and refinement of methodology

The stomach content data should be worked up and analysed throughout the first year to allow refinement and improvements to data collection methods to be identified and implemented as the project continues. For example, it may not be possible to obtain sufficient samples of some species, while others may be over sampled. Identification guides for principle prey items should be developed to speed up stomach content analysis. Stomach sampling should be optimized where possible to obtain freshly full stomachs rather than well digested ones. The necessity for bomb calorimetry should be assessed.

4. CONCLUSIONS AND RECOMMENDATIONS

By sampling the stomach-contents of fish during trawl surveys on the Chatham Rise we can obtain cost-effective, quantitative data on the feeding relationships between the key fish species and the larger ecosystem. Combining this research with an existing shipboard sampling program allows this work to sample large areas at relatively low cost, and to synergistically build on existing knowledge. The project requires additional sampling using

Table 4. Recommended sampling and identification work for Chatham Rise feeding study.

	Task 1 Middle-depth trawl surveys, summer	Task 2 Seasonal samples (Observer Programme)	Task 3 Seasonal samples (HFMC)
Purpose	Food-webs and trophic modeling snapshot	Temporal component	Temporal component
Number of fish species	Up to 30 species	Up to 30 species, but targeting ten most common other than hoki, hake or ling	3 species; hoki, hake and ling
Provisional sampling	500 stomachs of top 15, 100 of other 15 (9 000 total)	100 stomachs per month (36 000 total)	200 of hoki, hake and ling stomachs per month. (total 7200)
Stratification	By fish size, position in water column, depth and stratum, 24 hour variation	Stratification unlikely. Ensure trickle of samples to encourage range of sampling	Stratification unlikely Ensure trickle of samples to encourage range of sampling
Additional sampling	Fine-mesh-sampling of water column essential	Fine-mesh sampling not possible	Fine-mesh-sampling unlikely
Other methodologies	Stable isotope samples (see Appendix 3)	Stable isotope samples (see Appendix 3)	Stable isotope samples (see Appendix 3)
Identification of prey to species wherever possible or practicable.	Taxonomic keys Otolith key Protein & DNA analysis (see Appendix 4)	Taxonomic keys Otolith key Protein & DNA analysis (Appendix 4)	Taxonomic keys Otolith key Protein & DNA analysis (Appendix 4)

the Observer Programme and HFMC to assess the seasonal variation in feeding structure within these ecosystems. We would also be dependent on Observer Programmes and the goodwill of Fishing Companies if the project is to succeed in determining how fish diets vary with season.

We propose sampling only the Chatham Rise in depths of 200–800 m in the initial stage of the project. We believe that deeper parts of the Rise and other biota groups are also important in terms of gaining a better ecosystem perspective on predator-prey relations for the Chatham Rise. Other areas of the EEZ particularly the Sub-Antarctic and the west coast South Island (major spawning ground for many species and area of previous ecosystem study) and Hauraki Gulf (current area of study for shelf processes) are also important areas to study, but to sample them would require a dedicated ship-based sampling regime and this is considered beyond the scope of the current project.

The research proposed here will not only improve our knowledge and understanding of food-webs and energy flow in a key area of both commercial and environmental interest in New Zealand, but will have developed the expertise to refine the approach and extend it to other areas of New Zealand. The work will also have application to the development of marine ecosystem risk assessment that is currently underway in Australia, but is in its infancy in New Zealand. The proposal is summarized below in Table 5.

Table 5. Recommended programme to develop food-webs supporting important fisheries in New Zealand

Area	Chatham Rise
Depth range	200–800 m
Vessel use	Tangaroa (existing trawl surveys) Commercial vessels
Timing	January 2005 to January 2008
Methodology	Bottom trawling (demersal species) Midwater trawling (mesopelagic species-*Tangaroa* only)
Number of fish species	30
Maximum number of stomachs collected in first year	52 200
Sampling method	Stomachs and tissue samples collected at sea and frozen
Estimated maximum number of stomachs containing food in first year	48 600
Analysis	Numerical and gravimetric gut analysis; ID to species where possible. Stable isotope analyses on tissue samples from all fish species
Output	Stomach content database Characterisation and enumeration of diet items Overlap and linkages in food web Trophic level Annual consumption rates Biomass to production ratios Application to ecotrophic model
Options to consider within programme	Extension of sampling to deepwater fish

5. LINKS TO OTHER RESEARCH PROGRAMMES

The Chatham Rise fish diet study will mesh in perfectly with work proposed on the ecosystem as a whole on the Chatham Rise (NIWA Bid for Outcome Based Investment (OBI) Ecosystem Oceans, IO2 (ecotrophic studies), IO3 (climate) and IOB Fisheries Outcomes (impacts of fishing), 2004). It also has links to work proposed on exploring pre-industrial fisheries and stock abundance of fisheries (NIWA Expression of Interest Maori Research and Innovation 2004). Matt Dunn (NIWA) reviewed the final document.

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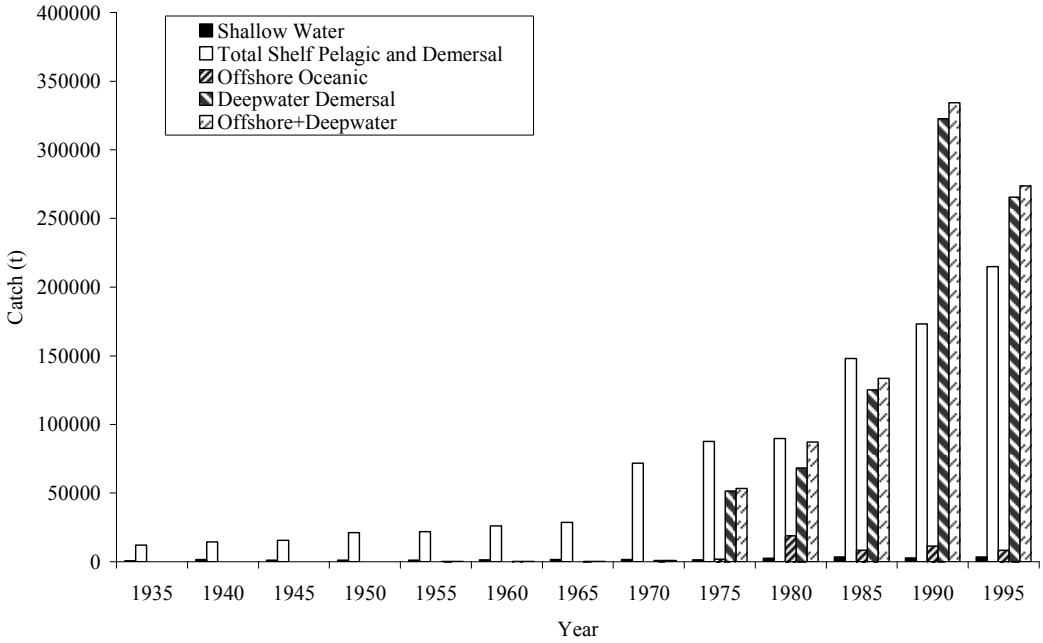

Shallow Water	Inshore Shelf Pelagic	Inshore Shelf Demersal	Central Shelf Pelagic	Central Shelf Demersal	Offshore Oceanic	Deepwater Demersal
grey mullet	pilchard	soles	jack mackerels	trumpeter	albacore	hoki
yellow-eye mullet	blue maomao	red mullet	blue mackerel	barracouta	skipjacks bluefin	hake
garfish	kahawai	porae		gemfish	tuna yellowfin	silver warehou
flounders	trevally	red gurnard		frostfish	tuna	white warehou
butterfish	kingfish	sea perch (sw)		red cod	bigeye tuna butterfly	orange roughy
parore		rig		tarakihi	tuna slender	oreos
		school shark		groper	tuna	s blue whiting
		blue cod		ling	broadbill	sea perch silver/lookdown
		elephantfish		stargazers spiny	marlins	dory
		blue warehou		dogfish		ribaldo
		blue moki		skates		dw sharks
		red moki		bluenose		cardinalfish
		snapper		alfonsino		ghostsharks
		john dory		rubyfish		silverside
		stargazers		red snapper		redbait
		leatherjacket				rays bream
		conger eel				grenadiers
						orange perch

Figure 1. Catch history of shallow coastal and deepwater fisheries in New Zealand, 1935 to 1995 (after Paul 2000).

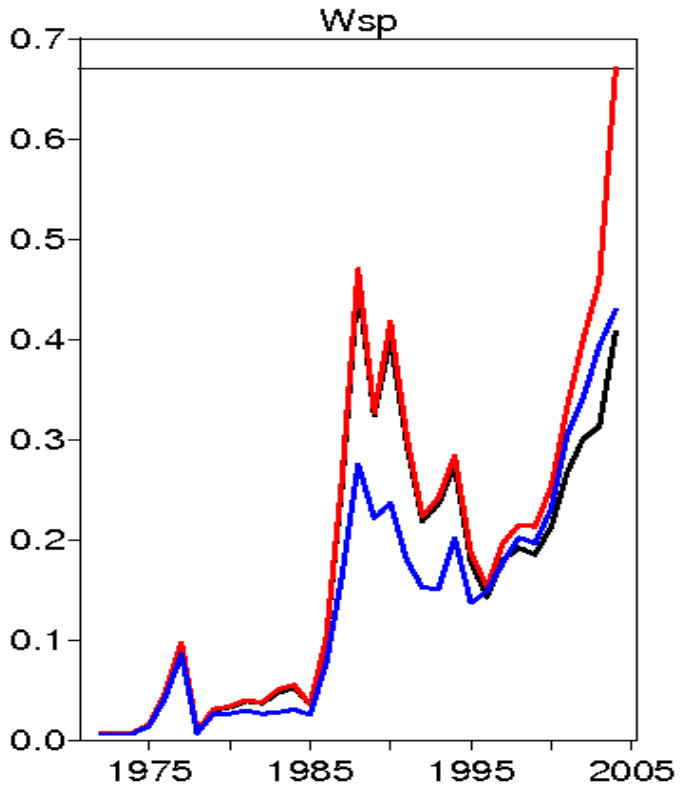

Figure 2. Exploitation rates of hoki in the western stock (Wsp). (Figure supplied by Chris Francis, NIWA)

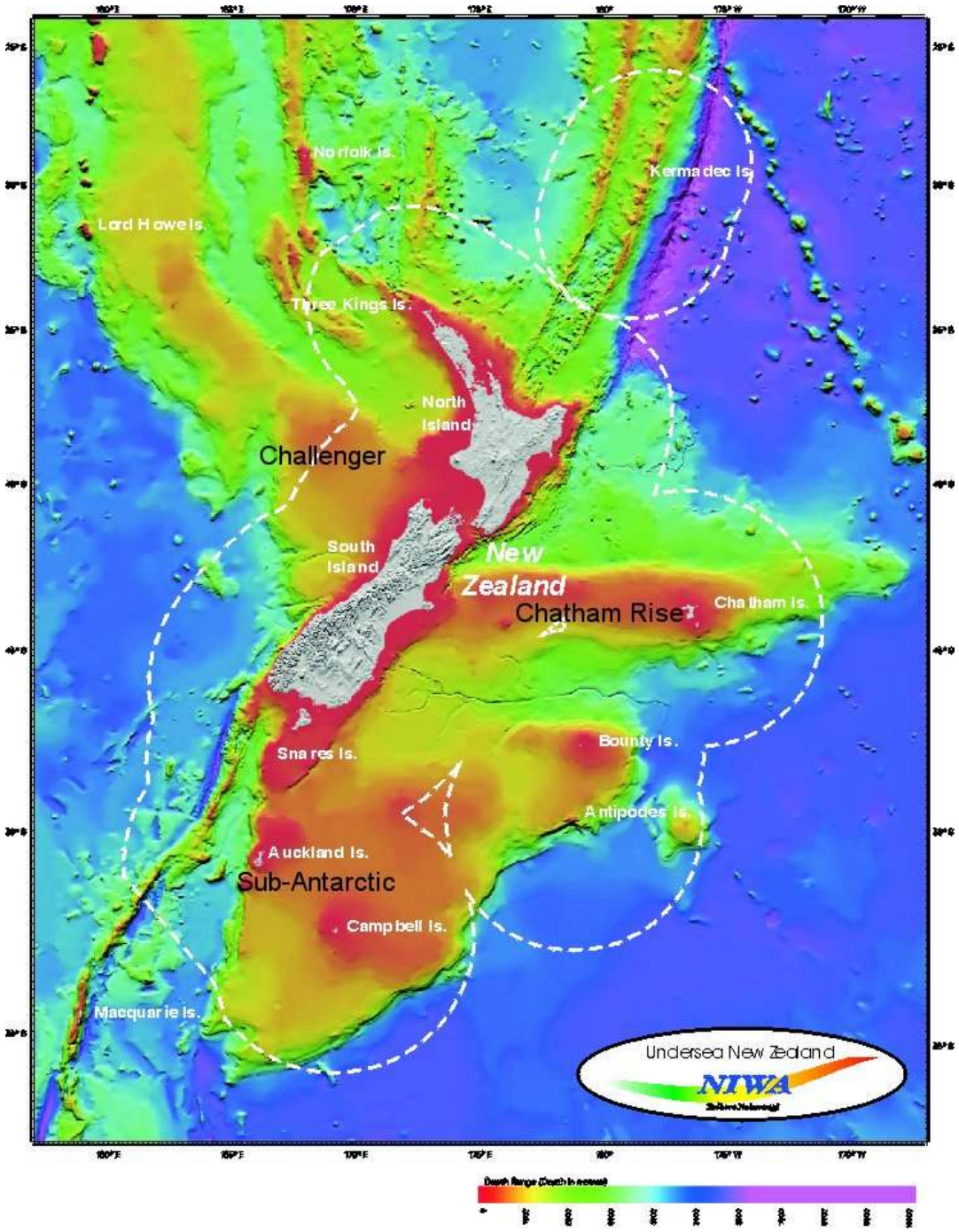

Figure 3. Bathymetry of New Zealand showing relatively shallow Pateaus and Rises (red).

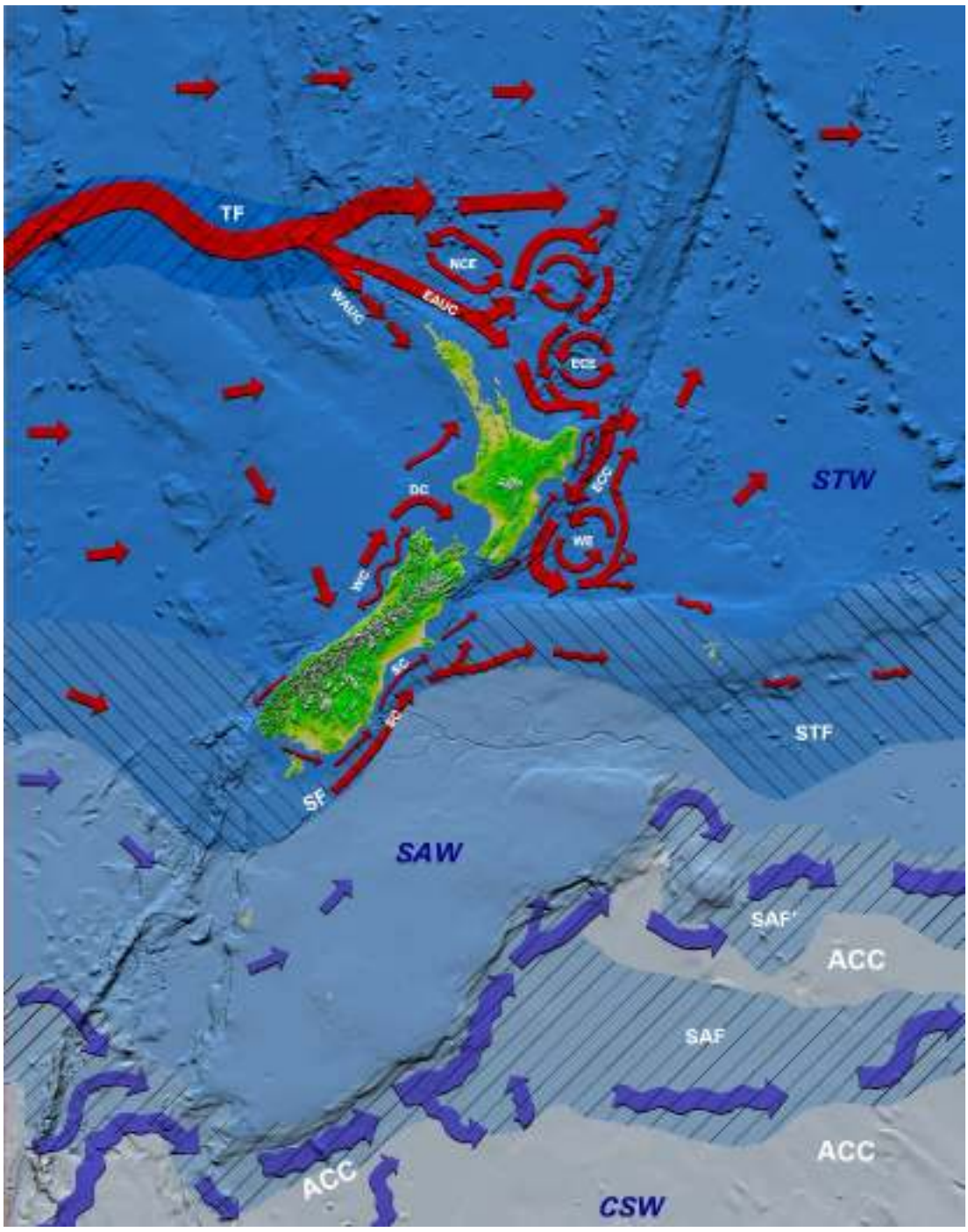

Figure 4. Hydrography of New Zealand

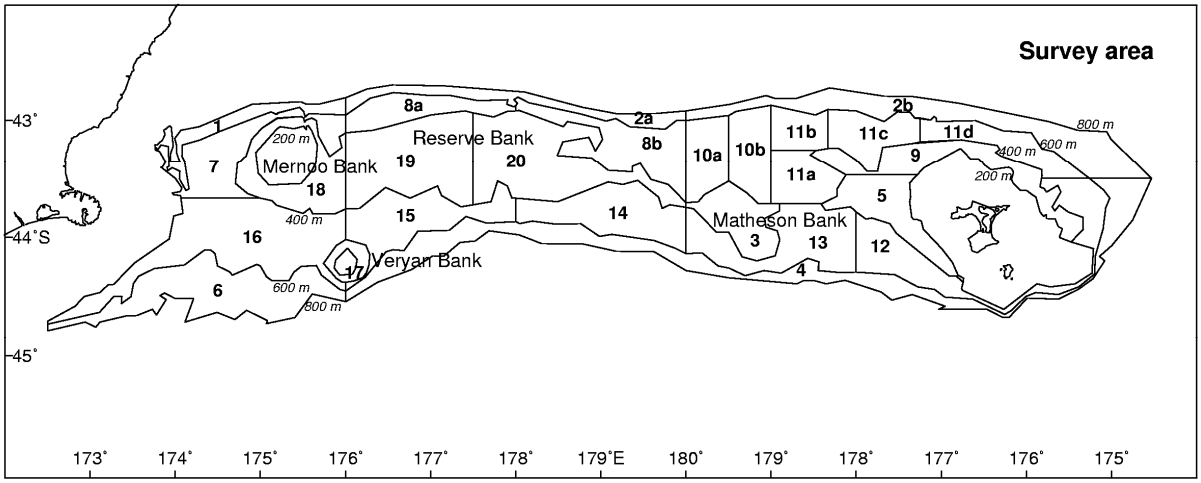

Figure 5. Chatham Rise trawl survey stratification, 200–800 m depths

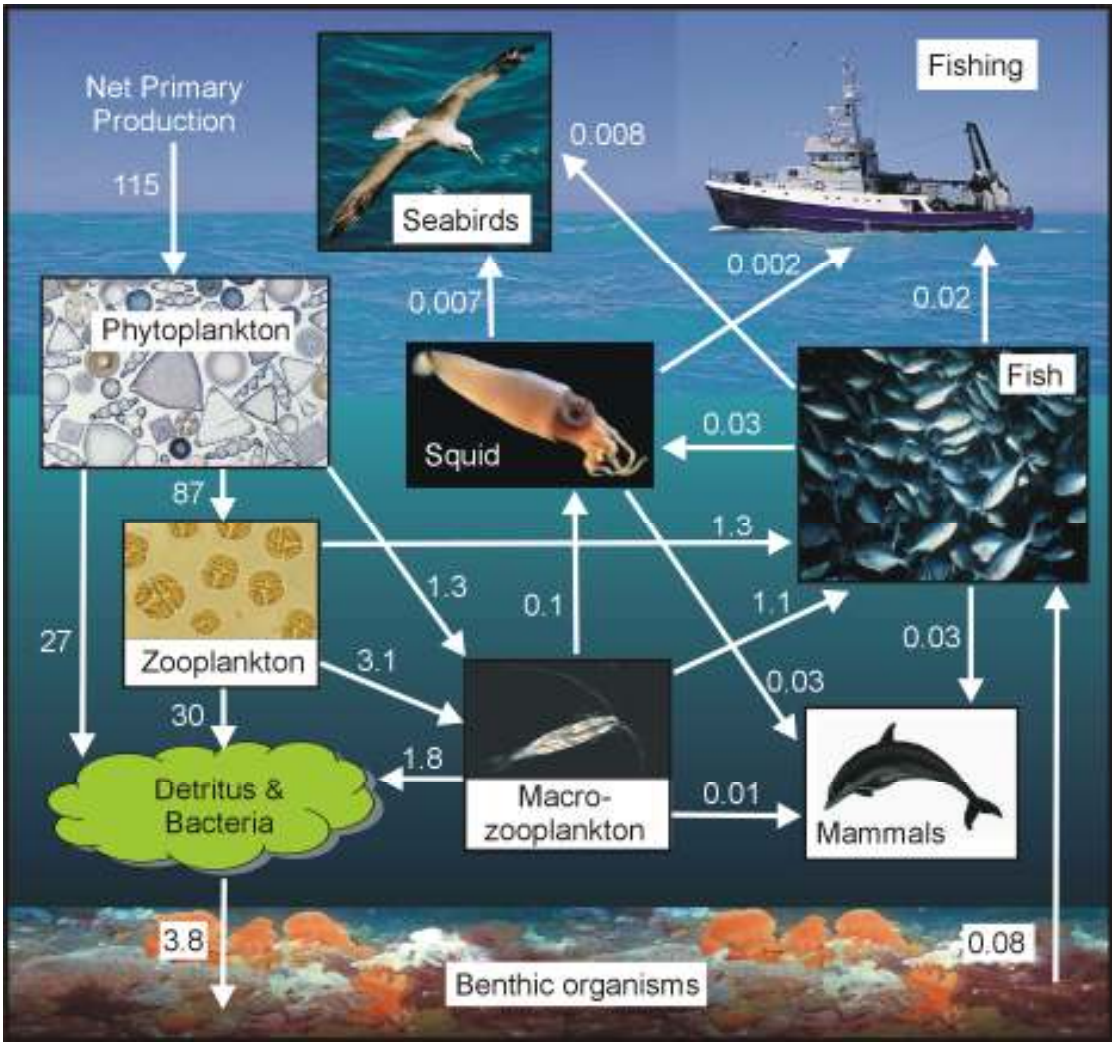

Figure 6. A trophic model of the Sub-Antarctic Plateau, New Zealand developed by NIWA. The growth of phytoplankton in this region generates organic matter containing about 115 million tonnes of carbon each year. This organic matter is called *Net Primary Production*. The numbers in the figure give the annual transfer of carbon between the organisms per year in millions of tonnes. The difference between the consumption of carbon *by* a group and the consumption of carbon *from* that group by other organisms is due to respiration (where the organic carbon is converted to carbon dixiode), and excretion of organic waste. Most of the excreted matter is broken down by bacteria as it sinks through the water column. Organic waste that reaches the sea-bed supports the benthic ecosystem.

Appendix 1. Example of biological data, including stomach content data collected routinely during trawl surveys

trip_code	species	fish_no	length	weight	sex	gonad_stage	stomach_state	stomach_cond	prey1	vol1	prey2	vol2	prey3	vol3	comments
aex8902	HOK	1	90	2.57E+03	2	2	3	2	FIS	80	PRA	20			
aex8902	HOK	2	75	1.18E+03	2	2	3	3	FIS	100					
aex8902	HOK	3	85	1.58E+03	1	2	0								
aex8902	HOK	4	85	1.64E+03	2	2	2	2	FIS	60	PRA	40			
aex8902	HOK	5	71	1.22E+03	1	2	0								
aex8902	HOK	6	93	2.18E+03	2	2	2	2	FIS	100					
aex8902	HOK	7	74	1.12E+03	1	2	0								
aex8902	HOK	8	89	2.35E+03	2	2	2	2	PRA	50	SEQ	50			
aex8902	HOK	9	70	9.40E+02	1	2	2	3	FIS	30	PRA	60	SEQ	10	
aex8902	HOK	10	88	2.11E+03	2	2	2	1	PRA	100					
aex8902	HOK	11	81	1.25E+03	1	2	9								
aex8902	HOK	12	100	2.57E+03	2	2	9								
aex8902	HOK	13	76	1.21E+03	1	2	0								
aex8902	HOK	14	78	1.64E+03	1	2	1	3	PRA	100					
aex8902	HOK	15	72	1.10E+03	2	2	2	1	PRA	100					
aex8902	HOK	16	91	1.93E+03	2	2	1	3	PRA	100					
aex8902	HOK	17	69	1.01E+03	2	2	0								
aex8902	HOK	18	89	2.06E+03	2	2	3	3	FIS	90	PRA	10			
aex8902	HOK	19	77	1.22E+03	1	2	1	3	FIS	100					
aex8902	HOK	20	86	1.82E+03	2	2	2	1	PRA	95	APH	5			

Stomach state, 0 = empty, 1 = trace, 2 = part full (25-75%), 3 = full, 9 = everted
Stomach condition, 1 = fresh, 2 = half digested, 3 = digested, 4 = mixed digestion states

Appendix 2. Delimiting and scaling ecosystems (from Livingston 2004)

An ecosystem is defined as a three dimensional space within which the interactions between the different residents (plants and animals) are much stronger than with the residents of neighboring ecosystems (Pauly & MaClean 2003, Pauly & Christensen 2003). There is a diverse variety of spatial scales to consider when delimiting ecosystems, from the microhabitat scale to basin-scale oceans. Factors that are practicable to use in defining an ecosystem include broad-scale knowledge of oceanography and bottom topography (Figures 7, 8), along with finer scale groupings that based on factors such as localised species assemblages, seasonal fisheries, and bottom type.

Beyond the shallow coastal shelf (0-200 m depth), bathymetric mapping of the New Zealand EEZ reveals three large plateaus in upper to mid-slope depths (200-1200 m), the Challenger Plateau, the Chatham Rise and the Campbell Plateau (Figure 3, main document). The West Wind Drift results in a general movement of water from west to east, and warm subtropical water (STW) to the north are separated from cooler Sub-Antarctic water (SAW) by a boundary zone, the Sub-Tropical Front (STF) which is quite diffuse to the west but forms a distinctive front lying across the Chatham Rise east of New Zealand (Figure 4, main document).

For the purposes of this work, we propose identifying "functional units" as proxies for ecosystems in order to identify potential regions for study. These functional units will be delimited based on known assemblages of fish, principal fisheries and known bathymetric and hydrographic features of the EEZ (Table 1 below).

Table 3. Proposed division of New Zealand into functional units as a proxy for ecosystems

Functional units	Depths, features	Main fisheries	Current sampling support
Chatham Rise (upper-slope)	200–800 m; STF	Hoki, hake, ling, warehou,	Annual trawl surveys, OP, HMC
Chatham Rise (mid-slope	800–1400 m	Orange roughy, oreo	ORMC Trawl surveys possible OP
East Coast South Island	0–400 m, coastal; STF	Red cod, barracouta, school shark, tarakihi, skates, spiny dogfish,	OP
East Coast South Island	400 m+		OP, HMC
East Coast North Island	0–400 m, coastal;	Snapper, blue moki, gemfish, blue cod, grey mullet, elephant fish, red john, dory, gurnard,	OP, coastal shelf systems
East Coast North Island	400 m+	orange roughy, bluenose, alfonsino	OP
Sub-Antarctic (Campbell Plateau, Puysegur) upper-slope	300–800 m	Hoki, hake, ling, warehou, Southern blue whiting	Annual trawl surveys (hoki); HMC, OP, acoustic survey (southern blue whiting
Sub-Antarctic, mid-slope	800–1400 m	Orange roughy	ORMC?OP
West Coast South Island	50–400 m	warehou, gemfish, red cod, inshore species	Kaharoa surveys out to 400 m in March
West Coast South Island	400–1200	Hoki, hake, orange roughy	OP hoki spawning season, HMC,
West Coast North Island	50–200 m	gemfish, jack mackerel	OP?
Challenger Plateau	500–800 m	nil	OP
Challenger Plateau	800–1200	Orange roughy	ORMC
Cook Strait	0-500 m	jack mackerel, hoki	HMC, OP, shed sampling, acoustic surveys (hoki)
Fiordland	0–200 m	Shellfish, juvenile nursery grounds	No sampling in place at present
Puysegur, Stewart and Snares Shelf	50–300 m	Groper, stargazer, barracouta, gemfish	Orange roughy
Offshore Islands	30–200	Squids, barracouta	No sampling in place at present
Seamounts/canyon features	200–1500 m	Orange roughy, oreos	proposed section of Seamounts Programme (FORST, MFish?)

Appendix 3. Application of stable isotope analysis to studies of food chain structure and function

The ratios of stable isotopes of nitrogen ($^{15}N/^{14}N$, conventionally expressed as $\delta^{15}N$) and carbon ($^{13}C/^{12}C$, $\delta^{13}C$) in consumers reflect those in their prey in a predictable manner. Specifically the $\delta^{15}N$ signature, and to a lesser extent the $\delta^{13}C$ signature, provide information about trophic status. Additionally, the $\delta^{13}C$ signature can provide information about the source of nutrients within a food chain. When analysed together, these signatures provide more information about a consumer's diet than either signature measured in isolation.

In a situation where a consumer's diet comprises more than one prey species, and where these potential prey species exhibit distinct isotope signatures, it should be possible to quantify the proportion of each specific prey type in a consumer's diet by constructing a dual-isotope multi-source mixing model. Additionally, by careful selection of consumer tissues, variation in diet could be measured over varying temporal scales since tissues with different metabolic turnover rates incorporate dietary information over correspondingly different temporal scales. For example, liver tissue has a relatively rapid turnover, and dietary information as revealed through stable isotope analysis will reflect the preceding few days. Conversely, collagen extracted from bone has a much slower turnover and isotopic information from this tissue will reflect the diet over the preceding months, possibly years.

In the case of hoki (or any other key species of interest) considerable background work would be required, particularly in identifying isotope signatures in key prey species. However, if applicable to this sort of investigation (ie if prey species have distinct isotope signatures), stable isotope analysis offers a time-integrated method for quantifying the diet of key consumers without the need to identify prey remains in stomach samples.

Appendix 4. Molecular tools for identification of soft tissues (part digested) in fish gut contents

One of the challenges of gut content analysis is achieving the necessary level of identification from part digested remains. Traditional biochemical approaches to gut content identification have applied serological methods which are time consuming, and often non-specific. Alternative, faster tools such as isoelectric focusing (IEF) and DNA methods will be evaluated for the identification of soft tissues in hoki gut contents. Hard parts such as otoliths and carapaces will be identified by traditional taxonomic comparison.

IEF of muscle proteins has been the preferred method for identification of teleost fillets and products (e.g. Rehbein 1990), and has been adopted by the US Food and Drug Administration for identification of fish product (Tenge et al. 1993). Unknown specimens are identified by matching their protein profiles against the profiles of known control specimens. The technique has been applied by NIWA staff for the identification of shark fins and fillets (Smith and Benson 2001), for distinguishing fillets from Patagonian and Antarctic toothfish (Smith et al. 2001), and for identifying fish prey items in gut contents of Westland black petrel (Freeman and Smith 1998).

DNA techniques are increasingly being applied in the forensic identification of fish products (e.g. Pank et al. 2001, Smith et al. 2001, Shivji et al. 2002), including cooked and canned products (Rehbein et al. 1999, Sebastio et al. 2002). Unknown specimens are identified by matching their DNA digestion profiles (restriction fragment length polymorphisms = RFLPs) or DNA sequences, against profiles or sequences from known specimens. DNA RFLPs and sequences have been used by NIWA staff for the identification of marine fishes (Smith et al. 2001, Smith and Paulin 2003).

Soft tissue samples from hoki (and other species) gut contents will be tested with IEF and DNA approaches to determine if IEF profiles and/or DNA sequences can be recovered from gut contents. IEF profiles or DNA sequences of the prey items, especially small pelagics, are unlikely to be available in existing IEF (e.g. Tenge et al. 1993) or DNA (e.g. GenBank) databases. Therefore, provided that IEF profiles of DNA sequences can be recovered from the hoki gut samples, an appropriate database will be established of the likely prey species, against which the unknown gut contents will be matched. DNA sequences will be deposited in GenBank for future reference.

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Appendix 5. Trophic levels of New Zealand species, or closely related species on Fishbase (Froese et al. 2003)

Species name	Common name	Trophic level
Alepocephalus bairdii	Baird's slickhead	2.8
Alopias spp	Thresher sharks	3.8
Anguilla australis	Short-finned eel	3.7
Aphanopus carbo	Black scabbardfish	3.4
Apogonidae	Cardinalfishes nei	3.4
Arctocephalus australis	South American fur seal	3.8
Atherinidae	Silversides(=Sand smelts)	2.8
Batoidimorpha(Hypotremata)	Rays, skates, mantas nei	3.6
Batrachoides spp	Toadfishes	3.5
Beryx spp	Alfonsinos	3.5
Callorhinchus spp	Elephantfishes	3.6
Bramidae	Pomfrets, ocean breams, nei	3.3
Caproidae	Boarfishes	3.5
Carangidae	Carangids nei	3.3
Carcharodon carcharias	Great white shark	3.8
Centrophorus granulosus	Gulper shark	3.6
Cephalopoda	Cephalopods nei	3.2
Cheilodactylus macropterus	Tarakihi	3.5
Chelidonichthys spp	Indo-Pacific gurnards	3.5
Chondrichthyes	Cartilaginous fishes nei	3.6
Chrysophrys aurata	Golden snapper	3.4
Conger spp	Conger eel	3.4
Coryphaenidae	Dolphinfishes, nei	3.3
Delphinus delphis	Common dolphin	4.2
Emmelichthyidae	Bonnetmouths,rubyfishes,etc.	3.4
Engraulidae	Anchovies nei	2.7
Epigonus telescopus	Black cardinal fish	3.5
Etmopterus spp	Lantern sharks	3.6
Euphausia spp	Antarctic krill, nei	2.2
Gastropoda	Gastropods nei	2.1
Genypterus blacodes	Pink cusk-eel	3.4
Hoplostethus atlanticus	Orange roughy	3.5
Jacquinotia edwardsii	Southern spider crab	2.3
Kathetostoma giganteum	Stargazer	3.5
Lamna nasus	Porbeagle	3.8
Lampanyctodes hectoris	Lanternfish	3.4
Latridae	Trumpeters	3.5
Latridopsis ciliaris	Blue moki	3.5
Macrourus spp	Grenadiers	3.8
Macruronus novaezelandiae	Blue grenadier	3.8
Maja squinado	Spinous spider crab	2.3
Maurolicus muelleri	Silvery lightfish	3.4
Mene maculata	Moonfish	3.4
Merluccius australis	Southern hake	3.8
Micromesistius australis	Southern blue whiting	3.8
Mola mola	Ocean sunfish	3.5
Muraenidae	Morays	3.5
Myctophidae	Lanternfishes	3.4
Nototodarus sloani	Wellington flying squid	3.2
Oreosomatidae	Oreo dories	3.5
Pampus spp	Pomfrets, nei	3.8
Parapenaeus longirostris	Deepwater rose shrimp	2.7
Parapercis colias	New Zealand blue cod	3.5
Pecten novaezelandiae	New Zealand scallop	2.1
Penaeus spp	Penaeus shrimps nei	2.3
Perca fluviatilis	European perch	3.5
Polyprion oxygeneios	Hapuku wreckfish	3.5
Portunidae	Swimming crabs nei	3.4
Rajiformes	Skates and rays, nei	3.5
Scombridae	Mackerels, nei	3.2
Scyliorhinus spp	Catsharks, nursehound	3.8
Spongidae	Sponges nei	2.3
Squalus acanthias	Picked dogfish	3.6
Sternoptychidae	Hatchetfishes	3.4
Teuthoidea	Various squids, nei	3.2
Thunnus alalunga	Albacore	4
Thunnus albacares	Yellowfin tuna	3.7
Thyrsites atun	Snoek	3.4
Todarodes pacificus	Japanese flying squid	3.2
Torpedo spp	Torpedo spp	3.5
Trachurus murphyi	Chilean jack mackerel	3.3
Trigla spp	Gurnards	3.5
Zeus faber	John dory	3.5