A review of deep-sea benthic biodiversity associated with trench, canyon and abyssal habitats below 1500 m depth in New Zealand waters

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EXECUTIVE SUMMARY

We review the state of knowledge of benthic biodiversity and ecosystem functioning in deep-sea abyssal, canyon and trench habitats in the New Zealand Exclusive Economic Zone and the Ross Dependency, and make recommendations for future deep-sea research in depths exceeding 1500 m.

All biological information in scientific papers and reports from New Zealand below 1500 m was reviewed and an exhaustive search of multiple data sources was conducted.

The area of the deep seafloor below 1500 m covers more than 65% of New Zealand's Exclusive Economic Zone. A total of 1489 benthic gear deployments have been conducted by New Zealand-based sampling initiatives since 1955, most of which were focused on obtaining geological samples. Less than 0.002 % of New Zealand's deep-sea environment (i.e. in terms of seabed area) below 1500 m has been sampled.

All taxonomy-based studies of all taxa reported in New Zealand waters below 1500 m have been reviewed. To date, 8 species of Bacteria, 293 species of Protozoa, 785 species of invertebrates, and 56 fish species have been recorded from water depths greater than 1500 m. Most of these species are known only from single or relatively few stations collected mainly during historical, non-New Zealand sampling initiatives, notably the British *Challenger*, Danish *Galathea* or Russian *Vityaz* expeditions. Many of these specimens are held at the associated institutions in London, Copenhagen and Moscow, and are therefore not immediately available for scientific study in New Zealand.

Few ecological studies in New Zealand waters have focused on assemblage patterns or processes at depths exceeding 1500 m. Of these, most have been on the Chatham Rise and surrounding areas, with sampling conducted across a wide depth range (from shallow to deep-sea sediments), sometimes as part of interdisciplinary research of particular ecosystem processes. Ecological information on benthic fauna and demersal fish from depths below 1500 m is restricted to the Kermadec Trench. Process-orientated studies are limited to pelagic-benthic coupling (and ocean productivity) research on the Chatham Rise slopes, and trophic interactions research in hadal environments (below 6000 m) of the Kermadec Trench. The scarcity of information from New Zealand is particularly evident when compared with other regions worldwide, for which detailed descriptions of invertebrate and fish assemblages exist, and where the availability of long-term and experimental data has enabled the elucidation of deep-sea ecosystem processes.

More than 8000 images are known to have been taken of the seafloor below 1500 m in the New Zealand region, covering an area of approximately 0.016 km^2. Over 4000 of the images held at NIWA exist either as paper prints or negatives and ideally should be digitised for future storage and access for analyses. Analysis of these photographic images should yield considerable information about deep-sea biodiversity and ecosystem function in the New Zealand region and could be used to answer a number of research questions (especially around deep-sea benthic biodiversity).

Recommendations on how to potentially further analyse existing data from images, databases and actual specimens are provided. The technical challenges, including gear requirements to sample deep-sea New Zealand benthos and potential future investments, are summarised.

Recent research in the Southern Ocean highlights the ecological and evolutionary importance of the southeastern Pacific Ocean. There are clearly many research questions about benthic ecosystems in New Zealand waters below 1500 m depth that if addressed could increase knowledge to levels similar to those in other regions of the globe. This would require expanding New Zealand's deep-sea sampling capabilities and developing a long-term, integrated research programme, potentially in collaboration with overseas research institutions.

1. INTRODUCTION

The objective of the review is to assess the state of knowledge of biodiversity and ecosystem function in New Zealand deep-sea abyssal, canyon and trench habitats, and make recommendations for future research, under Ministry of Fisheries (MFish) project ZBD2008-27.

1.1 Rationale and aims of the review

Seventy-one percent of the Earth's surface is covered by oceans. Of this, 87% of the ocean's surface and 90% of the ocean's volume is covered by water deeper than 1500 m. Habitats such as abyssal plains, deep-sea canyons, seamounts, channels and trenches that occur at depths below 1500 m occupy approximately 65% of New Zealand's Exclusive Economic Zone (EEZ), distributed in three depth zones — bathyal (down to 3000 m), abyssal (3000–6000 m) and hadal (below 6000 m). Little is known, however, about benthic biodiversity and ecosystem functioning in these zones in New Zealand, or how these are linked to more productive surface waters.

The ecological and evolutionary relationships between deep-sea benthic biodiversity in New Zealand and other similar habitats around the world are also unknown. The tectonic setting of New Zealand astride the boundary between the Pacific and Australian crustal plates provides a "natural laboratory" for studying such bathymetrically complex environments.

The rationale for the upper depth limit of 1500 m in the present review builds on the preliminary review of New Zealand's deep-water benthic biodiversity prepared by Key (2002), and relates to the current depth limit of fishing. 1500 m is the maximal depth coverage by biodiversity projects under the regional Ocean Survey 20/20 (OS2020) mapping programme, administered by Land Information New Zealand (LINZ). The present review also includes habitats such as slope, troughs, plateaux and seamounts where they occur below 1500 m water depth. For the purposes of this review, the "New Zealand region" is bounded by latitudes 24° S to 57°30' S and longitudes 157° E to 167° W. While the primary focus of the present review is abyssal environments within the New Zealand Exclusive Economic Zone (EEZ), we have included the Ross Sea as this is an area where New Zealand has responsibilities to the Comission for the Conservation of Antarctic Marine Living Resources.

Data from three primary sources were collated and summarised for the present review:

1) Scientific papers and reports: all published accounts of studies below 1500 m depth in the New Zealand region and the Ross Dependency, including peer-reviewed scientific literature, faunal monographs and technical reports.
2) Databases and collections: emphasis was made on data held by two nationally funded collections that contain most deep-water fauna samples collected historically in New Zealand waters. These samples are housed within NIWA's Invertebrate Collection (NIC), a core funded (ex FRST-funded) 'nationally significant' collection of marine invertebrates, and the National Museum of New Zealand Te Papa Tongarewa, funded by the Ministry of Culture and including deep-water invertebrates and fishes. Other relevant databases (e.g., Specify, Trawl) were also interrogated and relevant metadata collated.
3) Image collections: comprising all photographs of the seabed greater than 1500 m depth in the New Zealand region. These were taken mostly by NIWA or its predecessor organisation (the New

Zealand Oceanographic Institute of the DSIR), with a small number by foreign vessels. All are available to NIWA but many have not yet been formally databased.

1.2   Specific Objectives

Specific Objective 1

To assess the state of knowledge of biodiversity and ecosystem functioning in New Zealand deep-sea abyssal, canyon and trench habitats and make recommendations for future research.

1.3 Physical, geographical, and chemical description of the habitat being reviewed

The physiography of environments below 1500 m in the New Zealand region is varied and complex (Figure 1), reflecting tectonic evolution of the largely submerged 'Zealandia' subcontinent over the last 80 million years (Kamp 1986; Sutherland 1995, 1999a, b; King 2000a, b; Campbell & Hutching 2007; Wood & Stagpoole 2007). In particular, this tectonic activity has been dominated by the development of an active plate boundary between the Pacific and Australian plates since 25 million years ago.

The main bathymetric features around New Zealand, of which part or all occur at water depths below 1500 m (Thompson 1991; Figure 1), include:

- Deep-water basins (Southwest Pacific Basin, Tasman Basin, South Fiji Basin, South Norfolk Basin, Raukumara Plain and underlying basin, Tasman Basin, Emerald Basin);
- Sediment-filled troughs (New Caledonia Trough, Bellona Trough, Bounty Trough, Havre Trough, Hikurangi Trough, Solander Trough);
- Deep trenches (Puysegur and Kermadec trenches);
- Plateaux (the deeper flanks of the Campbell Plateau, Bounty Plateau, Hikurangi Plateau, Challenger Plateau);
- Seamounts (e.g., Gilbert Seamount, Dolphin Seamount, Bollons Seamount, Louisville Seamount Chain);
- Incised canyons and channels (e.g., Bounty Channel, Hikurangi Channel, Kaikoura Canyon, Cook Canyon, Hokitika Canyon, Cook Strait Canyon);
- Elevated volcanic ridges (Norfolk Ridge, West Norfolk Ridge, Three Kings Ridge, Colville Ridge, Kermadec Ridge, Puysegur Ridge, Macquarie Ridge); and
- Continental rises (the deeper flanks of Chatham Rise, Lord Howe Rise, Campbell Rise, Pukaki Rise).

The continental margin around New Zealand occurs mostly at water depths exceeding 200 m, extending to greater than 1500 m along most of the margin, except where the continental slope is intersected by prominent bathymetric ridges, rises and plateaux (Figure 1). The continental upper shelf and slope are incised by numerous submarine canyons, including several that extend below 1500 m.
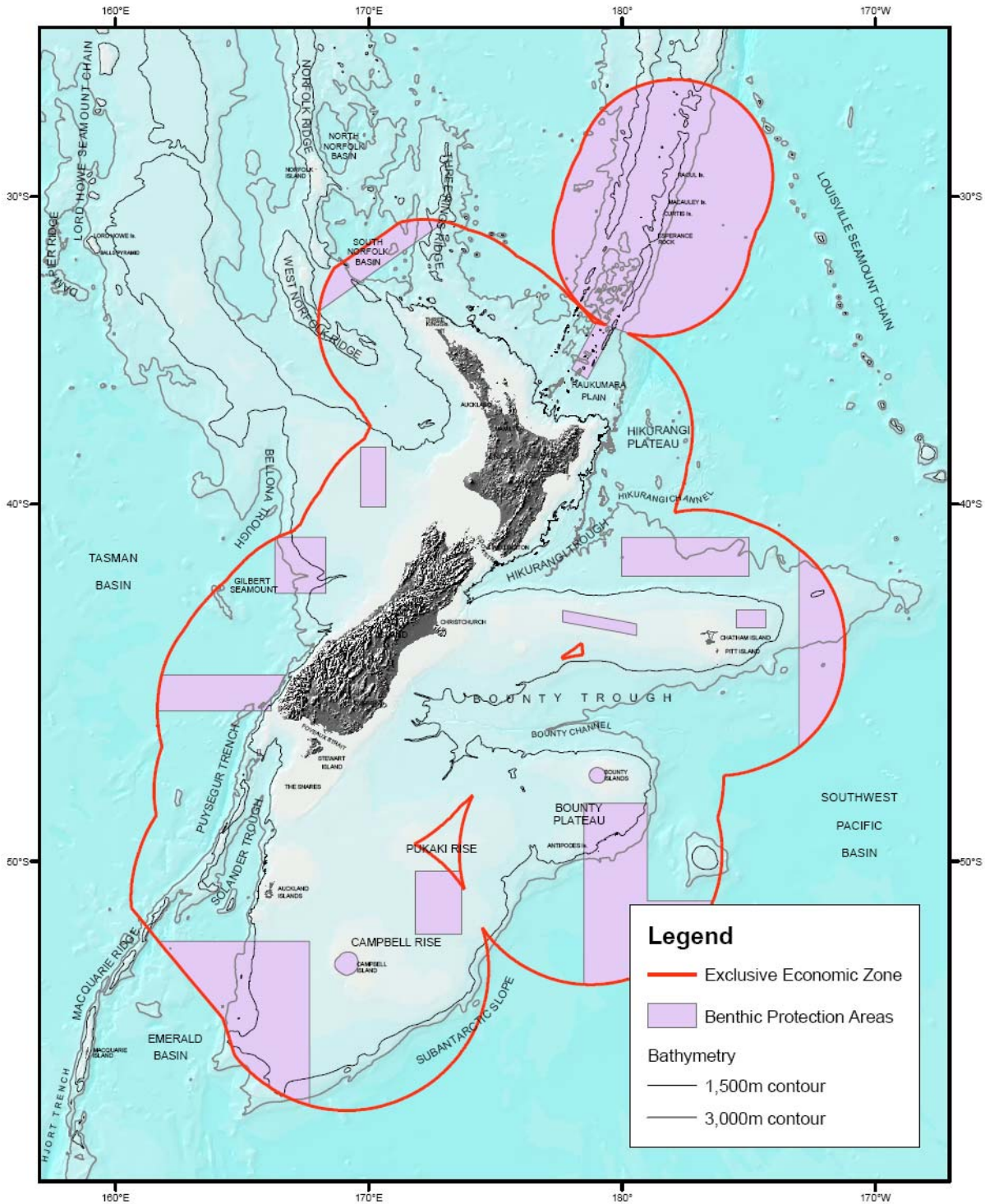
Figure 1: Prominent bathymetric features of the seafloor surrounding New Zealand.

The major deep-water basins are the Tasman Basin to the west and the Southwest Pacific Basin to the east of New Zealand. These basins have water depths generally greater than 4500 m and comprise typical abyssal environments that have formed on Cretaceous-aged basaltic seafloor, dominated by red-clay deep-ocean sediments (Mitchell et al. 1989). Smaller basins occur to the north of New Zealand that are associated with ancient volcanic ridges and occur at water depths of 3000–3500 m (South and North Norfolk basins, South Fiji Basin) (Malahoff et al. 1982). Sediment-filled troughs are

also features of the New Zealand region, including the New Caledonia, Solander and Bounty troughs. The Hikurangi Trough occurs along the active plate boundary off eastern North Island, while the newly forming Havre Trough, representing the offshore extension of the Taupo Volcanic Zone, comprises rifting volcanic crust with incipient seafloor spreading in the north (Wright 1993).

Along the plate boundary east of the North Island, Pacific ocean seafloor is being subducted at depth at a rate of 30–40 mm y^{-1}. The Kermadec-Tonga Trench that extends northeastwards for more than 1600 km exceeds 10 000 m in places but shallows to the south where it merges with the sediment-filled 4000–5000 m-deep Hikurangi Trough (Cole & Lewis 1981; Collot et al. 1994). A series of margin-parallel ridges occur along the Zealandia continental margin, associated with active thrust faulting related to the deformation of the over-riding Australian Plate above the subducting Pacific Plate (Cole & Lewis 1981; Davey et al. 1986; Barnes et al. 1998; Nicol et al. 2007). Southwest of Fiordland, there is an opposite situation at the shallower (approximately 6000 m) Puysegur Trench with the Australian Plate being subducted beneath the Pacific Plate (Collot et al. 1994). Running parallel and east of the Macquarie Ridge is the Macquarie Trench, which is approximately 5500 metres deep and breaks through the ridge line nearly 100 kilometres to the south of Macquarie Island, continuing southwards as the Hjort Trench to about 60° S within the Australian EEZ around Macquarie Island.

The Cretaceous-originating Bounty Trough and channel lie north of the Campbell Plateau, extending approximately 1000 km due east from the Otago shelf to the abyssal plain at depths down to approximately 3000–3500 m (Carter & Carter 1993). North of this sediment-filled feature the west–east-orientated continental ridge known as the Chatham Rise (Cullen 1980; Wood & Herzer 1993), with the subaerial Chatham Islands at its easternmost edge. The Chatham Rise extends from 300–400 m on its crest down to 3000–3500 m along its slopes. Sandy muds rich in glauconite (an iron-potassium micaceous mineral) and associated phosphorite are found on the Chatham Rise crest, with carbonate-rich sandy muds on the southern and eastern slopes and terrigenous muds and sands along its northern and western slopes (Mitchell et al. 1989). An unusual area of raised oceanic seafloor that is presently being subducted beneath the Hikurangi Trough-Kermadec Trench occurs north of the Chatham Rise. Known as the Hikurangi Plateau, this is an extensive piece of thickened, Cretaceous-aged basaltic seafloor studded with numerous volcanic seamounts. It ranges from 2500 to 4000 m (Davy et al. 2008).

The Hikurangi Channel meanders across the Hikurangi Plateau from the Kaikoura and Cook Strait canyons in central New Zealand to the abyssal water depths of the Southwest Pacific Basin. It is one of the longest deep-sea channels on Earth at over 3000 km length and is incised into the seafloor to several hundred metres with a width of 5–10 km (Lewis 1994). Active sediment flows (known as 'turbidites'), activated by earthquakes every few hundred years, are believed to be responsible for carving out and maintaining the Hikurangi Channel along its length. The channel is diverted from the Hikurangi Trough along the eastern seaboard of the North Island by a large submarine landslide known as the Ruatoria Debris Avalanche (Collot et al. 2001), which adds to the complex deep-water bathymetry in this region. North of East Cape, another large mass failure (Matakaoa Submarine Instability Complex) is found on the 2000–3000 m-deep Raukumara Plain and underlying sedimentary basin (e.g., Lamarche et al. 2008; Sutherland et al. 2009).

Seamounts are also a prominent feature of the abyssal environment around New Zealand. The most obvious elevations, typically less than 2000 m high, comprise the Louisville Seamount Chain, which extends more than 4000 km across the Southwest Pacific Basin (Lonsdale 1986). These volcanic seamounts are thought to increase in age towards the northwest, having been formed by the movement of the ocean floor over a 'hot-spot' of rising magma deep in the Earth's mantle, similar to the Hawaiian Islands. At the northwestern end of the chain, the oldest seamounts of the chain are being subducted at the Kermadec Trench (Lonsdale 1986) and mark the morphological break between the Kermadec and Tonga trenches. Other major seamounts include Bollons Seamount off the Campbell Plateau, which extends between 1000 and 4000 m depths, and the Gilbert and Dolphin seamounts off western South Island and southern Challenger Plateau, respectively. These seamounts have formed as

a consequence of past rifting processes more than 60 million years ago (e.g., Davy 2006). There are 660 seamounts with peaks below 1500 m in the New Zealand region, of which 351 are deeper than 3000 m. In the EEZ, 377 seamounts have peaks below 1500 m and 72 of these have summits below 3000 m (SEAMOUNT v2 database, accessed 30th September 2009; see Rowden et al. (2008)).

## 1.4 The physical and chemical environment of the deep-sea around New Zealand

The deep ocean floor around New Zealand (below 1500 m) is influenced by several water masses depending on bathymetry and latitude (e.g., Heath 1985; Tomczak & Godfrey 1994; Sokolov & Rintoul 2000). In the surface ocean, warm, saline, nutrient-depleted subtropical water bathes the entire continental shelf and lies north of the Subtropical Front, with cold, fresh, macronutrient-replete and micronutrient-deficient Subantarctic Surface water) southwards of the front to 50–55° S. Between 600–1450 m depth is Antarctic Intermediate Water (AAIW). This water mass is characterised by a salinity minimum (down to 34.50 psu), temperatures of 3–7 °C and moderately high oxygen concentrations (3.2–4.7 ml/l). Beneath AAIW lies North Pacific Deep Water (NPDW) between 1450–2550 m, with an oxygen minimum down to 2.8 ml/l, and Circumpolar Deep Water (CDW), consisting of three main water masses: upper from 2550–2900 m, middle 2900–3800 m and lower below 3800 m. Middle CDW is characterised by a salinity maximum reaching 34.7 psu, while the lower CDW has a characteristic oxygen maximum from 4.7–4.8 ml/l and a weak salinity minimum. LCDW is a remnant of North Atlantic Deep Water (NADW), which forms initially in the Norwegian Sea and can be detected in the Pacific as far south as 10° N (Reid & Lynn 1971). Below 3800 m to the abyssal seafloor lies Antarctic Bottom Water (AABW), which typically has very cold temperature signatures.

Deep ocean circulation in the SW Pacific Ocean is complicated by the submerged New Zealand continental landmass (Figure 2). The most prominent feature is the Antarctic Circumpolar Current (ACC), which is a global, eastward-directed current that operates at latitudes of approximately 45–50° S, driven by the westerly wind belt. Average current speed in the ACC is approximately 4 cm s^{-1}, although velocities of more than 40–50 cm s^{-1} have been measured in near-bottom environments through bathymetric gaps in the Macquarie Ridge (M. Williams, NIWA, pers. comm.). The ACC is situated south of the Subantarctic Front, which is locally bathymetrically tied to the southeastern edge of the Campbell Plateau. At abyssal depths along this margin, the Pacific Deep Western Boundary Current (DWBC) brings deep water (LCDW/NADW and AABW) into the SW Pacific Basin. The Pacific DWBC flows northwards along the eastern margin of the submerged New Zealand landmass and into the tropical and North Pacific Ocean, transporting 20 x 10^6 m^3 s^{-1} (Warren 1981). Along the pathway of the DWBC are associated sediment-drift deposits (Carter & McCave 1994) and fields of manganese nodules (Graham & Wright 2006).

The benthic boundary layer (BBL) is an important physical environment in the deep ocean, as it is here that relatively intense biological activity takes place compared to the overlying water column. The BBL has relatively high concentrations of particulate material and biologically active chemical substances, and typically has elevated abundance and biomass of organisms and metabolic rates (e.g., Wishner & Gowing 1987). The BBL can be greater than 100 m thick and may be disrupted by episodic benthic storms and nepheloid layers (e.g., Tucholke et al. 1985). The transfer of organic material from the surface ocean, through the deep ocean water column where it is remineralised and re-packaged by planktonic organisms, to the deep seafloor is a fundamental process affecting the structure and functioning of deep-water benthic communities (e.g., Gage 2003).

Water-column chemistry can also play a role in structuring benthic communities with oxygen levels being critical for all animal life. For example, in some deep-water environments, zones of low oxygen can develop owing to intense surface biological productivity, such as on upwelling continental margins (e.g., Peru, Oman) and in the deep marginal basins off southern California (e.g., Levin & Gage 1998).
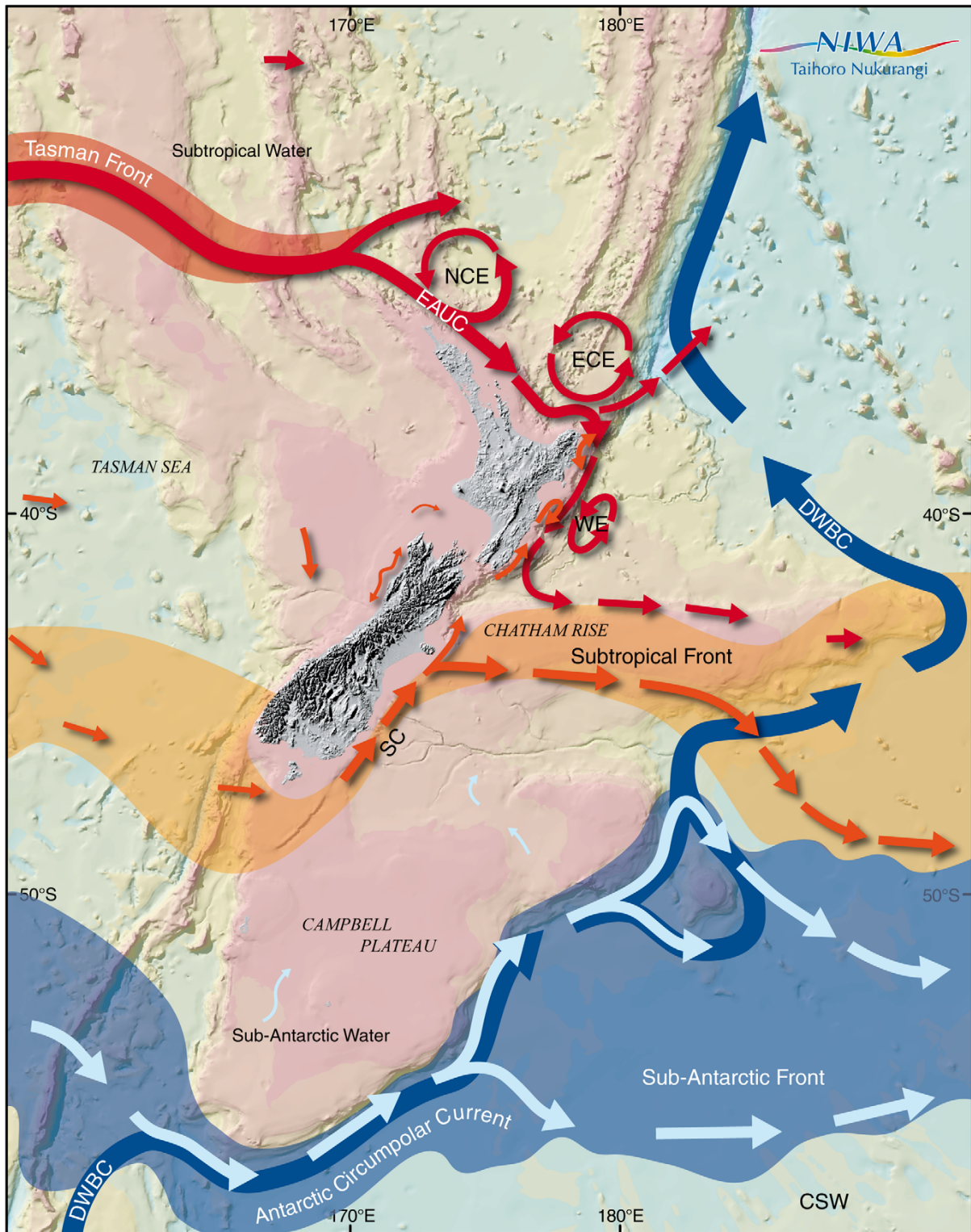
Figure 2: Circulation in the New Zealand region, showing the major fronts and eddy features. EAUC, East Auckland Current; NCE, North Cape Eddy; ECE, East Cape Eddy; SC, Southland Current; WE, Wairarapa Eddy; DWBC, Deep Western Boundary Current

For benthic organisms that use carbonate to form their exoskeletons or tests (e.g., foraminifera, corals, molluscs, bryozoans, crustaceans, echinoderms), the depth of the calcite saturation horizon (CSH) and aragonite saturation horizon (ASH) are also critical because of potential changes in ocean pH conditions arising from the increasing absorption of anthropogenic carbon dioxide into the deep-water masses of the Southern Ocean (e.g., Feely et al. 2004). In the New Zealand region, the depth of the

CSH is believed to be 2900–3250 m with the ASH at 1000–1300 m (as shallow as 500 m in the Ross Sea — H. Bostock & K. Currie, NIWA, pers. comm.). These chemical interfaces may be prone to rapid shoaling over the next 50 years (Orr et al. 2005), thereby affecting benthic communities over these depth ranges. Silica concentrations in the deep ocean may also affect the growth of deep-water siliceous organisms such as sponges.

Ross Dependency

On 30 July 1923, Britain claimed the Ross Dependency in Antarctica, and placed it in the care of New Zealand, whose jurisdiction was recognised internationally by the signing of the Antarctic Treaty in 1959. Since this time, New Zealand has maintained its sovereignty rights over the Ross Dependency, an area defined as all the islands and territories south of 60° S and between 160° E and 150° W. The Ross Sea forms the main oceanographic component of the Ross Dependency as a large 1000 km wide embayment on the coastline of Antarctica. The continental margin of the Ross Sea is characterised by complex morphology that varies from west to east, with the shelf break located at water depths of 400–500 m and the continental slope extending down to the abyssal seafloor at 3500–4000 m (Figure 3). West of 180° and south of 60° S, the margin is narrow and comprises a series of interconnected ridges, localised sediment-filled troughs, and seamount chains including the Balleny Islands (e.g., Cooper & Davey 1987). In this region, the north-trending Iselin Bank extends as a narrow ridge out from the Ross Sea continental margin towards the Scott Island massif, deepening gradually seaward from 500 m to below 1000 m (Cande & Stock 2000). East of Iselin Bank, continental-margin morphology is simpler, with the continental slope and rise merging into the eastern extent of the Amundsen Abyssal Plain (otherwise known informally as the Ross Sea Abyssal Plain) at water depths of 3500–4500 m.

Numerous isolated seamounts, north of 71° S, rise up from water depths greater than 3000 m to shallower than 1000 m. These features are associated with the deep-ocean Pacific–Antarctic Ridge, which is an active mid-ocean ridge between Antarctica and New Zealand. The Balleny Islands chain and the Scott Island massif are composed of oceanic basalt rocks (Green 1992) that are thought to comprise the youngest rocks in the seamount chain (approximately 10 million years old), which formed over a mantle plume initiated at the time of Gondwana spreading approximately 80 million years ago (Lanyon et al. 1993).

1.5   Historical sampling effort in New Zealand

There have been very few expeditions in the last 135 years that have specifically focused on obtaining biological samples from abyssal depths (greater than 1500m) in New Zealand waters. Yaldwyn (1957) provided a review of deep-water biological investigations in the New Zealand area, noting some of the earliest expeditions. These included the visit of H.M.S. *Challenger* to New Zealand in 1874 as part of its round-the-world expedition from 1873–76 (Hamilton 1896). This visit can be regarded as the start of deep-water investigation in New Zealand. The *Challenger* expedition sampled two abyssal stations to the west of New Zealand (2011 m and 4750 m water depths). The Carlsberg Foundation's Oceanographic Expedition round-the-world voyage of the *Dana* (1928–30) made the first bathypelagic collections from greater than 1500 m depth (three stations with depths exceeding 1800 m) (Jespersen and Tåning 1934). The Danish *Galathea* expedition in 1950–52 (Spärck 1951) sampled abyssal and hadal depths in the Kermadec region with six metre-wide sledge trawls down to 8300 m and a core sample taken from 9190 m. Investigations undertaken in 1957 and 1958 by the Zoology Department, Victoria University, led by Professor L. R. Richardson, sampled the Cook Strait fauna using two baited traps deployed at 2377 m depth. In 1958, the Soviet research ship *Vityaz* sampled two stations between 8928 and 10 002 m in the Kermadec Trench (Belyaev 1966).
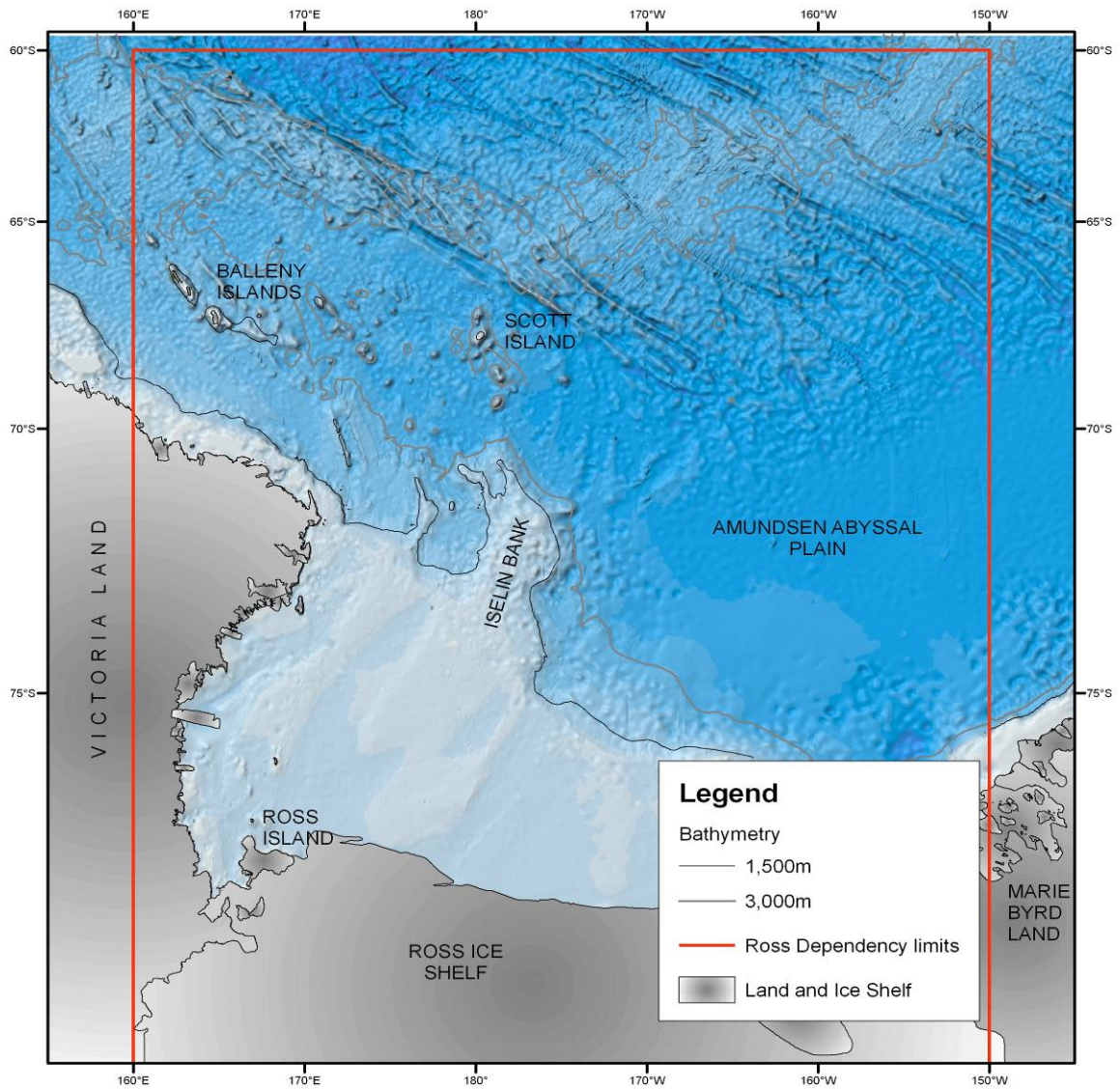
Figure 3: Prominent bathymetric features of the seafloor of the Ross Sea. The boundaries of the Ross region are shown as a red line.

Baited traps were successfully deployed in the Kermadec trench at 6000 m, 6890 m and 7966 m in 2001 by the Cook Cruise aboard RV *Melville* (Jamieson 2009a, b). In 2004, a NIWA survey of three seamounts on the Hikurangi Plateau was conducted by RV *Tangaroa* and a relatively small number of samples and seabed images were collected at depths below 1500 m (see voyage report by Clark (2004)). The 2005 cruise of RV *Ka'imikai-o-Kanaloa* to the Kermadec Arc took a number of samples using the ROV *Pisces V* from depths of 1577–1779 m on Brothers Seamount (Merle et al. 2005).

Several other New Zealand expeditions since 1955 occasionally sampled below 1500 m; these are summarised in Table 1 and Figure 4. The majority of these expeditions were focused on obtaining geological samples, the principal objective of the sampling undertaken at the stations being to collect sediment or rocks from the seafloor, and not benthic organisms. Very few localities were sampled below 3000 m depth, and these too were geologically focussed with benthic organisms obtained only opportunistically.
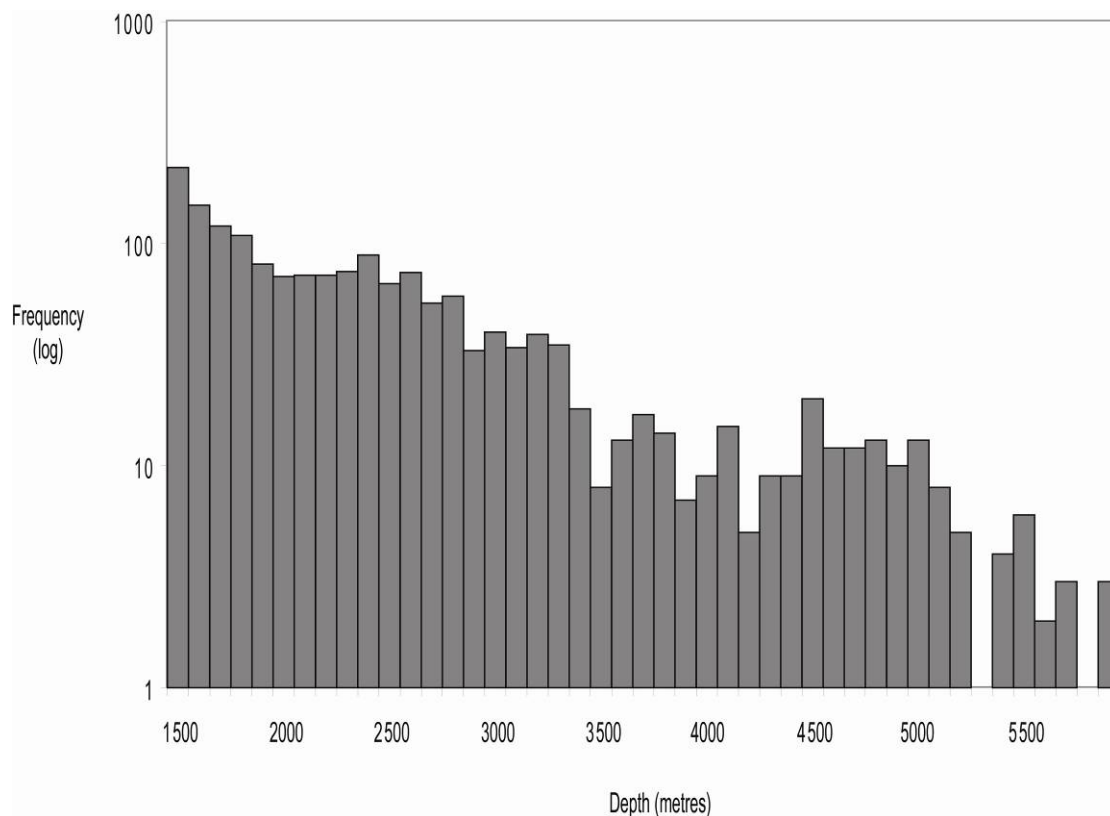
Figure 4: Number of benthic samples per 50 m depth bands below 1500 m taken by New Zealand-based expeditions since 1955.

Table 1: **New Zealand-based expeditions sampling benthos below 1500 m depth, arranged chronologically.**

Cruise Name	Cruise Leader	Vessel	Depth Range (m)	Number Benthos Stations	Number Camera Stations	Fisheries Management Area (see Figure 5)
1955						
Coastal II Lachlan	Garner, D. M.	Lachlan	1 898–2 045	2		FMA1
Coastal III Lachlan	Garner, D. M.	Lachlan	1 587–2 036	3		FMA1, FMA2
1956						
Chatham Tui	Burling, R. W.	Tui 1	1 536–3 515	5		FMA1,FMA2, FMA4
Kermadec Tui	Cassie, R. M.	Tui 1	1 741–5 448	4		FMA10
Tasman Tui	Garner, D. M.	Tui 1	4 883–4 883	1		FMA5
1957						
North East Tui	Burling, R. W.	Tui 1	1 902–1 975	1		FMA9
Kermadec Tui	Burling, R. W.	Tui 1	2 279–2 279	1		FMA9
Tasman Tui	Garner, D. M.	Tui 1	2 195–2 195	1		FMA7
1958						
Pacific II Tui	Brodie, J. W.	Tui 1	1 825–1 825	1		FMA9
1959						
Palliser I Viti	Skerman, T. M.	Viti	2 012–2 012	1		FMA2
1960						
Karamea Bight Taranui	Unknown	Taranui	2 700–2 700	2		FMA2
1961						
Chatham Viti	Willis, R. P.	Viti	1 530–1 530	2		FMA4
Carbon IV Viti	York, A. G.	Viti	2 000–2 960	5		FMA2, FMA4
1962						
Microbiology I Taranui	Singleton, R. J.	Taranui	2 195–2 195	1		FMA4
1963						
Midwater II Taranui	Estcourt, I. N.	Taranui	1 555–2 700	3		FMA2, FMA3
Chatham Gap Taranui	McKnight, D.G.	Taranui	1 637–1 637	1		FMA4
Maui Taranui	Pantin, H. M.	Taranui	2 540–3 292	2		FMA2, FMA3
Maui II Taranui	Unknown	Taranui	1 975–2 800	8		FMA2, FMA3
Solander Sediment Taranui	Unknown	Taranui	1 505–1 505	1		FMA3
1964						
Poor Knights Taranui	Eade, J. V.	Taranui	1 920–1 920	1		FMA2
Turnagain I Taranui	McDougall, J. C.	Taranui	2 025–2 025	1		FMA2
Caledonia South Coast Taranui	McDougall, J. C.	Taranui	1 518–1 946	4		FMA8, FMA9
1965						
Turnagain II Taranui	Lewis, K. B.	Taranui	552–2 469	19		FMA2

Slope Benthos Taranui	McKnight, D.G.	Taranui	1 847–1 847	1		FMA3
Campbell Plateau Endeavour	Unknown	Endeavour 3	1 463–1 555	2		

1966

Donated Stations	--	G.S. Lollypop	1 862–4 173	7	
Isopod Taranui	Unknown	Taranui	1 609–1 609	1	
USN Eltanin Cruise 23	Unknown	Eltanin	2 132–3 786	2	1

1967

Hikurangi Benthos Taranui	McKnight, D.G.	Taranui	1 525–2 070	5	
Campbell Plateau II Endeavour	Unknown	Endeavour 3	1 829–3 109	10	

1968

North West Slope Benthos Taranui	McKnight, D.G.	Taranui	1 488–1 936	3	
North East Slope Benthos Taranui	McKnight, D.G.	Taranui	1 295–1 690	1	

1969

Chatham Benthos Taranui	Dawson, E. W.	Taranui	2 257–2 257	1	1

1970

Norfolk Deep Core Taranui	Eade, J. V.	Taranui	2 070–3 830	4	
Otago Benthos Taranui	Luckens, P. A.	Taranui	1 500–1 600	3	2
Cook Benthos	Singleton, R. J.	Taranui	1 919–2 162	16	4

1971

Deep Core Taranui	Eade, J. V.	Taranui	1 910–2 735	5	
Bay of Plenty Taranui	Glasby, G. P.	Taranui	1 500–2 165	7	
Lord Howe Rise Taranui	McKnight, D.G.	Taranui	1 717–3 082	6	5
RV Kana Keoki, Wellington to Suva	Unknown	Kana Keoki	1 550–4 620	4	

1973

Hauraki Geology 2	Carter, L.	Tangaroa1	2 175–2 175	1	1
Planksed One	Eade, J. V.	Tangaroa1	1 504–4 433	20	2
Bounty Sediments	McDougall, J. C.	Tangaroa1	1 641–3 632	21	
Abyssal Benthos 1	McKnight, D.G.	Tangaroa1	1 534–3 250	10	8

1974

South Kermadec Airgun	Cullen, D. J.	Tangaroa1	2 391–5 355	5	
South Kermadec Ridge	McKnight, D.G.	Tangaroa1	1 021–2 590	7	2

1976

Bounty Trough Plankton and Sediment	Burns, D. A.	Tangaroa1	1 542–3 222	20	

1977

Inner Bounty Trough Sediments, Geology, Benthos	Carter, R.	Tangaroa1	1 800–2 200	9	
Raukumara	Cullen, D. J.	Tangaroa1	1 600–1 800	1	
Northland Plateau Sediments	Eade, J. V.	Tangaroa1	1 346–3 757	9	

1978

Survey	Author	Vessel	Depth			FMA
Campbell Plateau III	Davey, F. J.	Tangaroa1	1 363–2 519	4		
Palliser Benthos II	Dawson, E. W.	Tangaroa1	1 660–2 650	9		
Southern Coral	Dawson, E. W.	Tangaroa1	1 520–1 520	1		
Northland Carbonate Sediment	Nelson, C. S.	Tangaroa1	1 530–2 680	7		
1979						
South Island Eastern Margin Sediments	Carter, L.	Tangaroa1	1 560–2 303	8	3	
National Museum Benthic Biology	Del Main, W.	Tangaroa1	213–2 738	13		
Canyon Coral	Del Main, W.	Tangaroa1	1 586–2 677	6		
Bounty Sedimentation	McDougall, J. C.	Tangaroa1	1 668–4 390	10		
1980						
Western Boundary Currents I	Carter, L.	Tangaroa1	1 633–5 100	12	9	
Lincolns Inn	McKnight, D.G.	Tangaroa1	1 760–4 441	10		
Minerva 80	McKnight, D.G.	Tangaroa1	2 200–3 391	4	1	
East Cape/Hauraki Gulf	Newman, P. H.	Tangaroa1	2 188–2 188	1		
Misc. biology stations	Read, G.	Unknown	2 200–2 250	2		
ANZCAN cable samples	Unknown	Monowai	1 570–4 973	25		
1981						
Tonga Sediments	Glasby, G. P.	Tangaroa1	1 598–3 843	47		
Hikurangi Margin Geology	Lewis, K. B.	Tangaroa1	1 140–3 241	43		
Southern Benthomass 81	McKnight, D.G.	Tangaroa1	1 670–1 670	1	1	
West Coast North Island Benthic Cruise	Wells	Tangaroa1	1 622–1 634	1		
1982						
Kermadec Coral	Dawson, E. W.	Tangaroa1	1 590–6 078	3	5	FMA10
Southern Havre Trough	Glasby, G. P.	Tangaroa1	1 598–3 559	46		FMA1,FMA2, FMA10
Tasman Basin	McKnight, D.G.	Tangaroa1	1 500–7 421	20	14	FMA10
Kaikoura Benthic	Swanson, K.	Tangaroa1	1 500–2 155	7		FMA6
1983						
Western Boundary Currents 2	Carter, L.	Tangaroa1	2 991–4 821	16	5	FMA2,FMA6, FMA10
Norfolk Basin Geology. (Geophysics NR8302)	Unknown	Tangaroa1	1 250–3 380	14		FMA2
						FMA4, FMA5
1984						
Oamaru Coastal Mapping	Arron, E.	Tangaroa1	1 510–1 820	5		
						FMA1,FMA2, FMA7
1987						FMA2, FMA4
Bay of Plenty Structure and Sediments	Wright, I. C.	Rapuhia	1 654–3 065	34		
1988						FMA9
Hikurangi Trough sediments 1	Barnes, P.	Rapuhia	1 534–2 724	34		FMA1
Hikurangi Trough sediments 2	Barnes, P.	Rapuhia	2 030–2 570	7		
Bounty Trough Sediments	Carter, L.	Rapuhia	4 296–4 861	21		
Manganense Crusts	Glasby, G. P.	Rapuhia	1 500–3 700	49		FMA4
Bay of Plenty Geology 1	Wright, I. C.	Rapuhia	330–3 170	5		
1989						FMA9

Title	Author	Vessel	Depth			FMA
Hikurangi Trough sediments 3	Barnes, P.	Rapuhia	1 695–2 904	38		FMA3
Fisheries voyage. Species: ORH; Areas: KAIK,WAIR,R	Grimes, P.	Will Watch	1 146–1 538	5		FMA9
Havre Trough / Kermadec Ridge Geology	Unknown	Nesmeyanov	1 700–8 720	23		
Marine Photosynthesis and Optics	Vincent, W.	Rapuhia	2 100–2 100	1		
Bay of Plenty Geology 3	Wright, I. C.	Rapuhia	1 510–2 960	32	6	FMA9
						FMA1
1990						FMA8, FMA9
Ocean Cross Roads 2	Carter, L.	Rapuhia	3 060–4 929	12		
Fisheries voyage. Species: ORH,SSO,BOE,; Areas: NE	Fenaughty, J. M.	Cordella	1 498–1 507	1		
Fisheries voyage. Species: ORH; Areas: KAIK,WAIR,R	Grimes, P.	Cordella	1 200–1 500	6		
Southern Havre Trough Geology	Unknown	Vulkanolog	1 200–1 800	3		FMA1, FMA9
						FMA3,FMA4, FMA6
1991						
Chatham Drift 1	Carter, L.	Rapuhia	2 030–5 374	16	1	FMA2, FMA4
To the end of the Hikurangi Channel	Lewis, K. B.	Rapuhia	2 200–4 780	16		
Bay of Plenty-Southern Havre Trough Geology	Wright, I. C.	Rapuhia	1 180–3 280	22		
						FMA2
1992						FMA1, FMA2
Kaikoura Margin Active Processes	Barnes, P.	Rapuhia	2 428–2 462	6		
Fisheries voyage. Species: ORH,SSO,BOE; Areas: NWC	Fenaughty, J. M.	Tangaroa2	1 487–1 518	2		
Fisheries voyage. Species: ORH,SSO,BOE; Areas: KAI	Grimes, P.	Tangaroa2	1 475–1 505	2		FMA3,FMA4, FMA6
Chatham Rise/Bounty Plateau Oreo Fisheries trawl survey	Hart, A.	Tangaroa2	1 999–2 000	1		
Chatham Rise-Sediment Trap Experiments	Nodder, S.	Rapuhia	1 500–2 700	3		
Southern Havre Trough Volcanoes	Wright, I. C.	Rapuhia	1 460–3 190	34	94	FMA3, FMA2
1993						FMA1, FMA2
Deep Western Boundary Current Dynamics	Carter, L.	Lavrentyev	2 990–5 435	7	1	
Fisheries voyage. Species: ORH; Areas: ECNI,RICH,P	Clark, M.	Tangaroa2	887–1 500	1		
Fisheries voyage. Species: ORH; Areas: KAIK,WAIR,R	Grimes, P.	Tangaroa2	1 436–1 517	3		FMA6
Fisheries voyage. Species: SSO,BOE,ORH; Areas: SWC	McMillan, P.	Tangaroa2	1 461–1 500	1		FMA2, FMA7
Chatham Rise-Sediment Geochemistry and Benthos	Nodder, S.	Lavrentyev	1 493–2 347	11		FMA6
Southern Havre Trough Tectonics	Wright, I. C.	Lavrentyev	1 366–2 650	21		FMA9
1994						

Holes in the bottom of the sea (HIBOS)	Carter, L.	Giljanes	1 480–3 595	12	5	FMA3
Fisheries voyage. Species: ORH,BOE,SSO; Areas: NEC	Fenaughty, J. M.	Tangaroa2	1 482–1 707	8		FMA1,FMA2, FMA3,FMA4, FMA6
Fisheries voyage. Species: ORH; Areas: KAIK,CLAR,W	Grimes, P.	Tangaroa2	1 435–1 527	3		FMA2, FMA3
GEODYNZ Hikurangi backup cruise	Lewis, K. B.	Giljanes	1 100–3 000	10		FMA3,FMA4, FMA6
Swath Northern plate boundary	Wright, I. C.	Giljanes	1 240–2 060	4		
1995						
Chatham Rise	Hall, J.	Unknown	1 511–2 480	2		FMA4, FMA6, FMA7 FMA2
1996						FMA1
Chatham Rise sediment trap moorings	Nodder, S.	Tangaroa2	2 202–2 202	2		FMA2
Kermadec Volcanoes	Wright, I. C.	Tangaroa2	1 330–3 300	80	47	FMA1, FMA9
1997						
Fiordland Tectonics	Barnes, P.	Tangaroa2	750–3 674	11		FMA2, FMA10
Pacific Gateway Palaeoceanography	Carter, L.	Tangaroa2	3 678–4 527	5		FMA2
Julie Hall cruise	Hall, J.	Tangaroa2	2 282–2 670	2		FMA3
Chatham Rise Benthics	Nodder, S.	Tangaroa2	2 072–2 330	15	2	FMA9
1998						
SubAntarctic 1 (SAA 1)	Stanton, B. R.	Tangaroa2	1 744–5 000	5		FMA6
Volcano-tectonic development of the central Havre Trough and Kermadec Island Arc	Stoffers, P .	Sonne	1 400–2 662	36	2	FMA2, FMA10
1999						
Active Seabed Process- Hikurangi Fan (TAN9907)	Lewis, K. B.	Tangaroa2	1 461–5 607	17		FMA1,FMA2, FMA8, FMA9
Subantarctic 3 (SAA 3) (TAN9909)	Morris, M. et al.	Tangaroa2	4 314–4 975	21	15	FMA6
NZAPLUME-1 NIWA-IGNS-NOAA (TAN9903)	Wright, I. C/de Ronde, C.	Tangaroa2	1 166–1 651	8		FMA2
2000						
UNCLOS Southern and Western Regions	Mitchell, J.	Tangaroa2	1 971–4 786	17		FMA5, FMA6
Chatham Rise: Carbon Flux Processes (3065)	Nodder, S.	Tangaroa2	2 297–2 600	7		FMA4, FMA6
2001						
Seamounts of the outer Bay of Plenty	Clark, M.	Tangaroa2	1 197–2 550	22		FMA2
Poverty Bay Seamount Re-entrant	Lewis, K. B.	Tangaroa2	1 572–3 214	5		FMA2
Biophysical Moorings 1 (3076)	Nodder, S.	Tangaroa2	2 660–3 265	8		FMA2, FMA6
Benthic Lander-Twilight Zone	Nodder, S.	Tangaroa2	2 310–3 125	17	1	FMA2,FMA4, FMA6

2002

MARGINZ1	Carter, L.	Tangaroa2	2 516–2 516	1		FMA2
ZEALANDIA-Cretaceous and Cenozoic Volcanism	Prof. Dr. Hoernle	Sonne	1 534–6 182	53		FMA2, FMA4
Kermadec Ridge volcanics	Wright, I. C.	Tangaroa2	1 268–2 529	32	7	FMA2, FMA10

2003

NORFANZ	Clark, M.	Tangaroa2	1 530–1 934	5		FMA9
SubAntarctic (SAA 5) (3094)	Neil, H.	Tangaroa2	1 476–2 650	7		FMA4, FMA6

2004

Alpine Fault II and Past Glaciers, Fiordland	Barnes, P.	Tangaroa2	493–3 698	27	2	FMA5
Bay of Plenty and Hikurangi Plateau Seamounts	Clark, M.	Tangaroa2	1 420–2 985	33	3	FMA1, FMA2
Kermadec volcanics-NZPLUME III	Wright, I. C.	Tangaroa2	1 499–2 008	3		FMA10

2005

Kermadec Pisces Dive Ops survey leg 2	Clark, M.	Ka'imikai-O-Kanaloa	1 577–1 779	6		FMA2
West Coast Sediments	Neil, H.	Tangaroa2	1 505–3 860	23		FMA7

2007

West Coast South Island Canyons	Neil, H.	Tangaroa2	1 537–3 157	11		FMA7
Chatham Rise Biodiversity	Nodder, S.	Tangaroa2	1 757–1 820	2	2	FMA3, FMA4
Challenger Plateau Ocean Survey 2020	Nodder, S.	Tangaroa2	1 713–1 773	2	2	FMA8, FMA9
Kermadec Volcanics	Wright, I. C.	Tangaroa2	1 320–3 721	26		FMA2, FMA10

2008

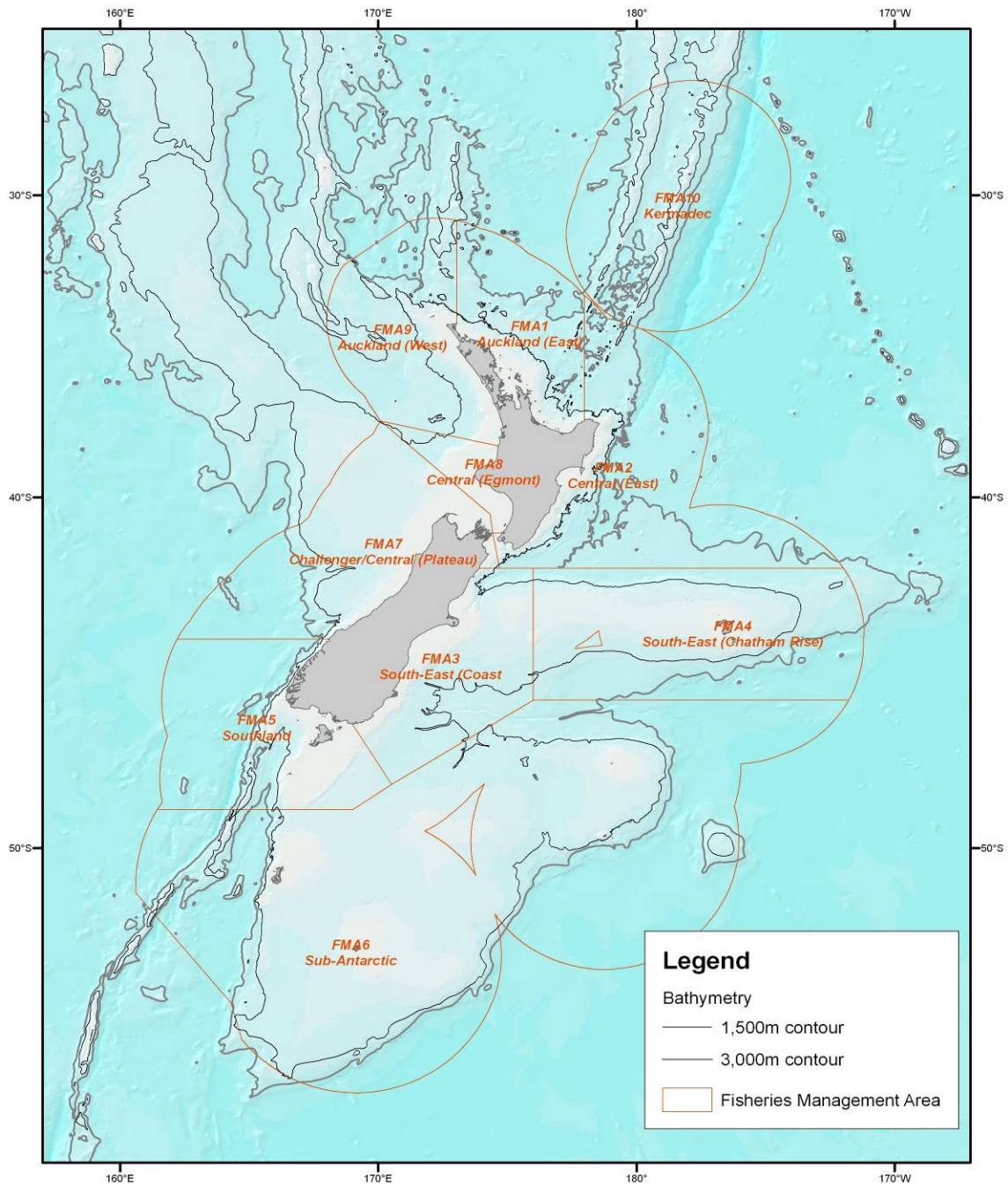|						
Biophysical Moorings 15	Nodder, S.	Tangaroa2	2 710–3 108	2		FMA2, FMA6

Figure 5: Fisheries management areas of New Zealand as referred to in Table 1.

From the tabulated summary of the benthic invertebrate sample and camera stations occupied by New Zealand-based expeditions since 1955 (Table 1), it appears that most samples were taken during the last decade (Figure 6). If only the number of records below 3000 m are considered (Figure 7), it is apparent that over the last 20 years, fewer than 20 biological samples have been collected in New Zealand's abyssal waters by New Zealand expeditions, with the majority of invertebrate and camera samples collected in the three decades before 1987.
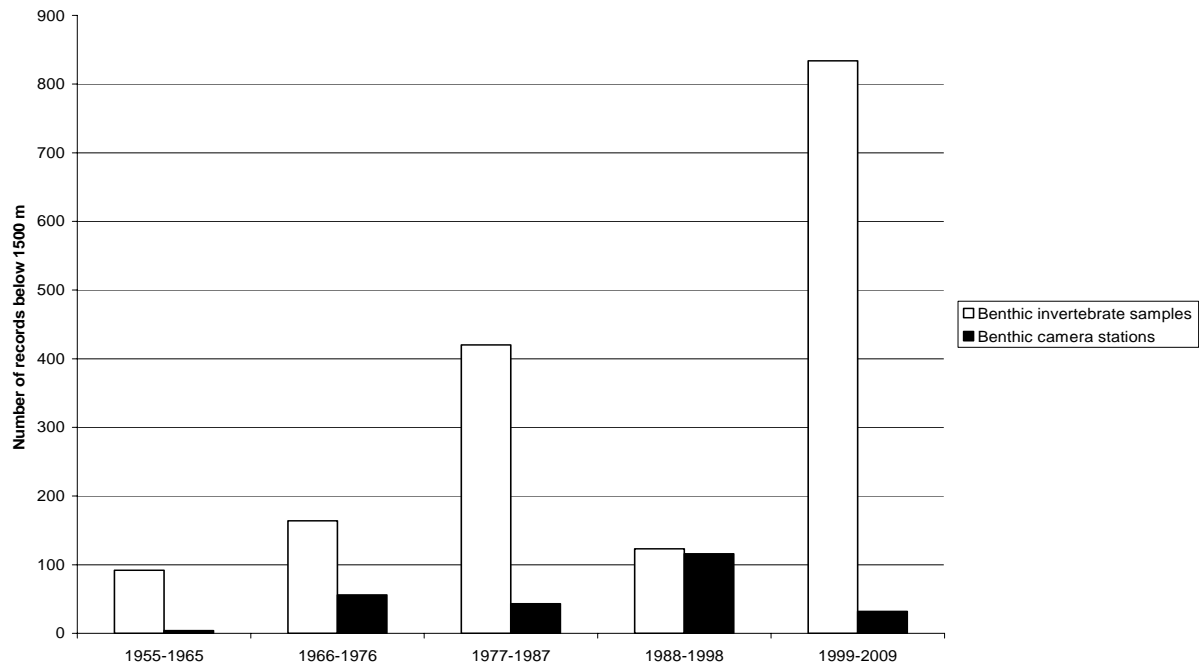
Figure 6: Number of records for each decade since 1955 for benthic invertebrate samples (blue bars) and benthic camera stations (red) sampled by New Zealand-based expeditions in water depths below 1500 m.
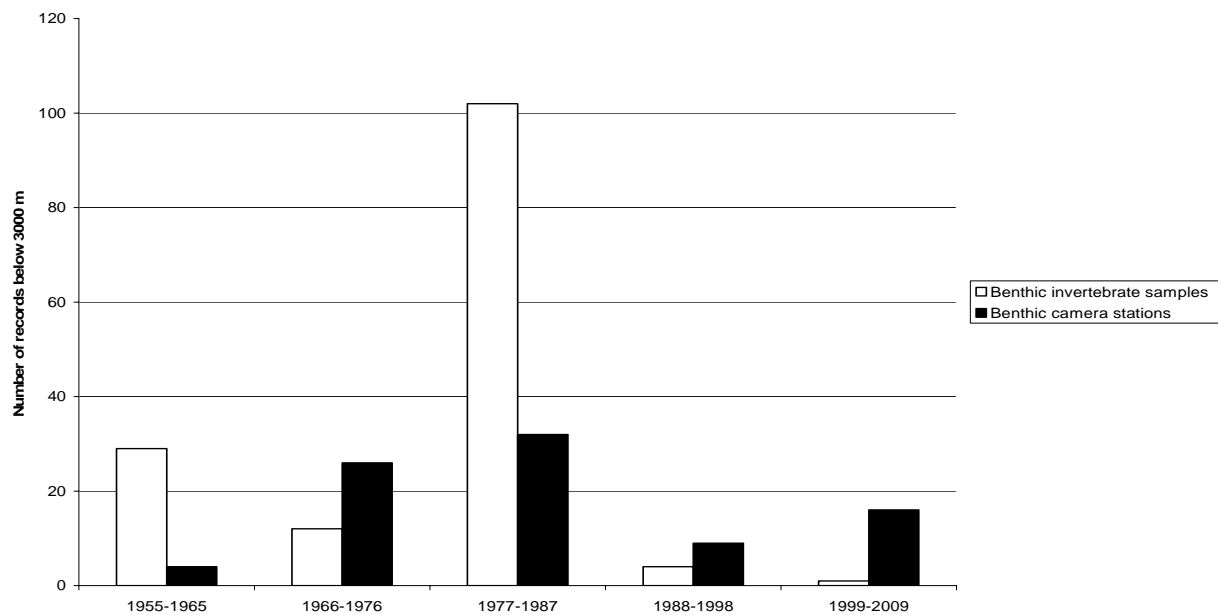
Figure 7: Number of records for each decade since 1955 for benthic invertebrate samples (blue bars) and benthic camera stations (red) sampled by New Zealand-based expeditions in water depths below 3000 m.

2. TAXONOMIC STUDIES

All published taxonomy-based studies of New Zealand waters below 1500 m depth have been reviewed here. Bacteria are discussed separately from the kingdoms Protozoa and Animalia. Only species considered to be benthic (i.e., living on or in the seafloor) or demersal (i.e., swimming near and/or associated with the seafloor) are included in the review.

An extensive checklist of all reported species of Protozoa and Animalia is provided, giving the species name, authority, endemicity status in New Zealand waters and known depth range. To date, most species in the New Zealand abyssal fauna are known only from single or relatively few stations (collected by historical expeditions, such as the British *Challenger* and Danish *Galathea* expeditions, as mentioned previously).

2.1   Prokaryota

Marine microbes form an integral part of marine ecosystems and contribute significantly to the biogeochemical processes of coastal and ocean environments, particularly in marine sediments. Worldwide, bacteria can constitute up to 50% of the total carbon or living aquatic biomass, and production rates may rival or sometimes exceed primary production rates by phytoplankton. Bacteria are the dominant organisms involved in processes of organic matter remineralisation and decomposition, and are the principal agents for chemical transformations and recycling of nutrients and gases in both the water column and in sediments. Compared to surface waters, the abyss is characterised by high nutrients, low temperatures and high pressure. Bacteria must be able to survive in these seemingly adverse conditions. Bacteria that can withstand extreme pressures are referred to as piezophilic (formerly named barophilic). In the ocean, the pressure increases by approximately 0.1 MPa (1 atmosphere) for every 10 m increase in water depth, so the maximum pressure in the deepest trench in New Zealand waters (Kermadec Trench, 10 183 m) is approximately 100 MPa (approximately 1000 atmospheres).

Two different strategies exist for analysing bacteria from deep-sea sediments: using culture-dependent and culture-independent techniques. Culture-dependent techniques involve the actual culture of organisms from the deep, which requires high-pressure culture vessels and a method of getting the samples to the surface under pressure. The culture research to date has shown that a wide range of Archaea can be isolated, belonging to both the Euryarchaea and Crenarchaea (reviewed in Bartlett et al. (2007)). *Eubacteria* have been isolated from abyssal depths and appear to belong to a narrow range of organisms mainly allied to the γ-Proteobacteria, within the orders Alteromonadales and Vibrionales and including the genera *Colwellia*, *Moritella*, *Photobacterium* and *Shewanella* (reviewed in Bartlett et al. (2007)). In addition to these genera, cultures of *Desulfovibrio*, *Thermotogales* and *Carnobacterium* have also been recovered.

2.1.1 Methods

For the purposes of this review of New Zealand deep-sea bacterial communities, a review of sequence data of isolates that are held in the European Molecular Biology Laboratory (EMBL) Nucleotide Sequence Database was conducted based on the following criteria: (1) Sequence length greater than

1200 base pairs for the 16S rRNA gene; (2) free-living and not associated with other organisms or endosymbionts; and (3) isolated from sediment or seawater below 1500 m. The culture-independent studies using clone libraries and metagenomic techniques were not included in this review since there is a question about whether these organisms are actually alive and metabolically active in situ. DNA can 'survive' intact in sediments (i.e., outside and/or inside a non-living cell) for long periods of time, especially in deep-sea sediments. Therefore, sequences only of actual living cells were included in the analysis and only if a depth was associated with the sequence in the EMBL database or indicated in the original publication. Sequences that have been published or are currently unpublished were included to give the greatest possible diversity of bacteria. Their status in EMBL was used to establish the identity of the bacteria in this review. No assessment as to the accuracy of the EMBL identification was possible, however.

2.1.2 Results

No sequences from New Zealand isolates were recovered from the EMBL database. In fact, very few bacteria have been isolated from sediments (181 isolates) and seawater (30) deeper than 1500 m worldwide (Tables 2 and 3). The depths that have been sampled do not cover the whole depth range down to 10 000 m and sampling appears to have been quite limited spatially. From this analysis, very few Archaea have been isolated, with only two isolated from sediments and one from seawater (Tables 2 and 3). From a global perspective, actinobacteria (35% of total) dominate in deep-sea sediments, followed by γ-proteobacteria (31%), firmicutes (13%) and α-proteobacteria (10%) (Table 2). No actinobacteria have been isolated from seawater (Table 3). The most dominant group in seawater appears to be γ-proteobacteria (60% of the total) followed by firmicutes (17%) and α-proteobacteria (7%).

Currently, very little information exists about marine bacteria in New Zealand marine sediments from more than 1500 m water depth. However, from the very limited work that has been undertaken it would appear that unique marine bacteria exist in these sediments. A preliminary study by Maas et al. (2005), using Marine Agar 2216 (Difco) and atmospheric pressure conditions, isolated 10 strains from New Zealand sediments from 1500–4000 m (Table 4, E. Maas, NIWA, unpublished data). The isolated strains included α-proteobacteria and γ-proteobacteria. Interestingly, even with this limited sampling two new genera were discovered, and within one of these genera two new species were identified.

Table 2:   Bacterial isolates from deep-sea sediments below 1500 m depth from all ocean basins. The data source is the *European Molecular Biology Laboratory (EMBL) Nucleotide Sequence Database*.

Water Depth Range (m)	Broad Taxonomic Group (Class)	Number of Isolates	Genus Identification
1 500–2 000	Euryarchaeota	1	Unidentified methanogen (1)
	Tenericutes	1	*Haloplasma contractile* (1)
	Eubacterium	5	Unidentified eubacterium (1)
	γ-Proteobacteria	25	*Halomonas* sp. (5), *Pseudoalteromonas elyakovii* (1), *Shewanella piezotolerans* (1), *Shewanella psychrophila* (1), *Pseudoalteromonas* sp. (17)
2 000–3 000	Euryarchaeota	1	*Methanocaldococcus indicus* (1)
	Actinobacteria	47	'actinobacterium' (44), *Rhodococcus* sp. (2), *Microbacterium* sp. (1)
	α-Proteobacteria	13	*Novosphingobium* sp. (2), *Roseovarius* sp. (1), *Sulfitobacter* sp.(5), *Thalassobius* sp. (1), *Thalassospira* sp. (1), Unidentified sp. (3),
	Aquificae	3	*Persephonella guaymasensis* (1), *Persephonella marina* (1), *Thermovibrio ammonificans* (1)
	Bacteroidetes	5	*Rhodothermus* sp. (1), *Flavobacterium* sp. (1) *Leeuwenhoekiella marinoflava* (2), *Salegentibacter* sp. (1)
	γ-Proteobacteria	20	*Pseudidiomarina* sp. (1), *Cycloclasticus* sp. (1), *Halomonas* sp. (1), *Pseudoalteromonas* sp. (8), *Alcanivorax dieselolei* (7), *Alcanivorax* sp., *Marinobacter* sp. (1)
	Planctomyces	1	*Planctomyces* sp. (1)
3 000–4 000	*Deinococcus -Thermus*	1	*Thermus* sp. (1)
	Firmicutes	1	*Bacillus* sp. (1)
4 000–5 000	Actinobacteria	1	*Streptomyces* sp.
5 000–6 000	Actinobacteria	9	*Brevibacterium* sp. (2), *Kocuria* sp. (1), *Microbacterium indicum* (3), *Microbacterium* sp., *Rothia* sp. (1)
	α-Proteobacteria	3	*Brevundimonas* sp. (1), *Paracoccus* sp. (2)
	β-Proteobacteria	1	*Bordetella* sp. (1)
	Firmicutes	9	*Bacillus* sp. (4), *Oceanobacillus* sp. (1), *Staphylococcus* sp. (4),
	γ -Proteobacteria	4	*Alcanivorax dieselolei* (1), *Pseudoalteromonas* sp. (3)
6 000–7 000		0	
7 000–8 000		0	
8 000–9 000		0	
9 000–10 000		0	
>10 000	Actinobacteria	6	Actinomycetales bacterium (6)
	α-Proteobacteria	3	Unidentified (3)
	Firmicutes	14	*Bacillus* sp. (1), Unidentified (13)
	γ-Proteobacteria	7	*Pseudoalteromonas* sp. (1), Unidentified (6)
Total number of isolates		181	

Table 3: **Bacterial Isolates from seawater below 1500 m depth across all ocean basins. The data source is the** *European Molecular Biology Laboratory (EMBL) Nucleotide Sequence Database.*

Water Depth Range (m)	Broad Taxonomic Group (Class)	Number of Isolates	Genus Identification
1 500–2 000	Euryarchaeota	1	*Thermococcus* sp. (1)
	Firmicutes	3	*Halanaerobium* sp. (3)
	γ-Proteobacteria	2	*Halomonas axialensis* (1)*, Salinisphaera shabanensis* (1)
2 000–3 000	Euryarchaeota	1	*Thermococcus* sp. (1)
	Firmicutes	1	*Marinococcus* sp. (1)
	γ-Proteobacteria	9	*Flexistipes sinusarabici* (1)*, Halomonas hydrothermalis* (1)*, Halomonas meridiana* (2)*, Halomonas* sp. (1)*, Halomonas neptunia* (1)*, Halomonas sulfidaeris* (1)*, Marinobacter* sp. (1)*, Photobacterium phosphoreum* (1)
3 000–4 000	α-Proteobacteria	1	Unidentified (1)
	Bacteroidetes	1	*Cytophaga* sp. (1)
	ε-Proteobacteria.	1	Unidentified (1)
	Firmicutes	1	*Halanaerobium* sp. (1)
	γ-Proteobacteria	5	*Alteromonas* sp. (1)*, Halothiobacillus* sp. (1)*, Idiomarina* sp. (1)*, Marinobacte*r sp. (1)*, Pseudoalteromonas* sp. (1)
4 000–5 000	α-Proteobacteria	1	*Oceanicola* sp. (1)
	γ-Proteobacteria	1	*Pseudoalteromonas* sp. (1)
	Proteobacteria	1	Unidentified (1)
5 000–6 000	γ-Proteobacteria	1	*Rheinheimera pacifica* (1)
7 000–8 000		0	
8 000–9 000		0	
9 000–10 000		0	
>10 000		0	
Total number of isolates		30	

Table 4: Bacterial isolates from New Zealand deep-sea sediments below 1500 m depth (Maas et.al. 2005).

Water Depth Range (m)	Broad Taxonomic Group (Class)	Number of Isolates	Genus Identification
1 500–2 000	α-Proteobacteria	1	*Stappia marina* (1)
2 000–3 000	α-Proteobacteria	2	New genus (1), *Sulfitobacter pontiacus* (1)
	γ-Proteobacteria	2	*Glaciecola polaris*, *Pseudoalteromonas* sp. (1)
3 000–4 000	α-Proteobacteria	3	New genus 2 (3)
	γ-Proteobacteria	2	*Pseudoalteromonas carrageenovora* (2)
Total number of isolates		10	

2.2   Kingdom Protozoa

The Protozoa reviewed for this report comprise solely the phylum Foraminifera, with almost all species belonging to the class Foraminiferea, the sole exception being a member of class Xenophyophorea. Some 293 species are distributed amongst 11 orders (see species checklist below). Foraminiferan skeletal remains that dominate seafloor sediments are classified as calcareous or pelagic ooze and are found around New Zealand (Mitchell et al. 1989). Unfortunately, in most instances, it is not possible to know if foraminiferan species were alive or dead when sampled. Figure 8 shows the number of species of Foraminifera known from depth intervals below 1500 m. It is perhaps surprising to observe a relatively large number of species, nearly 200 each, in the two depth intervals between 2000 and 3999 m, but it must be emphasised that the bulk of New Zealand deep-sea samples were collected by geological surveys (see Table 1) in which the Foraminifera were the only benthic organisms examined taxonomically. This depth distribution is probably at least partly influenced by changes in sampling effort.
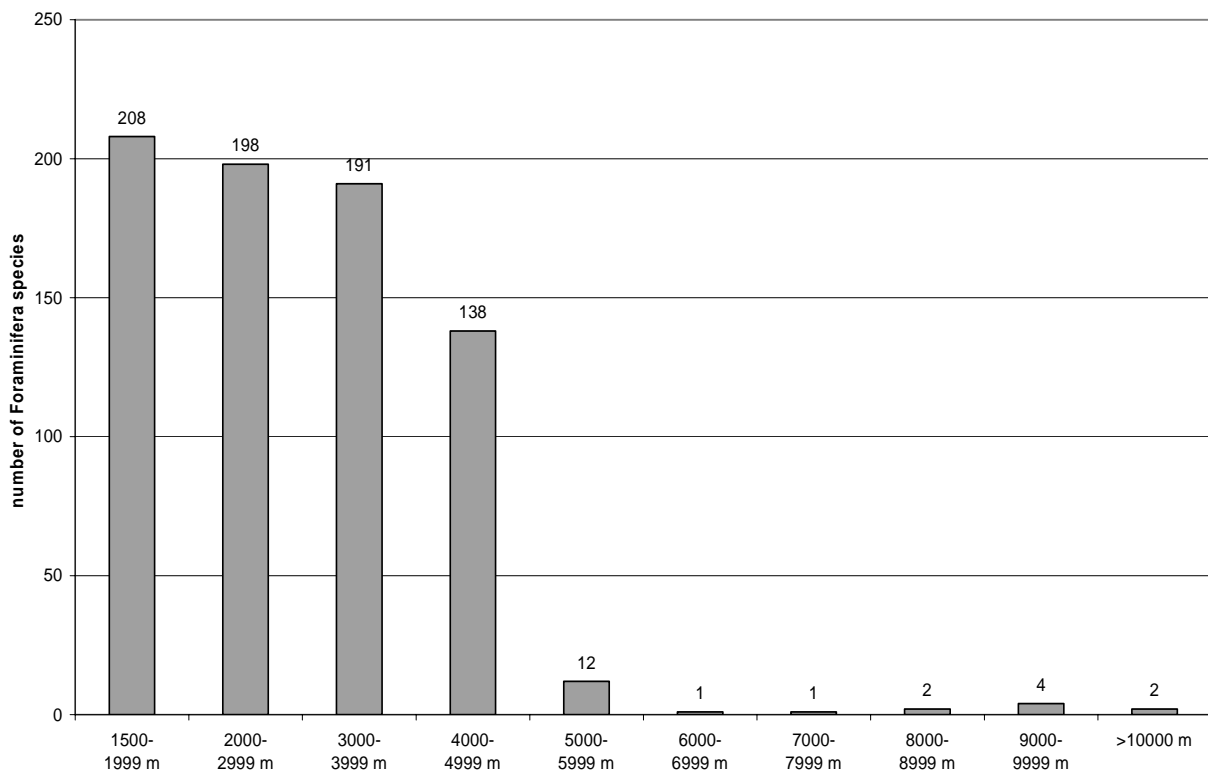
Figure 8: Distribution of foramiferal diversity in the New Zealand region by selected depth intervals.

2.3   Kingdom Animalia

Invertebrates

A total of 12 971 marine species, including pelagic taxa, are known from the New Zealand region (Gordon 2009), of which 11 544 are invertebrates belonging to 29 phyla (including one invertebrate chordate — amphioxus). Of these invertebrate species, 785 species, belonging to 15 phyla, are found below 1500 m depth (Figure 9).
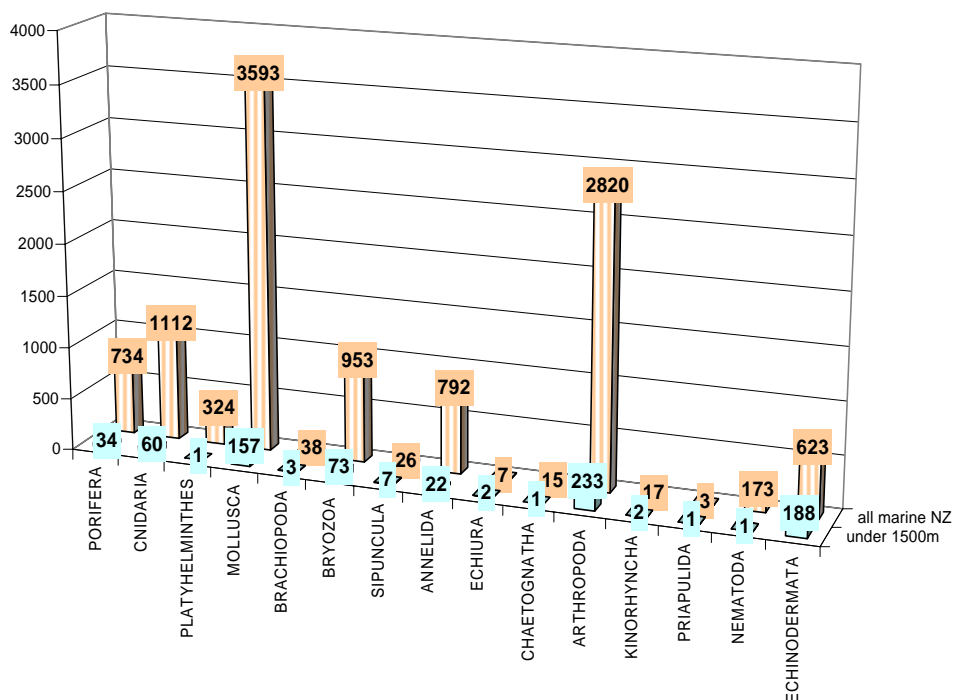
Figure 9: Numbers of species for specific phyla of New Zealand invertebrates found below 1500 m depth (shaded blue), compared to the numbers of species of these taxa known in total from the New Zealand marine environment (shaded brown). Numbers are from Gordon (2009).

To date, 785 extant invertebrate species are known from New Zealand benthic habitats below 1500 m (see accompanying checklist). The checklist includes known benthic and demersal species, although some single species might also be bathypelagic, but the lifestyle of many species is not known. The bulk of species are known from the shallower end of the reviewed depth range (Figure 10). This depth distribution is influenced strongly by sampling effort. It is notable that in the depth interval 3000–3999 m, more species of Foraminifera (191 species, Figure 8) are known than the species of all invertebrate classes (123 species, Figure 10) in the same depth interval.

The distribution of invertebrate species amongst major invertebrate taxa is shown in Figure 11. Of the major taxonomic groups depicted, the molluscan class Gastropoda contains the most species, with just under 100 species known from New Zealand waters below 1500 m. Phylum Bryozoa is represented by 73 species. Some groups of Crustacea are also relatively speciose, in the orders Decapoda (65) and the Isopoda (63). The echinoderm class Asteroidea is the other important deep-sea taxonomic group, with more than 60 species so far recorded from water depths below 1500 m in the New Zealand region.

In comparison, Brandt et al. (2009) studied the depth distribution of some major invertebrate groups in the Southern Ocean. In the case of bivalves, gastropods and polychaetes, the number of species per depth zone decreased from the shelf to the slope at around 1000 m depth and then had consistently low numbers below this depth to the abyssal plain. Isopods showed the opposite trend, in that they were less species-rich in the upper 1000 m, but increased in species numbers from the slope to bathyal and abyssal depths. In the Southern Ocean, isopod species richness per 100 m depth interval was highest around 3000 m, with 241 species, and generally high between 3000 and 4000 m (146–241 species). The numbers of species were still relatively high (133–154) between 4500 and 4700 m, but then decreased to 99 and then 76 over the next two 100 m-depth intervals.
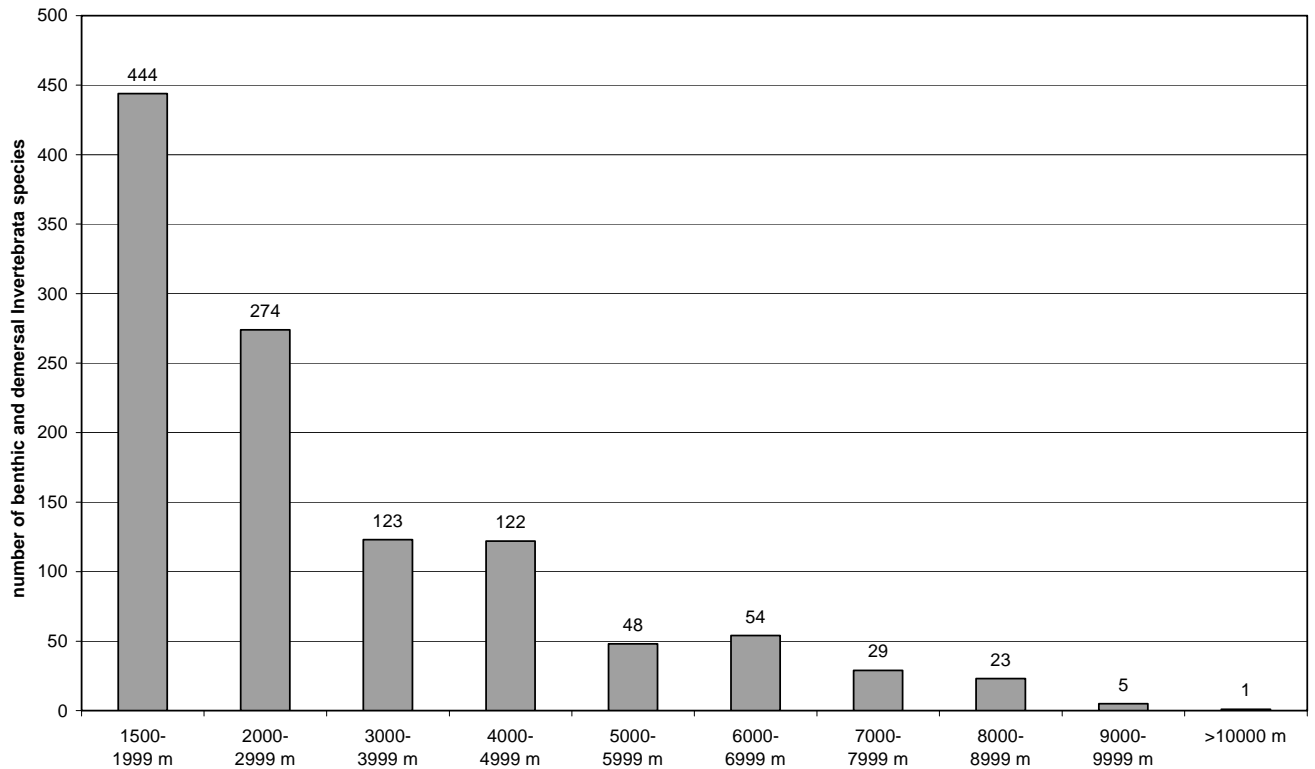
Figure 10: Distribution of the number of invertebrate species in the New Zealand region by depth intervals (below 1500 m).

At 5000 m depth, only 14 species of isopods were recorded (Brandt et al. 2009). Brandt et al. (2009) also suggested that there were low numbers of Polychaeta species between 3000 and 4000 m in the Southern Ocean (149 species), although more polychaete taxa are known from Antarctica from this abyssal depth interval than all invertebrate species from New Zealand waters.
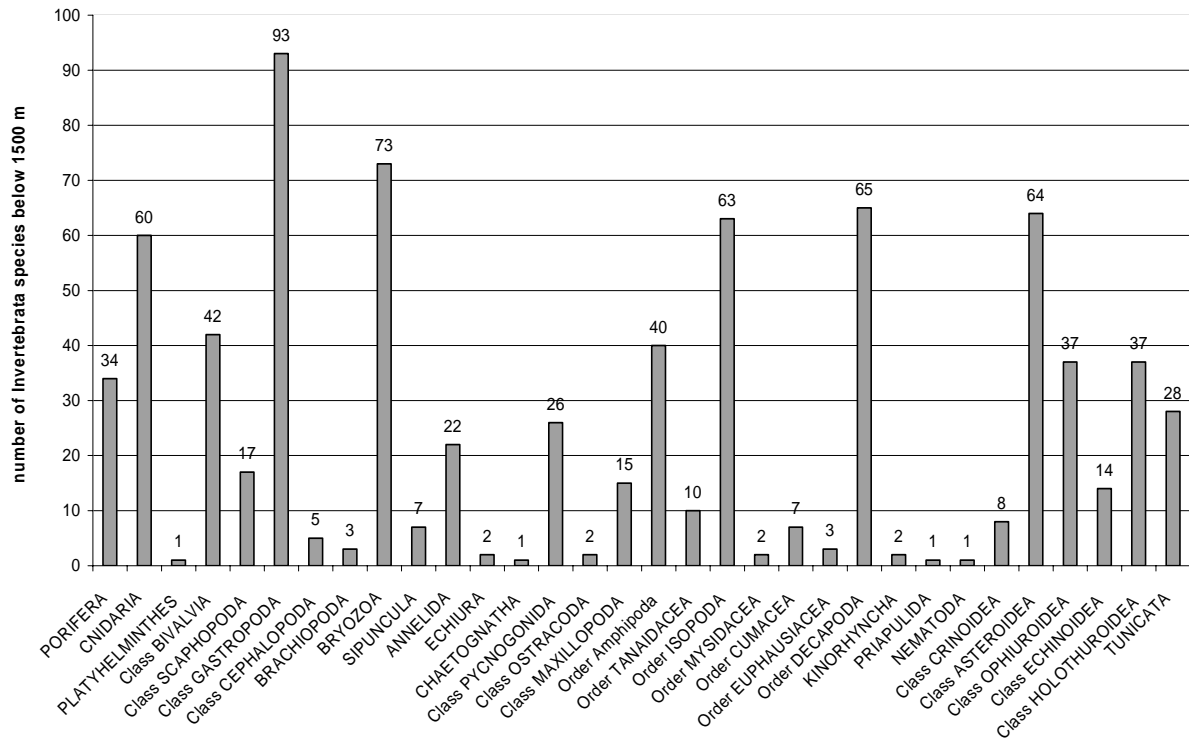
In the text below, available information on the main selected invertebrate taxonomic groups from New Zealand deep-sea environments is reviewed further.

Gastropoda

With 93 recorded species, Gastropoda appears to be the most speciose major taxon below 1500 m in New Zealand waters. It should also be noted that Gastropoda contains the highest number of known, but as-yet-unnamed genera and species (i.e., 10 in the family Turridae, 4 in the Naticidae and 3 in the Marginellidae). Two species of *Sabatia* and three species of *Philine* have not been identified beyond genus. So, while nearly 100 species and 55 genera of Gastropoda are known to occur below 1500 m in New Zealand waters, many of them await formal description.

Bryozoa

The deep-sea Bryozoa (moss animals, sea mats, lace corals) are reasonably well-studied in New Zealand waters. Based on samples collected from 122 benthic stations by the New Zealand Oceanographic Institute, along with some records from the *Galathea* Expedition (Hayward 1981), Gordon (1987) identified all deep-water bryozoans in the New Zealand region. On soft substrata, rooted species predominated, while on hard substrata, encrusting forms prevailed.

number of invertebrata species below 1500 m

PORIFERA 34 · CNIDARIA 60 · PLATYHELMINTHES 1 · Class BIVALVIA 42 · Class SCAPHOPODA 17 · Class GASTROPODA 93 · Class CEPHALOPODA 5 · BRACHIOPODA 3 · BRYOZOA 73 · SIPUNCULA 7 · ANNELIDA 22 · ECHIURA 2 · CHAETOGNATHA 1 · Class PYCNOGONIDA 26 · Class OSTRACODA 2 · Class MAXILLOPODA 15 · Order Amphipoda 40 · Order TANAIDACEA 10 · Order ISOPODA 63 · Order MYSIDACEA 2 · Order CUMACEA 7 · Order EUPHAUSIACEA 3 · Order DECAPODA 65 · KINORHYNCHA 2 · PRIAPULIDA 1 · NEMATODA 1 · Class CRINOIDEA 8 · Class ASTEROIDEA 64 · Class OPHIUROIDEA 37 · Class ECHINOIDEA 14 · Class HOLOTHUROIDEA 37 · TUNICATA 28

Figure 11: The distribution of 785 species among 32 major taxonomic groups of invertebrates found below 1500 m depth in the New Zealand region.

The two-dimensional encrusting morphology is proportionally as common in the deep-sea as in coastal waters, although colony size tends to be smaller in deeper waters. More recently, many new deep-sea bryozoans have been collected by NIWA, resulting in a total of 73 species recorded from 1500 m or greater. This diversity may be compared with that so far known for the rest of the world (Table 5). New Zealand has a significant proportion of the world's known diversity of deep-sea Bryozoa, although this is likely to reflect sampling effort and the existence of a specialist authority in this part of the world. New sampling continues to turn up additional taxa and it is likely that the bryofauna below 1500 m will easily exceed 200 species.

Table 5: Numbers of species of bryozoans of the orders Ctenostomata, Cheilostomata and Cyclostomata from 1500–6000 m depths in the New Zealand region, compared to the rest of the world, excluding New Zealand (see Gordon 1987). Note that many species occupy several depth intervals.

	Ctenostomata		Cheilostomata		Cyclostomata		Totals	
Depth range (m)	NZ	World	NZ	World	NZ	World	NZ	World
1 500–1 999	5	7	51	117	1	6	55	130
2 000–2 499	1	10	29	107	0	1	30	118
2 500–2 999	1	8	13	94	0	6	14	108
3 000–3 499	2	8	12	84	0	2	14	94
3 500–3 999	0	8	8	72	0	4	8	84
4 000–4 499	1	13	8	49	0	2	9	64
4 500–4 999	0	8	3	41	0	1	4	50
5 000–5 499	0	4	1	34	0	1	1	39
5 500–5 999	0	1	1	7	0	0	1	8
6 000+	0	0	1	2	0	1	1	3

Arthropoda

New Zealand marine arthropods mostly comprise crustaceans, with smaller numbers of Pycnogonida (sea spiders), marine mites (Halacaridae) and insects. Halacarid mites are known to live at abyssal depths but only shallow-water forms are so far known from New Zealand.

Most deep-sea crustaceans found in New Zealand belong to the order Decapoda and superorder Peracarida. Sixty-five species of decapods in five infraorders occur in the study area. The commonest deep-sea decapods are the squat lobsters (Galatheidae), hermit crabs (Paguridae and Parapaguridae) and deep-sea blind lobsters (Polychelidae) (Ahyong 2008). Most squat lobsters and hermit crabs occur on the slope at depths shallower than 3000 m, but some occur down to almost 5000 m, and one polychelid lobster ranges to almost 6000 m. Six species of true crab (Brachyura) have been recorded from the New Zealand region, mostly between 1500 and 3000 m, and one, *Teratomaia richardsoni*, is exceptional in having been collected from the Kermadec Trench at 7140–7160 m by the *Galathea* Expedition (Stn 651, 16 February 1952) (Griffin & Tranter 1986). Recently, Jamieson et al. (2009b) announced the apparent first finding of decapod Crustacea from the hadal zone, observing the shrimps *Benthesicymus* and *Acanthephyra* in the Kermadec Trench at depths of 6780 m. Evidently, Jamieson et al. (2009b) overlooked the *Galathea* record of *Teratomaia richardsoni*, reported some two decades earlier (Griffin & Tranter 1986). A suite of caridean and dendrobranchiate shrimps are also present in deep New Zealand waters, generally at 3000 m or less. As reported by Jamieson et al. (2009b), a number of species occur in the Kermadec Trench at hadal depths.

By far the dominant deep-sea crustaceans are the peracarids, chiefly isopods (63 species), amphipods (40 species), tanaids (10 species) and cumaceans (7 species). In contrast to the decapods, the peracarids are generally very small, usually not exceeding a few millimetres in length, and are typically inbenthic and epibenthic. They are, however, abundant in most deep-sea samples, and comprise a significant component of the macroinvertebrate biomass (Sanders & Hessler 1969). Amphipods and isopods are the most diverse of the deep-sea peracarids recorded in New Zealand waters. Both groups occur across the full bathymetric range considered here, but apparently have highest diversity at depths shallower than 3000 m. Whereas deep-sea amphipods belong to families that are most diverse in shallow water, many deep-sea isopods, including those recorded from New Zealand, belong to exclusively deep-sea clades, possibly suggesting a longer phylogenetic history in the deep sea (Hessler & Wilson 1983; Wilson & Hessler 1987). It is notable that 13 of 40 and 14 of 63 deep-water amphipods and isopods, respectively, have been recorded from the Kermadec Trench.

Relatively few deep-sea cumaceans and tanaidaceans are known from New Zealand waters, and though not surprising for Cumacea, the low number of known deep-sea Tanaidacea probably does not reflect actual diversity. Only 10 species are so far known from New Zealand (of which four occur in the Kermadec Trench), compared to more than 100 recorded from the deep-sea in the Gulf of Mexico (Larsen 2005). Tanaidaceans are generally recognised to be particularly abundant at abyssal depths (Larsen 2005) and therefore can be expected to be highly diverse also in New Zealand waters. Ostracods and maxillipodan crustaceans such as copepods and barnacles are abundant in shelf waters, but are represented by only 17 known species at depths between 1500 and 5000 m, of which 10 species do not range deeper than 2000 m.

The Pycnogonida has low known generic and specific diversity in deep New Zealand waters (10 genera, 28 species), with most occurring at water depths less than 3000 m, and none known beyond 6000 m.

Annelida

In New Zealand waters deeper than 1500 m, class Polychaeta is represented by at least 21 species and class Clitellata by one species. Twenty-two recorded deep-sea species of Annelida is very low in comparison to the known diversity across all New Zealand marine environments (including shallow waters) from which 792 species of Annelida are known, 767 of which belong to the Polychaeta (Glasby & Read 2009). Interestingly, four species of polychaetes are reported below 8000 m, each belonging to a different order. Overall, recorded deep-water polychaete diversity is low, with a maximum of two species per family. This apparent low diversity is almost certainly an artefact of low sampling effort.

Asteroidea

The 64 species of Asteroidea found in New Zealand waters below 1500 m are distributed amongst seven orders. Order Paxillosida contains three families and has most species (23), of which all except two have been described. The relatively large number of described seastar species compared to the other classes of Echinodermata is mainly due to the fact that two active asteroid taxonomists worked in New Zealand — Helen Clark and Donald McKnight, who together described more than half of the known New Zealand Asteroidea below 1500 m (Clark & McKnight 2000; Clark & McKnight 2001; McKnight 2006).

Fishes

The New Zealand deep-sea benthic/demersal fish fauna is poorly known. This situation is mainly the consequence of little sampling beyond 1500 m with specialist gear, particularly around the North Island and Kermadec Islands. To date, about 56 species have been recorded from depths below 1500 m in the region (see checklist). The list includes only published names and is based on the Roberts et al. (2009) 'Checklist of New Zealand Chordata', supplemented by selected records published since the preparation of the 'Checklist' in about 2000. Scientific names and taxonomic authorities used in the checklist were obtained from Eschmeyer & Fricke (2009), and the taxonomic classification includes common names down to family level (after Nelson (2006)).

Because of the lack of sampling, depth records for fish are unlikely to represent the actual range of each species, with some known only from one or a few captures (Figure 12). The following references were used to obtain depth ranges: Didier (2002, 2008), Didier & Seret (2002), Gomon et al. (2008), Jamieson et al. (2009a), Hoese et al. (2006), Karmovskaya & Merrett (1998), Last & Stevens (2009), Nielsen et al. (1999), Nielsen & Merrett (2000), Sazonov & Williams (2001), Sulak (1977) and Sulak & Shcherbachev (1988). Selected records from the MFish *trawl* database were also used to extend published data. Some depths were also obtained from Fishbase (Froese & Pauly 2009).

While 46 species are known in the depth interval 1500–1999 m, only one species has been captured at depths greater than 6000 m in New Zealand. *Notoliparis kermadecensis* (Nielsen 1964), the Kermadec snailfish (6660–6890 m), is endemic to New Zealand and was collected from the Kermadec Trench during the Danish *Galathea* expedition. It is known only from the five type specimens, plus images of a living fish recorded using baited camera landers at 6890 m in the Kermadec Trench (Jamieson et al. 2009a). The holotype of the abyssal cusk-eel (*Abyssobrotula galatheae*) was also collected from the Kermadec Trench by the *Galathea* at 5230–5340 m. This species is now known to be cosmopolitan with a recorded depth range of about 3100–8370 m, with the deepest record from the Puerto Rico Trench. *Abyssobrotula galatheae* is regarded as the "deepest living species of fish known" (Nielsen 1977). Four of the deep-sea tripod fishes (*Bathymicrops brevianalis* 4810–5900 m, *Bathypterois longicauda* 4663–5900 m, *B. longipes* 2615–5610 m, and *B. oddi* 4400–5550 m) have recorded depth records close to 6000 m and it is likely that more fish species will eventually be sampled at depths greater than 6000 m.

Four of the 56 fish species from depths below 1500 m are recorded as endemic to New Zealand (7%). These species include one deep-sea tripod fish (*Bathypterois oddi*), one grenadier (*Coryphaenoides microstomus*), one eelpout (*Pachycara garricki*) and the Kermadec snailfish (*Notoliparis kermadecensis*).
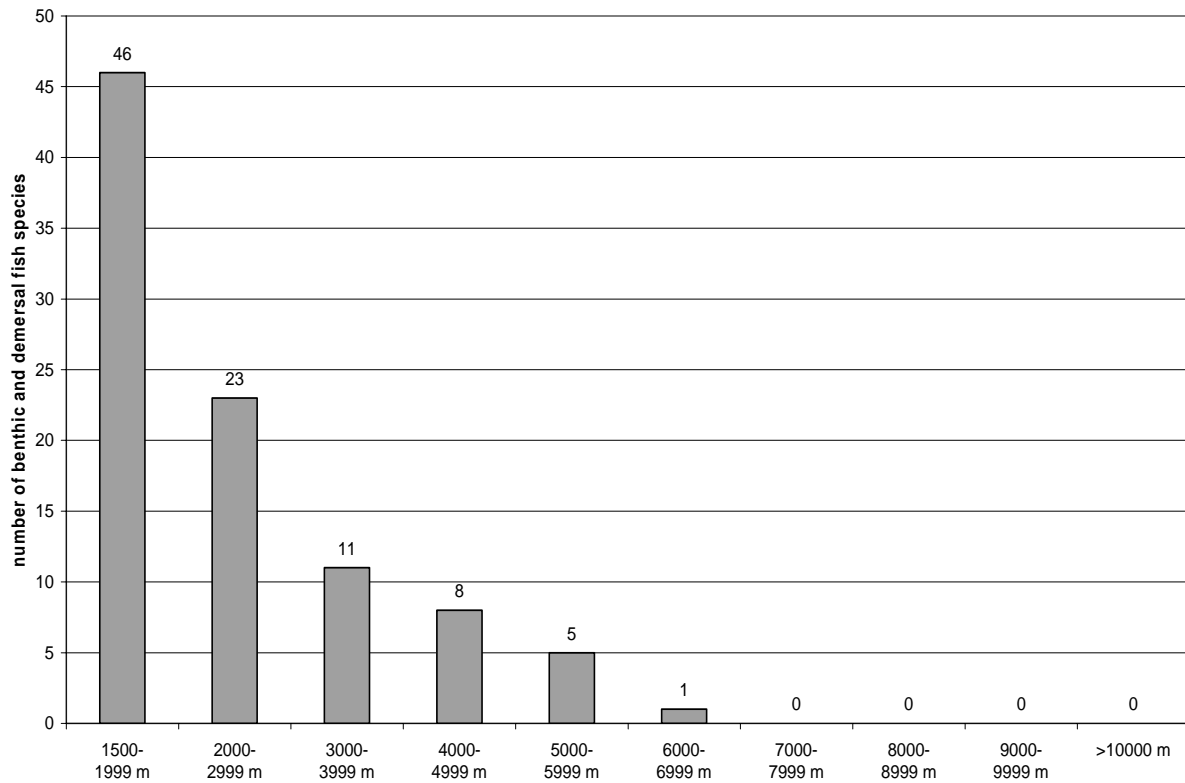
Figure 12: Distribution of benthic and demersal fish species in the New Zealand region at different depth intervals below 1500 m depth.

The majority of New Zealand fishes from all depths are either chondrichthyans (cartilaginous fishes) or actinopterygians (ray-finned fishes). Living chondrichthyans number 106 species in 59 genera. Living actinopterygians comprise about 90% of the fauna, with 1065 species belonging to 29 orders, 185 families and 592 genera (King et al. 2009). The New Zealand benthic/demersal fishes recorded from depths greater than 1500 m include 11 species of chondrichthyans from 7 families and 9 genera. The remaining 45 species (80%) are actinopterygians from 17 families and 35 genera. These include five albuliform species (halosaurs, spiny eels), six anguilliform species (cutthroat eels, duckbill eels), seven argentiform species (pencilsmelts, slickheads), seven aulopiform species (deep-sea tripod fishes, deep-sea lizardfishes), 14 gadiform species (bathygadids, grenadiers or rattails, macrouroids, trachyrincids, deep-sea cods), four ophidiform species (cusk-eels, aphyonids) and two scorpaeniform species (snailfishes, eelpouts).

Checklist of New Zealand marine fauna below 1500m

The checklist of species pertains to the wider New Zealand region (bounded by 24°–57°30' S and 157° E–167° W). Species that are endemic in the New Zealand EEZ are signified by the letter 'E' that follows the entry; 'K' signifies a record in the Kermadec Trench. Depth ranges in the New Zealand region are included if known.

KINGDOM PROTOZOA
PHYLUM FORAMINIFERA — Forams
Class FORAMINIFEREA
Order ALLOGROMIIDA
ALLOGROMIIDAE
Placopsilinella aurantiaca Earland, 1934 3650 m

Order ASTRORHIZIDA
BATHYSIPHONIDAE
Bathysiphon filiformis M. Sars, 1872 1640 m
Bathysiphon saeva (Saidova, 1975) 1637 m
HIPPOCREPINIDAE
Hyperammina cylindrica Parr, 1950 1640 m
Hyperammina kermadecensis Saidova, 1975 **E K** 9995–10002 m
Hyperammina sp. 2328 m
Saccorhiza ramosa (Brady, 1879) 1552 m
Saccorhiza sp. indet. **K** 4680 m
KOMOKIIDAE
Normanina ultrabyssalica Saidova, 1975 **E K** 9995–10002 m
PSAMMOSPHAERIDAE
Psammophax consociata Rhumbler, 1931 1320–3650 m
Psammosphaera fusca Schulze, 1875 3650 m
Psammosphaera testacea Flint, 1899 1730 m
RHABDAMMINIDAE
Dendrophrya kermadecensis Saidova, 1975 **E K** 8520–9120 m
Marsipella elongata Norman, 1878 1320–4100 m
Rhizammina algaeformis Brady, 1879 1552–1730 m
Rhizammina spp. indet. (2) 3650–4430 m
SACCAMMINIDAE
Lagenammina arenulata (Skinner, 1961) 3290–3970 m
Lagenammina bulbosa (Chapman & Parr, 1937) 3650–3970 m
Lagenammina difflugiformis (Brady, 1879) 230–5000 m
Saccammina sphaerica M. Sars, 1872 1320–2250 m

Order LITUOLIDA
AMMODISCIDAE
Ammodiscus mestayeri Cushman, 1919 1552–2330 m
Ammodiscus sp. 2300–3970 m
Ammolagena clavata (Jones & Parker, 1860) 620–1640 m
Glomospira gordialis (Jones & Parker, 1860) 3290–3970 m

Usbekistania charoides (Jones & Parker, 1860) 3290–4160 m
AMMOSPHAEROIDINIDAE
Adercotryma glomeratum (Brady, 1878) 1320–4680 m
Cystammina pauciloculata (Brady, 1879) 1460–3650 m
Recurvoidatus parcus Saidova, 1970 3230–4680 m
Recurvoides contortus Earland, 1934 460–4680 m
Recurvoides cf. *contortus* Earland, 1934 1730 m
CYCLAMMINIDAE
Cyclammina cancellata Brady, 1879 1640–4530 m
Cyclammina pusilla Brady, 1884 1300–4100 m
Cyclammina trullissata Brady, 1879 1460–3970 m
DISCAMMINIDAE
Discammina compressa (Goës, 1882) 100–3000 m
GLOBOTEXTULARIIDAE
Rhumblerella humboldtii Todd & Brönniman, 1957 3452 m
HAPLOPHRAGMOIDIDAE
Buzasina galeata (Brady, 1881) 3550–4100 m
Buzasina ringens (Brady, 1879) 2284 m
Cribrostomoides crassimargo Norman, 1892 4160 m
Cribrostomoides subglobosus (Cushman, 1910) 2250–4160 m
Cribrostomoides subtrullissatus (Parr, 1950) 4100 m
Cribrostomoides wiesneri (Parr, 1950) 1320–3650 m
Haplophragmoides neobradyi Uchio, 1960 4530 m
Haplophragmoides sphaeriloculum Cushman, 1910 2030–4100 m
Labrospira spiculotesta (Zheng, 1979) 110–3290 m
HORMOSINIDAE
Hormosina globulifera Brady, 1879 1640–2330 m
Hormosinella distans Brady, 1881 4160 m
Hormosinella guttifera (Brady, 1881) 4100 m
Reophax dentaliniformis Brady, 1881 1320–2250 m
Reophax nodulosus Brady, 1879 2250–4100 m
Reophax spiculifer Brady, 1879 2328 m
Reophax subfusiformis Earland, 1933 2330–3970 m
Reophax sp. indet. 4680 m
LITUOLIDAE
Ammobaculites cf. *catenulatus* Cushman & McCulloch, 1939 **K** 4680 m
Ammobaculites microformis Saidova, 1970 3970 m
Ammobaculites paradoxus Clark, 1994 1400–4100 m
Ammomarginulina ensis Wiesner, 1931 1320–4160 m

Eratidus foliaceus (Brady, 1881) 3290–3970 m

Order TROCHAMMINIDA
TROCHAMMINIDAE
Alterammina alternans (Earland, 1934) 3540–4430 m

Paratrochammina challengeri (Brönnimann & Whittaker, 1988) **K** 460–4680 m

Paratrochammina simplissima (Cushman & McCulloch, 1939) 210–4430 m

Paratrochammina sp. 3290 m

Portatrochammina bipolaris Brönnimann & Whittaker, 1980 4430 m

Portatrochammina sorosa (Parr, 1950) 1756 m

Trochammina cf. *curvativa* Saidova, 1975 1840 m

Trochammina tasmanica Parr, 1950 3650–4680 m

Trochamminopsis xishaensis (Zheng, 1988) 3650 m

Order TEXTULARIIDA
EGGERELLIDAE
Dorothia rotunda (Chapman, 1902) 3550 m

Eggerella bradyi (Cushman, 1911) 746–4680 m

Karreriella bradyi (Cushman, 1911) 1552–4160 m

Karreriella novangliae (Cushman, 1922) 710–3540 m

Karreriella cf. *novangliae* (Cushman, 1922) 3540 m

Karrerulina conversa (Grzybowski, 1901) 1130–3970 m

Martinottiella communis (d'Orbigny, 1826) 400–4160 m

Martinottiella omnia Saidova, 1975 2390–3452 m
TEXTULARIIDAE
Siphotextularia flintii (Cushman, 1911) 1130–4160 m

Siphotextularia fretensis Vella 1957 **E** 18–2330 m

Siphotextularia rolshauseni Phleger & Parker, 1951 1300–4500 m

Textularia earlandi Parker, 1952 3000 m

Textularia lythostrota (Schwager, 1866) 1552–1685 m

Order SPIRILLINIDA
PATELLINIDAE
Patellina corrugata Williamson, 1858 90–4430 m

Order MILIOLIDA
HAUERINIDAE
Miliolinella subrotundata (Montagu, 1803) 6–4430 m

Miliolinella vigilax Vella, 1957 **E** 1552–4500 m

Pyrgo imlimba Saidova, 1975 1552 m

Pyrgo murrhina (Schwager, 1866) 498–4440 m

Pyrgo serrata (Bailey, 1862) 1552–3540 m

Pyrgo tasmanensis Vella, 1957 **E** 1552 m

Quinqueloculina oblonga (Montagu, 1803) 18–4440 m

Quinqueloculina parvaggluta Vella, 1957 **E** 100–4440 m

Quinqueloculina seminula (Linnaeus, 1758) 6–4440 m

Quinqueloculina venusta Karrer, 1868 3290 m

Sigmoilopsis elliptica (Galloway & Wissler, 1927) 3287–4490 m

Sigmoilopsis schlumbergeri (Silvestri, 1904) 22–2765 m

Sigmoilopsis wanganuiensis Vella, 1957 **E** 1668 m

Spirosigmoilina pusilla (Earland, 1934) 1130–3540 m

Spirosigmoilina tenuis (Czjzek, 1848) 750–1840 m

Triloculina tricarinata d'Orbigny, 1826 280–4440 m

Order LAGENIDA
ELLIPSOLAGENIDAE
Bifarilaminella advena (Cushman, 1923) 3540 m

Fissurina aligeria caudimarginata McCulloch, 1977 1460–3540 m

Fissurina antiqua Yassini & Jones, 1995 370–2540 m

Fissurina apiculata punctulata (Sidebottom, 1912) 300–4440 m

Fissurina cf. *apiculata punctulata* (Sidebottom, 1912) 1840–4430 m

Fissurina auriculata (Brady, 1881) 3650–4100 m

Fissurina crassiporosa McCulloch, 1977 300–2030 m

Fissurina infimabrocha Loeblich & Tappan, 1994 3290 m

Fissurina longispina (Brady, 1881) 4430 m

Fissurina nudiformis McCulloch, 1977 90–2420 m

Fissurina cf. *prolata* (McCulloch, 1977) 460–4160 m

Fissurina revertens (Heron-Allen & Earland, 1932) 1650–1830 m

Fissurina spinosa (Sidebottom, 1912) 1730 m

Fissurina spinulata McCulloch, 1977 280–1730 m

Fissurina staphyllearia Schwager, 1866 100–2250 m

Fissurina spp. indet. (20) 720–4430 m

Lagenosolenia cf. *habrotes* McCulloch, 1977 4430 m

Lagenosolenia incomposita Patterson & Pettis, 1986 620–3290 m

Lagenosolenia scintillans (McCulloch, 1977) 2030 m

Lagenosolenia 13 spp. indet. 390–4680 m

Oolina costata (Williamson, 1958) 3540 m

Oolina cf. *costata* (Williamson, 1958) 3000 m

Oolina emaciata (Reuss, 1863) 510–4430 m

Oolina felsinea (Fornasini, 1894) 850–3550 m

Oolina globosa (Montagu, 1803) 280–3290 m

Oolina hexagona (Williamson, 1848) 210–4680 m

Oolina melo d'Orbigny, 1839 90–3170 m

Oolina piriformis Yassini & Jones, 1995 1830–4680 m

Oolina setosa (Earland, 1934) 4440 m

Oolina spp. indet. (7) 620–4680 m

Parafissurina caledoniana McCulloch, 1981 1460–1830 m

Parafissurina curta Parr, 1950 4100 m

Parafissurina faceta McCulloch, 1977 620–3000 m

Parafissurina cf. *lateralis* (Cushman, 1913) 720–3540 m

Parafissurina limpidiformis McCulloch, 1977 1130–3540 m

Parafissurina sublata Parr, 1950 3290 m

Parafissurina ventricosa (Silvestri, 1904) 3170 m

Parafissurina spp. indet. (8) 170–4100 m

Pseudofissurina mccullochae Jones, 1994 3540 m

Pseudofissurina metaconica (McCulloch, 1977) 2420 m

Pseudofissurina unicostata (Sidebottom, 1912) 2420 m

GLANDULINIDAE

Seabrookia earlandi (Wright, 1891) 850–4680 m

NODOSARIIDAE

Glandulonodosaria calomorpha (Reuss, 1866) 570–4100 m

Laevidentalina aphelis Loeblich & Tappan, 1987 446–2328 m

Laevidentalina bradyensis (Dervieux, 1894) 2330–3550 m

Laevidentalina elegans (d'Orbigny, 1846) 1685–4138 m

Laevidentalina guttifera (d'Orbigny, 1846) 1552 m

Laevidentalina subemaciata (Parr, 1950) 4680 m

Nodosaria simplex Silvestri, 1872 2250 m

VAGINULINIDAE

Astacolus crepidulus (Fichtel & Moll, 1798) 3452 m

Lagena authentica McCulloch, 1977 3290 m

Lagena chasteri Millet, 1901 2030–4680 m

Lagena costata (Williamson, 1858) 620–4440 m

Lagena cf. *doveyensis* Haynes, 1973 1130–4440 m

Lagena hispida Reuss, 1858 290–3550 m

Lagena meridonalis (Wiesner, 1931) 570–4680 m

Lagena multilatera McCulloch, 1977 300–4100 m

Lagena nebulosa (Cushman, 1923) 280–4680 m

Lagena cf. *peculiariformis* Albani & Yassini, 1995 460–1730 m

Lagena peterroyi Yassini & Jones, 1995 3000 m

Lagena sulcata (Walker & Jacob, 1798) 850–3650 m

Lagena spp. indet. 620–5000 m

Lenticulina australis (Parr, 1950) 90–4138 m

Lenticulina gibba (d'Orbigny, 1826) 210–2420 m

Lenticulina orbicularis (d'Orbigny, 1826) 2074 m

Lenticulina subgibba Parr, 1950 1518–4500 m

Lenticulina suborbicularis Parr, 1950 4138 m

Procerolagena spp. 1552–5000 m

Order ROBERTINIDA

EPISTOMINIDAE

Hoeglundina elegans (d'Orbigny, 1826) 91–3000 m

Order BULIMINIDA

BOLIVINIDAE

Bolivina alata (Seguenza, 1862) 110–3170 m

Bolivina cacozela Vella, 1957 E 1756–4500 m

Bolivina compacta Sidebottom, 1905 100–1650 m

Bolivina lobata Brady, 1881 230–3287 m

Bolivina pusilla Schwager, 1866 1730–2540 m

Bolivina pygmaea (Brady, 1881) 160–1830 m

Bolivina robusta Brady, 1881 18–4680 m

Bolivina seminuda (Cushman, 1911) 110–4680 m

Bolivina spinescens Cushman, 1911 1840 m

Bolivina subexcavata Cushman & Wickenden, 1929 6–4680 m

Bolivna subspinescens (Cushman, 1922) 22–2420 m

Bolivina sp. 510–3170 m

BOLIVINITIDAE

Abditodentrix pseudothalmanni (Boltovskoy & Guissani de Kahn, 1981) 100–4680 m

Bolivinita quadrilatera (Schwager, 1866) 210–3170 m

BULIMINELLIDAE

Buliminella elegantissima (d'Orbigny, 1839) 1668–4138 m

BULIMINIDAE

Bulimina marginata f. *acaenapeza* Loeblich & Tappan, 1994 1300–2540 m

Bulimina m. f. *aculeata* d'Orbigny, 1826 49–4680 m

Bulimina m. f. *marginata* d'Orbigny, 1826 6–1670 m

Bulimina striata d'Orbigny, 1826 110–2250 m

Bulimina truncana Gumbel, 1868 155–4490 m

Globobulimina pacifica Cushman, 1927 280–2330 m

Praeglobobulimina pupoides (d'Orbigny, 1846) 3170 m

CASSIDULINIDAE

Cassidulina carinata Silvestri, 1896 6–5000 m

Cassidulina norvangi Thalmann, 1952 121–4440 m

Cassidulina spiniferiformis McCulloch, 1977 4680 m

Ehrenbergina carinata Eade, 1967 **E** 1080–3540 m

Ehrenbergina glabra Heron-Allen & Earland, 1922 1518–4138 m

Ehrenbergina hystrix Brady, 1881 4138–4490 m

Ehrenbergina trigona Goës, 1896 498–5000 m

Evolvocassidulina cf. *belfordi* Nomura, 1983 100–4440 m

Evolvocassidulina bradyi (Norman, 1881) 4500 m

Favocassidulina australis Eade, 1967 **E** 3290 m

Globocassidulina canalisuturata Eade, 1967 **E** 18–2000 m

Globocassidulina crassa (d'Orbigny, 1839) 1518–4500 m

Globocassidulina gemma (Todd, 1954) 1670 m

Globocassidulina minuta (Cushman, 1933) 90–3550 m

Globocassidulina producta (Chapman & Parr, 1937) 1830 m

Globocassidulina spherica Eade, 1967 **E** 1518–3650 m

Globocassidulina subglobosa (Brady, 1881) 194–5000 m

Islandiella cf. *smechovi* (Voloshinova, 1952) 90–4680 m

Lernella inflata (Le Roy, 1944) 4440 m

CAUCASINIDAE

Francesita advena (Cushman, 1922) 2700–4100 m

FURSENKOINIDAE

Cassidella bradyi (Cushman, 1922) 194–4440 m

Fursenkoina complanata (Egger, 1893) 230–4680 m

Fursenkoina schreibersiana (Czjzek, 1848) 750–4680 m

Fursenkoina sp. A 3452 m

Rutherfordoides rotundata (Parr, 1950) 280–4680 m

STAINFORTHIIDAE

Virgulopsis turris (Heron-Allen & Earland, 1922) **E** 1756 m

UVIGERINIDAE

Neouvigerina proboscidea (Schwager, 1866) 18–4680 m

Trifarina angulosa (Williamson, 1858) 6–4530 m

Trifarina occidentalis (Cushman, 1923) 90–4680 m

Uvigerina mediterannea Hofker, 1932 1552–4530 m

Uvigerina peregrina Cushman, 1923 6–4680 m

Order ROTALIIDA

BAGGINIDAE

Baggina cf. *philippinensis* Loeblich & Tappan, 1994 90–2330 m

Valvulineria minuta (Schubert, 1904) 1840 m

CHILOSTOMELLIDAE

Chilostomella oolina Schwager, 1878 280–2330 m

CIBICIDAE

Cibicides aff. *deliquatus* Finlay, 1940 E 290–3000 m

Cibicides dispars (d'Orbigny, 1839) 6–4500 m

Cibicides micrus Bermúdez, 1949 1552 m

Cibicides variabilis (d'Orbigny, 1826) 90–4680 m

Cibicides wuellerstorfi (Schwager, 1866) 234–3452 m

Cibicidoides bradyi (Trauth, 1918) 109–4500 m

Cibicidoides mundulus (Brady, Parker & Jones, 1888) 2670 m

Cibicidoides neoperforatus (Hornibrook, 1989) 3970 m

Cibicidoides pachyderma (Rzehak, 1886) 750–2030 m

Cibicidoides robertsonianus (Brady, 1881) 794–4430 m

Cibicidoides tesnersianus Saidova, 1975 390–3550 m

Cibicidoides vehemenus Saidova, 1975 3550 m

DISCORBINELLIDAE

Discorbinella bertheloti (d'Orbigny, 1839) 6–4430 m

Discorbinella complanata (Sidebottom, 1918) 90–5000 m

Discorbinella subcomplanata (Parr, 1950) 1668–3452 m

Discorbinella timida Hornibrook, 1961 1668–2074 m

Discorbinella sp. indet. 3170 m

Laticarinina altocamerata (Heron-Allen & Earland, 1922) **E** 137–4680 m

Laticarinina pauperata (Parker & Jones, 1865) 1552–2150 m

ELPHIDIIDAE

Elphidium advenum f. *limbatum* (Chapman, 1907) 100–2330 m

Elphidium charlottense (Vella, 1957) 6–4440 m

Elphidium novozealandicum Cushman, 1936 **E** 110–2330 m

Notorotalia aucklandica Vella, 1957 **E** 2765 m

Notorotalia profunda Vella, 1957 E 90–2330 m

EPONIDIDAE

Ioanella tumidula (Brady, 1884) 90–5000 m

Porogavelinella ujiiei Kawagata, 1999 1670–3287 m

GAVELLINELLIDAE

Gyroidinoides kawagatai Ujiié 1995 460–5000 m

Gyroidinoides pulisukensis (Saidova 1975) 238–4440 m

Gyroidinoides soldanii (d'Orbigny, 1826) 18–4500 m

GLABRATELLIDAE

Glabratella margaritacea (Earland, 1933) 4430 m

Pileolina radiata Vella, 1957 **E** 90–4430 m

Pileolina zealandica Vella, 1957 **E** 90–4430 m

Planoglabratella opercularis (d'Orbigny, 1826) 110–2330 m

HERONALLENIIDAE

Heronallenia lingulata (Burrows & Holland, 1895) 720–4440 m

Heronallenia parva Parr, 1950 1685–4138 m

Heronallenia polita Parr, 1950 2074–4138 m

Heronallenia pulvinulinoides (Cushman, 1915) 720–4430 m

HETEROLEPIDAE

Anomalinoides globulosus (Chapman & Parr, 1937) 1830–3540 m

Anominaloides spherica (Finlay, 1940) **E** 6–1825 m

Anomalinoides cf. *spherica* (Finlay, 1940) **E** 90–4440 m

Anomalinoides tasmanica (Parr, 1950) 110–4160 m

Anomalinoides spp. indet. (3) 100–4160 m

NONIONIDAE

Astrononion stelligerum (d'Orbigny, 1839) 120–2700 m

Haynesina depressula (Walker & Jacob, 1798) 6–4680 m

Melonis affinis (Reuss, 1851) 91–4680 m

Melonis pompilioides (Fichtel & Moll, 1798) 1000–4680 m

Melonis spp. indet. (2) 1240–2540 m

Laminononion novozealandicum Cushman & Edward, 1937 6–4680 m

Nonion spp. indet. (2) 290–2330 m

Nonionella auris (d'Orbigny, 1839) 194–4680 m

Nonionella grateloupi (d'Orbigny, 1826) 90–4100 m

Nonionella magnalingua Finlay, 1940 **E** 300–1640 m

Pseudononion granuloumbilicatum Zheng, 1979 90–3540 m

Pullenia bulloides (d'Orbigny, 1826) 110–5000 m

Pullenia quinqueloba (Reuss, 1851) 230–4680 m

Pullenia salisburyi Stewart & Stewart, 1930 154–4530 m

ORIDORSALIDAE

Oridorsalis umbonatus (Reuss, 1851) 291–5000 m

OSANGULARIIDAE

Osangularia bengalensis (Schwager, 1866) 379–3650 m

PARRELLOIDIDAE

Parrelloides cf. hyalinus (Hofker, 1951) 4430 m

PLANORBULINIDAE

Planorbulina acervalis Brady, 1884 1685 m

PLANULINIDAE

Planulina ariminensis d'Orbigny, 1826 2074 m

Planulina sp. 2670 m

PSEUDOPARRELLIDAE

Alabaminella weddellensis (Earland, 1936) 22–5000 m

Eilohedra vitrea (Parker, 1953) 22–2000 m

Epistominella bradyi (Earland, 1934) 90–4680 m

Epistominella exigua (Brady, 1884) 100–5000 m

Epistominella umbonifera (Cushman, 1933) 1200–4440 m

Epistominella sp. 3000 m

ROSALINIDAE

Gavelinopsis praegeri (Heron-Allen & Earland, 1913) 18–4440 m

Planodiscorbis rarescens (Brady, 1884) 160–2330 m

Rosalina irregularis (Rhumbler, 1906) 90–4430 m

Rosalina vitrizea Hornibrook, 1961 **E** 1130–4430 m

Rosalina sp. 3970 m

SPHAEROIDINIDAE

Sphaeroidina bulloides d'Orbigny, 1826 6–4680 m

Class XENOPHYOPHOREA
Order PSAMMINIDA
SYRINGAMMINIDAE
Aschemonella scabra Brady, 1879 **K** 6076–9174

KINGDOM ANIMALIA
PHYLUM PORIFERA — Sponges
Class DEMOSPONGIAE
Subclass TETRACTINOMORPHA
Order ASTROPHORIDA

PACHASTRELLIDAE
Poecillastra schulzei (Sollas, 1886) 1906–2040 m

'LITHISTID' DEMOSPONGIAE
PLEROMIDAE
Pleroma aotea Kelly, 2003 **E** 1503–1538 m

Order HADROMERIDA
POLYMASTIIDAE
Acanthopolymastia acanthotoxa (Koltun, 1964) 1338–1537 m
SUBERITIDAE
Suberites sp. 2217 m

Subclass CERACTINOMORPHA
Order POECILOSCLERIDA
CLADORHIZIDAE
Abyssocladia bruuni Lévi, 1964 **E K** 5230–5340 m

Asbestopluma biserialis (Ridley & Dendy, 1886) 2640 m

Asbestopluma hadalis Lévi, 1964 **K** 6960–7000 m

Asbestopluma wolffi Lévi, 1964 **K** 6620–6730 m

Asbestopluma sp. 2446–2675 m

Chondrocladia asigmata Lévi, 1964 **E** 2640 m

Chondrocladia sp. 2526–2550 m

Cladorhiza sp. 1091–1697

COELOSPHAERIDAE
Histodermella sp. 2810–2849 m
LATRUNCULIIDAE
Latrunculia sp. 2595–2700 m
MYCALIDAE
Mycale (*Ectomyxilla*) sp. 1440–2675 m

Mycale (*Mycale*) sp. 1958–2312 m

Order HALICHONDRIDA
AXINELLIDAE
Homaxinella sp. 2446–2675 m

Order DICTYOCERATIDA
THORECTIDAE
Semitaspongia pulvinata Cook & Bergquist, 2000 **E** 2400 m

Class HEXACTINELLIDA
Subclass AMPHIDISCOPHORA
Order AMPHIDISCOSIDA
HYALONEMATIDAE
Hyalonema sp. 1491–1530 m
MONORAPHIDIDAE
Monoraphus chuni Schulze, 1904 2550–2526 m
PHERONEMATIDAE
Pheronema sp. 1503–1538 m

Subclass HEXASTEROPHORA
Order AULOCALYCOIDA
AULOCALYCIDAE
Euryplegma auriculare Schulze, 1886 **E** 1906–2700 m

Order HEXACTINOSIDA

APHROCALLISTIDAE
Chonelasma lamella Schulze, 1886 2595–2700
Eurete simplissima Semper, 1868 1338–2312 m
Heterorete cf. *pulchra* Dendy, 1916 1705–1930 m
Periphragella sp. 1652–1669 m
FARREIDAE
Farrea medusiforma medusiforma 1958–2312 m
Farrea occa similaris 1958–2700 m

Order LYSSACINOSIDA
EUPLECTELLIDAE
Corbitella speciosa (Quoy & Gaimard, 1833)
    1705–1930 m
Regadrella phoenix Schmidt, 1880 1906–2348 m
LEUCOPSACIDAE
Chaunoplectella sp. 1513–2312 m
ROSSELLIDAE
Caulophacus (*Caulodiscus*) sp. 2207–2748 m
Caulophacus (*Caulophacus*) *hadalis* Lévi, 1964 **K**
    6660–6770 m
Crateromorpha (*Aulochone*) sp. 2605–2748 m

PHYLUM CNIDARIA — Cnidarians
Class ANTHOZOA
Subclass OCTOCORALLIA Octocorals
Order ALCYONACEA Soft corals
ALCYONIIDAE
Anthomastus sp. 1506–2312 m
CLAVULARIIDE
Clavularia notanda Tixier-Durivault, 1964 **K** 4510
    m
Order GORGONACEA Gorgonians
ACANTHOGORGIIDAE
Acanthogorgia sp. 1491–2982 m
CHRYSOGORGIIDAE
Chrysogorgia sp. 1513–2182 m
CORALLIIDAE
Corallium sp. **E** 1525–2147 m
ISIDIDAE
Acanella sp. 1515–2320 m
Isidella sp. 2250 m
Keratoisis glaesa Grant, 1976 **E** 1805–2340 m
Keratoisis sp. 1805–2340 m
PARAGORGIIDAE
Paragorgia arborea (Linnaeus, 1758) 1525–1798
    m
PLEXAURIDAE
Placogorgia sp. 1491–1506 m
Villogorgia sp. 1722–2120 m
PRIMNOIDAE
Callogorgia sp. 3950 m
Candidella sp. 1495–1608 m
Narella sp. 2400–2407 m
Paracalyptrophora sp. 1495–1608 m
Primnoella krampi Madsen, 1956 **E K** 5850 m
Primnoella sp. 1330–2312 m

Order PENNATULACEA Sea pens
ANTHOPTILIDAE
Anthoptilum sp. 1515–1773 m

KOPHOBELEMNIDAE
Kophobelemnon stelliferum (Müller, 1776) 1812–
    1813 m
PENNATULIDAE
Pennatula inflata Kükenthal, 1910 1730–1772 m
Pteroeides sp. 1515–1530 m
UMBELLULIDAE
Umbellula sp. K 6180–6730 m Madsen 1956

Subclass HEXACORALLIA Hexacorals
Order ACTINIARIA Sea anemones
ACTINOSCYPHIIDAE
Actinoscyphia sp. 1730–1772 m
ACTINOSTOLIDAE
Bathydactylus kroghi Carlgren, 1956 E K 8210–
    8300 m
Hadalanthus knudseni Carlgren, 1956 K 6660–
    6770
GALATHEANTHEMIDAE
Galatheanthemum profundale Carlgren, 1956 K
    5850–8300 m
LIPONEMATIDAE
Liponema sp. 3250 m

Order ZOANTHIDEA Zoanthid anemones
EPIZOANTHIDAE
Epizoanthus paguriphilus Verrill, 1882 1941–1996
    m
Epizoanthus sp. 1491–2162 m

Order ANTIPATHARIA Black corals
CLADOPATHIDAE
Trissopathes tristicha (van Pesch, 1914) 1476–
    1880 m
LEIOPATHIDAE
Leiopathes sp. 1495–1556 m
SCHIZOPATHIDAE
Bathypathes alternata Brook, 1889 1491–1506 m
Bathypathes patula Brook, 1889 **K** 4540–4670 m
Bathypathes sp. 1722–2120 m
Parantipathes n. sp. **E** 1400–1600 m
Schizopathes affinis Brook, 1889 4570–4744 m

Order CORALLIMORPHARIA Corallimorphs
CORALLIMORPHIDAE
Corallimorphus niwa Fautin, 2009 1713–1773 m
Corallimorphus sp. 2526–2550 m

Order SCLERACTINIA Stony corals
Suborder FUNGIINA
FUNGIACYATHIDAE
Fungiacyathus (*Fungiacyathus*) *fragilis* Sars, 1872
    1029–1772 m

Suborder CARYOPHYLLIINA
CARYOPHYLLIIDAE
Caryophyllia ambrosia Alcock, 1898 701–1600 m
Caryophyllia diomedeae Marenzeller, 1904 660–
    1619 m
Caryophyllia scobinosa Alcock, 1902 784–2312 m

Caryophyllia sp. 1730–2850 m
Crispatotrochus curvatus Cairns, 1995 **E** 128–2505 m
Deltocyathus formosus Cairns, 1995 142–1930 m
Desmophyllum dianthus (Esper, 1794) 25–1680 m

Class SCYPHOZOA Jellyfish
Order CORONATAE
NAUSOTHOIDAE
Nausithoe punctata Köllicker, 1853 **K** 610–7000 m [i.e., polyp "*Stephanoscyphus*"]

Class HYDROZOA
Subclass HYDROIDOLINA
Order LEPTOTHECATA Thecate hydroids
AGLAOPHENIIDAE
Gymnangium japonicum Watson & Vervoort, 2001 328–1637 m
Lytocarpia spiralis (Totton, 1930) **E** 55–1660 m
Lytocarpia tenuissima (Bale, 1914) **K** 34–6720 m
HEBELLIDAE
Halisiphonia galatheae Kramp, 1956 **E K** 8210–8300 m
HALECIIDAE
Halecium beanii (Johnston, 1838) 29–2250 m
LAFOEIDAE
Acryptolaria conferta conferta (Allman, 1877) 95–4405 m
Cryptolarella abyssicola (Allman, 1888) **K** 2470–4670 m
Zygophylax sp. 1652–1669 m
PLUMULARIIDAE
Plumularia sp. 1730–1772 m
SERTULARIIDAE
Symplectoscyphus sp. 1503–1538 m
TIARANNIDAE
Stegolaria sp. 1812–1813 m

Order ANTHOATHECATA
Suborder CAPITATA
STYLASTERIDAE Hydrocorals
Lepidotheca inconsuta Cairns, 1991 787–1500 m

PHYLUM PLATYHELMINTHES —
   Flatworms
Subphylum RHABDITOPHORA
Class NEOOPHORA
Subclass RHABDOCOELA
Infraclass REVERTOSPERMATA
Order FECAMPIIDA
FECAMPIIDAE
Fecampia abyssicola Christensen, 1981 **K** 4540 m

PHYLUM MOLLUSCA — Shellfish
Class APLACOPHORA
Subclass CHAETODERMOMORPHA
CHAETODERMATIDAE
Chaetoderma sp. Wolff 1960 **K** 6660–6770 m

Class BIVALVIA Clams

Subclass PALAEOTAXODONTA
Order NUCULOIDA
MALLETIIDAE
Malletia cuneata (Jeffreys, 1876) **E** 1713–4510 m
Malletia galatheae Knudsen, 1970 **E K** 3580 m
Malletia pallida E.A. Smith, 1885 **K** 4670 m
NEILONELLIDAE
Neilonella kermadecensis Knudsen, 1970 **E K** 4540 m
NUCULANIDAE
Bathyspinula calcar (Dall, 1908) 4540 m
Bathyspinula kermadecensis (Knudsen, 1970) **E K** 5850–5900 m
Bathyspinula tasmanica Knudsen, 1970 **E K** 3850 m
Ledella kermadecensis Knudsen, 1970 **E K** 2470 m
Ledella sp. 2 **E** 2602–2677 m
Ledella sp. 4 **E** 3253–3347 m
TINDARIIDAE
Spinula oceanica Filatova, 1958 **K** 4670 m
Tindaria antarctica Thiele *in* Thiele & Jaeckel, 1931 4400–4540 m

Subclass PTERIOMORPHA
Order ARCOIDA
ARCIDAE
Bathyarca orbiculata (Dall, 1881) **K** 4670 m
Bentharca asperula (Dall, 1881) **K** 4090–4670 m
Bentharca sp. 1652–1669 m
LIMOPSIDAE
Pectunculina tasmani Dell, 1956 1713–1773 m

Order MYTILOIDA
MYTILIDAE
Bathymodiolus tangaroa Cosel & B. Marshall, 2003 **E** 1572 m
Benthomodiolus lignocola Dell, 1987 **E** 2127–2130 m

Order PTERIOIDA
LIMIDAE
Limatula sp. 7 **E** 3253–3347 m
Limatula sp. 8 **E** 3253–3347 m
Limea sp. 3 **E** 3253–3347 m
PROPEAMUSSIDAE
Cyclopecten fluctuosus Dijkstra & B. Marshall, 2008 1760–1799 m
Cyclopecten textus Dijkstra & B. Marshall, 2008 2928–2930 m
Cyclopecten sp. **K** 4670 m
Parvamussium maorium Dell, 1956 1730–1772
Propeamussium meridionale (E.A. Smith, 1885) 2470–4670 m

Subclass HETERODONTA
Order VENEROIDA
KELLIELLIDAE
Kelliella bruuni (Filatova, 1969) **K** 5850–5900 m
Kelliella tasmanensis Knudsen, 1970 **E K** 4400 m

Kelliella sp. Knudsen 1970 **K** 4540 m
KELLIIDAE
Pseudokellia gradata Thiele, 1912 1534 m
SEMELIDAE
Abra profundorum (E.A. Smith, 1885) **K** 4090–
   4670 m

Order MYOIDA
PHOLADIDAE
Xylophaga galatheae Knudsen, 1961 **K** 4090 m
Xylophaga hadalis Knudsen, 1961 **K** 6660–6770
   m

Subclass ANOMALODESMATA
Order PHOLADOMYOIDA
CUSPIDARIIDAE
Cardiomya sp. 2 **E** 1570 m
Cuspidaria delli Knudsen, 1970 **E K** 4400 m
Cuspidaria sp. 6 **E** 1570 m
Cuspidaria sp. 7 **E** 1570 m
Cuspidaria sp. 2605–2748 m
Myonera tasmanica (Knudsen, 1970) **K** 4390–
   4400 m

Order POROMYOIDA
POROMYI DAE
Cetoconcha galatheae Knudsen, 1970 **E K** 4400 m
Poromya sp. **E** 1760–1799
Poromya sp. 1713–2675 m

Class SCAPHOPODA
Order DENTALIIDA
DENTALIIDAE
Fissidentalium sp. 1 **E** 2200 m
Fissidentalium sp. 4 **E** 1586 m
GADILINIDAE
Episiphon sp. **E** 3253–3347 m
LAEVIDENTALIDAE
Laevidentalum sp. 1 **E** 1760–1799 m

Order GADILIDA
ENTALINIDAE
Costentalina sp. **E** 3253–3347 m
Rhomboxiphus sp. 2 **E** 3253–3347 m
Rhomboxiphus sp. 3 **E** 1760–1799 m
GADILIDAE
Cadulus sp. 2 **E** 3253–3347 m
Compressidens sp. **E** 1586 m
Gadila sp. **E** 1760–1799 m
Polyschides sp. 1 **E** 2602–2677 m
Polyschides sp. 2 **E** 3253–3347 m
Siphonodentalium sp. **E** 1676 m
PULSELLIDAE
Annulipulsellum sp. **E** 1760–1799 m
Pulsellum sp. **E** 1676 m
WEMERSONIELLIDAE
Chistikovia kermadecae Scarabino, 1995 **E** 2470–
   4570 m
Wemersoniella knudseni Scarabino, 1995 **E** 4105–
   4630 m

Class GASTROPODA Snails, sea slugs
Subclass PROSOBRANCHIA
Order DOCOGLOSSA
LEPETIDAE
Genus et sp. indet. 1 **E** 1570 m
Genus et sp. indet. 2 **E** 1570 m

Order COCCULIFORMIA
BATHYSCIADIIDAE
Bathysciadium sp. 1 **E** 1586 m
Bathysciadium sp. 2 **E** 1586 m
PSEUDOCOCCULINIDAE
Caymanabyssia rhina B.A. Marshall, 1986 **E** 2127–
   2130

Order VETIGASTROPODA
CHILODONTIDAE
Brookula sp. 6 **E** 1676 m
Brookula sp. 12 **E** 1676 m
Calliotropis sp. 5 **E** 1676 m
FISSURELLIDAE
Clathrosepta sp. **E** 1520 m
Puncturella sp. **E** 1570 m
PENDROMIDAE
Rugulina sp. 3 **E** 2200 m
SEGUENZIIDAE
Asthelys cf. *simplex* (Watson, 1879) 4419–4421 m
Basilissa? sp. **E** 1570 m
Carenzia fastigiata B.A. Marshall, 1983 **E** 1760 m
Fluxinella lepida B.A. Marshall, 1983 **E** 1760 m
Guttula galatheae Knudsen, 1964 **E K** 6660–6770
   m
Halystes chimaera Marshall, 1988 4058–4077 m
Quinnia patulus (B.A. Marshall, 1983) 1760 m
Seguenzia compta B.A. Marshall, 1983 **E** 1586–
   1760 m
Seguenzia conopia B.A. Marshall, 1983 **E** 1676–
   1760 m
Sericogyra periglenes Marshall, 1988 **E** 1670–
   1799 m
Genus et sp. indet. **E** 1570 m
SKENEIDAE
Granigyra sp. 2 **E** 1586 m
Leptogyra constricta B.A. Marshall, 1988 **E** 2127–
   2130 m
Lirapex sp. 1 **E** 3253–3347 m
Putilla sp. **E** 2200 m
Trenchia wolffi Knudsen, 1964 **E K** 6620–6730 m
Trenchia sp. 2 **E** 3253–347 m
Xyloskenea costulifera B.A. Marshall, 1988 **E**
   2127–2130 m
Genus et sp. indet. 2 **E** 1760–1799 m
SOLARIELLIDAE
Zetela kopua B.A. Marshall, 1999 1570–2700 m
TROCHIDAE
Bathymophila gravida B.A. Marshall, 1999 **E**
   1137–1570 m
Bathymophila valentia B.A. Marshall, 1999 **E**
   1216-1570 m

Order NEOTAENIOGLOSSA
CASSIDAE
Oocorys sp. **E** 1570 m
CERITHIOPSIDAE
Cerithiella sp. **E** 1713–1773 m
EPITONIIDAE
Papuliscala sp. **E** 1760–1799 m
EULIMIDAE
Crinolamia kermadecensis (Knudsen, 1964) **E K**
   8210–8230 m
Melanella hadalis Knudsen, 1964 **E K** 6660–6770
   m
NATICIDAE
Falsilunatia amphiala (Watson, 1881) **E** 1713–
   1773 m
Genus et sp. indet. 1 **E** 1570 m
Genus et sp. indet. 2 **E** 1570 m
Genus et sp. indet. 3 **E** 1570 m
Genus et sp. indet. 8 **E** 2602–2677 m
PISANIURIDAE
Pisaniura sp. **E** 1680 m
RANELLIDAE
Sassia remensa (Iredale, 1936) 1534 m
THALASSOCYNIDAE
Thalassocyon tui Dell, 1967 1713–2849 m
TRIPHORIDAE
Genus et sp. indet. 6 **E** 1570 m
VELUTINIDAE
Lamellaria sp. 1730–1772 m
ZEROTULIDAE
Zerotula sp. **E** 1586 m

Order NEOGASTROPODA
CANCELLARIIDAE
Admete bruuni Knudsen, 1964 **E K** 6660–6770 m
Oamaruia sp. 1 **E** 2476–2542 m
Oamaruia sp. 2 **E** 2476–2542 m
Genus et sp. indet. 2476–2542
CONIDAE
Pontiothauma? sp. **E** 1570 m
Speoides sp. 1730–1772
MARGINELLIDAE
Genus et sp. indet. 1 **E** 1570 m
Genus et sp. indet. 2 **E** 1570 m
Genus et sp. indet. 3 **E** 1570 m
NASSARIIDAE
Nassarius ephamillus (Watson, 1882) 1513–2012
   m
MITRIDAE
Charitodoron sp. **E** 1570 m
Eumitra sp. **E** 1570 m
MURICIDAE
Pagodula sp. **E** 1713–2748 m
TURRIDAE
Aforia lepta (Watson, 1881) 1730–1772 m
Aforia sp. **E** 2476–2542 m
Comitas sp. **E** 1812–1823 m
Paracomitas sp. 1 **E** 1760–1799 m
Paracomitas sp. 5 **E** 1760–1799 m

Xanthodaphne membranacea (Watson, 1886)
   1730–2012 m
Xanthodaphne xanthias (Watson, 1886) 2012 m
Genus et sp. indet. 14 **E** 1570 m
Genus et sp. indet. 18 **E** 1570 m
Genus et sp. indet. 39 **E** 1570 m
Genus et sp. indet. 42 **E** 2476–2542 m
Genus et sp. indet. 51 **E** 1760–1799 m
Genus et sp. indet. 52 **E** 2476–2542 m
Genus et sp. indet. 53 **E** 2602–2677 m
Genus et sp. indet. 55 **E** 1586 m
Genus et sp. indet. 57 **E** 1586 m
Genus et sp. indet. 58 **E** 4062–4066 m

Subclass OPISTHOBRANCHIA
Order INCERTAE SEDIS
ACTEONIDAE
Neacteonina sp. **E** 1760–1799 m
Genus et sp. indet. 2 **E** 2602–2677 m

Order CEPHALASPIDEA
CYLICHNIDAE
Cylichna? sp. **E** 1570 m
Cylichnium sp. 1812–1813 m
Sabatia sp. 1 **E** 1570 m
Sabatia sp. 2 **E** 1520 m
Scaphander otagoensis Dell, 1956 1713–1793 m
HAMINOEIDAE
Genus et sp. indet. **E** 1760–1799 m
PHILINIDAE
Philine sp. 4 **E** 1586 m
Philine sp. 5 **E** 2200 m
Philine sp. 8 **E** 4405–4441 m
RETUSIDAE
Retusa sp. 9 **E** 2200 m

Order NOTASPIDEA
PLEUROBRANCHIDAE
Bathyberthella zelandiae Willan, 1983 1640–1676
   m

Order NUDIBRANCHIA
HETERODORIDIDAE
Heterodoris antipodes Willan, 1981 1760 m

Class CEPHALOPODA
Subclass COLEOIDA
Order TEUTHIDA
CRANCHIIDAE
Bathothauma lyromma Chun, 1906 1350–1500 m

Order VAMPYROMORPHA
Vampyroteuthis infernalis Chun, 1903 **K** 4400–
   7800 m

Order OCTOPODA
GRIMPOTEUTHIDIDAE
Grimpoteuthis abyssicola O'Shea, 1999 3154–
   3180 m

Grimpoteuthis innominata (O'Shea, 1999) **E** 1705–2002 m
OCTOPODIDAE
Thaumeledone marshalli O'Shea, 1999 1999–2476 m

PHYLUM BRACHIOPODA — Lamp shells
Subphylum LINGULIFORMEA
Class LINGULATA
Order ACROTRETIDA
DISCINIDAE
Pelagodiscus atlanticus (King, 1868) 1329–3020 m

Subphylum RHYNCHONELLIFORMEA
Class RHYNCHONELLATA
Order TEREBRATULIDA
Suborder TEREBRATELLINIDA
MEGATHYRIDIDAE
Gwynia macrodentata Lüter, 2008 **E** 1605–1865 m
PHANEROPORIDAE
Phaneropora galathea Zezina, 1981 240–1640 m

PHYLUM BRYOZOA — Bryozoans
Class GYMNOLAEMATA
ALCYONIDIIDAE
Bockiella abyssicola Gordon, 1986 **E** 4405–4421 m
CLAVOPORIDAE
Metalcyonidium n. sp. **E** 3480 m
Pseudalcyonidium n. sp. 1 **E** 765–1676 m
Pseudalcyonidium n. sp. 2 **E** 750–1586 m
PACHYZOIDAE
Pachyzoon n. sp. 1 **E** 760–1586 m
Pachyzoon n. sp. 1 **E** 760–3480 m
Pachyzoon n. sp. 3 **E** 750–1640 m

Order CHEILOSTOMATA
Suborder NEOCHEILOSTOMINA
Infraorder FLUSTRINA
BRYOPASTORIDAE
Bryopastor challengeri Gordon, 1982 914–1573 m
Bryopastor aff. *pentagonus* (Canu & Bassler, 1929) **E** 750–1640 m
BUGULIDAE
Bugula decipiens Hayward, 1981 4670 m
Bugula sp. Hayward 1981 **K** 8210–8300 m
Camptoplites bicornis elatior (Kluge, 1914) 914–4744 m
Camptoplites bicornis ssp. 1 Hayward 1981 **K** 5850–5900 m
Camptoplites bicornis ssp. 2 Hayward 1981 **K** 2470 m
Cornucopina bella (Busk, 1884) 1338–1537 m
Cornucopina salutans Gordon, 1986 **E** 526–2257 m
Himantozoum clavulum Hayward, 1981 **E K** 4410 m
Himantozoum taurinum Harmer, 1926 **K** 2470 m
Himantozoum n. sp. 1 **E** 1605–1785 m

Himantozoum n. sp. 2 **E** 1705 m
Kinetoskias elongata Harmer, 1926 1373–1676 m
CALLOPORIDAE
Bryocalyx cinnameus Cook & Bock, 2000 **E** 750–1676 m
Concertina cultrata Gordon, 1986 **E** 750–3480 m
Ellisina n. sp. **E** 1225–1676 m
Pyriporoides libita (Gordon, 1989) **E** 995–1750 m
Genus nov. et n. sp. 1 **E** 860–3480 m
Genus nov. et n. sp. 2 **E** 1386–1676 m
CANDIDAE
Amastigia cf. *nuda* Busk, 1852 **E K** 2470 m
Amastigia n. sp. 1 **E** 2200 m
Notoplites armigera Hayward, 1981 **E K** 2470 m
Notoplites klugei (Hasenbank, 1932) 1640 m
Notoplites n. sp. **E** 1573 m
Penemia ignota (Hayward, 1981) **E K** 189–2470 m
Penemia pacifica (d'Hondt & Schopf, 1984) 2200–2328 m
CELLARIIDAE
Euginoma conica Gordon, 1986 1463–3480 m
Euginoma n. sp. **E** 1573–2200 m
Formosocellaria magnifica (Busk, 1884) 3480 m
Henrimilnella n. sp. **E** 750–1676 m
Melicerita chathamensis Uttley & Bullivant, 1972 **E** 183–1676 m
Melicerita ejuncida Gordon, 1986 768–1676 m
Melicerita n. sp. **E** 1573 m
Steginocellaria magnimandibulata (Gordon, 1986) **E** 914–2250 m
CHAPERIIDAE
Chaperiopsis (*Clipeochaperia*) *chathamensis* (Uttley & Bullivant, 1972) **E** 183–2257 m
EUOPLOZOIDAE*
Euoplozoum cirratum (Busk, 1884) 1958–2312 m
FARCIMINARIIDAE
Columnella magna (Busk, 1884) **K** 1295–4405 m
Columnella n. sp. **E** 1640 m
Farciminaria n. sp. **E** 2096 m
Farciminellum hexagonum (Busk, 1884) **K** 4400–4670 m
MICROPORIDAE
Micropora n. sp. **E** 995–1750 m
Gen. nov. et n. sp. **E** 2376–2385 m
QUADRICELLARIIDAE
Acanthodesiomorpha problematica d'Hondt, 1981 3999 m

Infraorder ASCOPHORINA
BIFAXARIIDAE
Bifaxaria modesta Gordon, 1993 1573 m
Domosclerus cf. *corrugatus* (Busk, 1884) **K** 575–4410 m
Domosclerus cf. *rugatus* (Harmer, 1957) **K** 5230–5340 m
Raxifabia tunicata Gordon, 1988 1573 m
BITECTIPORIDAE
Bitectipora n. sp. **E** 1750 m
Metroperiella n. sp. **E** 1750 m
CALWELLIIDAE

Onchoporoides moseleyi (Busk, 1884) 575–2677 m

CATENICELLIDAE
Talivittaticella problematica (d'Hondt, 1981) 1288–4077 m

CELLEPORIDAE
Galeopsis mimicus Gordon, 1989 **E** 248–1140 m
Galeopsis pentagonus (d'Orbigny, 1847) 165–2257 m
Galeopsis polyporus (Brown, 1952) **E** 20–2257 m

CONESCHARELLINIDAE
Crucescharellina aster Gordon & d'Hondt, 1997 1267–1573 m
Ptoboroa pulchrior (Gordon, 1989) **E** 914–3347 m
Trochosodon gordoni Bock & Cook, 2004 **E** 750–1676 m
Trochosodon mosaicus Gordon, 1989 **E** 178–3347 m
Trochosodon urnalis Gordon, 1989 **E** 750–4059 m
Trochosodon n. sp. **E** 765–3235 m
Trochosodon sp. 1 1573 m

PETRALIELLIDAE
Riscodopa parva Gordon, 1989 **E** 794–4059 m

SIPHONICYTARIDAE
Siphonicytara n. sp. 1573 m

SMITTINIDAE
Smittina n. sp. **E** 1750 m

CLASS STENOLAEMATA
Order CYCLOSTOMATA
Suborder RECTANGULINA
LICHENOPORIDAE
Disporella sacculus Gordon & Taylor, 2001 **E** 1476–1750 m

PHYLUM SIPUNCULA
Class SIPUNCULIDEA
Order GOLFINGIIFORMES
GOLFINGIIDAE
Golfingia appendiculata (Sato, 1934) 4510 m
Golfingia margaritacea (Sars, 1851) **K** 136–5285 m
Golfingia muricaudata (Southern, 1913) **K** 4410 m

PHASCOLIONIDAE
Phascolion denticolum Sato, 1937 3710–4510 m
Phascolion lutense Selenka, 1885 **K** 4410 m

THEMISTIDAE
Themiste minor (Ikeda, 1904) 126–4510 m

Class PHASCOLOSOMATIDEA
Order PHASCOLOSOMATIFORMES
PHASCOLOSOMATIDAE
Phascolosoma pectinatum Keferstein, 1867 4670 m

PHYLUM ANNELIDA — Bristleworms, leeches
Class POLYCHAETA
Order CAPITELLIDA
CAPITELLIDAE
Notomastus sp. Kirkegaard 1956 8210–8300 m

MALDANIDAE
Maldanella harai (Izuka, 1902) 6620–6770 m

Order OPHELIIDA
OPHELIIDAE
Kesun abyssorum Monro, 1913 6960-7000 m

SCALIBREGMIDAE
Pseudoscalibregma pallens Levenstein, 1962 8928–9174 m
Travisia sp. 1812–1813 m

Order EUNICIDA
LUMBRINERIDAE
Paraninoe fusca Moore, 1911 6620–7000 m

ONUPHIDAE
Leptoecia benthaliana (McIntosh, 1885) 1730–1772 m

Order PHYLLODOCIDA
NEPHTHYIDAE
Aglaophamus elamellata (Eliason, 1951) 6180–7000 m
Micronephthys abranchiata (Ehlers, 1913) 8928–9174 m

POLYNOIDAE
Bathyeliasona abyssicola (Fauvel, 1913) 7250–7290 m
Bathykermadeca hadalis (Kirkegaard, 1956) 6660–8300 m

Order OWENIIDA
OWENIIDAE
Galathowenia australis (Grube, 1866) 1812–1813 m
Myriothele sp. Kirkegaard 1956 6180–8300 m

Order SABELLIDA
SABELLIDAE
Jasmineira sp. Kirkegaard 1956 6620–8300 m

SERPULIDAE
Genus et sp. indet. Kirkegaard 1956 6620 m

SIBOGLINIDAE
Oasisia fujikurai Miura & Kojima, 2006 **E** 1598 m

Order SPIONIDA
CIRRATULIDAE
Genus et sp. indet. Levenstein 1962 9995–10002 m

Order TEREBELLIDA
ALVINELLIDAE
Paralvinella sp. 1598–1647 m

AMPHARETIDAE
Amphisamytha sp. 1598 m
Genus et sp. indet. Kirkegaard 1956 6660–6720 m

TRICHOBRANCHIDAE
Terebellides stroemi Sars, 1835 6660–6770 m

Class CLITELLATA
Order EUHIRUDINEA
Suborder RHYNCHOBDELLIDA

PISCICOLIDAE
Galatheabdella bruuni Richardson & Meyer, 1973
  E 3880–4400 m

PHYLUM ECHIURA
Order ECHIUROINEA
BONELLIIDAE
Pseudoikedella achaeta (Zenkevitch, 1958) 4400–
  4670 m
Torbenwolffia galatheae Zenkevitch, 1966 **K**
  5850–8300 m

PHYLUM CHAETOGNATHA
Class SAGITTOIDEA
Order PHRAGMOPHORA
Genus et sp. indet. 1642–2560 m

**PHYLUM ARTHROPODA — Sea spiders,
  crustaceans**
Subphylum CHELICERATA
Class PYCNOGONIDA
Order PANTOPODA
PHOXICHILIDIIDAE
Anoplodactylus speculus Child, 1995 1586–1676
  m
Anoplodactylus typhlops Sars, 1888 1586–1640 m
ASCORHYNCHIDAE
Ascorhynchus antipodus Child, 1987 **E** of
  Antipodes Islands 5340 m
Ascorhynchus cooki Child, 1987 2476–2505 m
Ascorhynchus orthostomum Child, 1998 **E** 1586 m
AUSTRODECIDAE
Pantopipetta australis (Hodgson, 1914) 1586 m
CALLIPALLENIDAE
Oropallene dolichodera Child, 1995 1676 m
Oropallene metacaula Child, 1995 **E** 1586 m
COLOSSENDEIDAE
Colossendeis angusta Sars, 1877 3580–5340 m
Colossendeis australis Hodgson, 1907 2127–2130
  m
Colossendeis bruuni Fage, 1956 **K** 4410 m
Colossendeis colossea Wilson, 1881 1573–2640 m
Colossendeis cucurbita Cole, 1909 2640–4400 m
Colossendeis macerrima Wilson, 1881 1713–4410
  m
Colossendeis megalonyx Hoek, 1881 2476 m
Colossendeis stramenti Fry and Hedgpeth, 1969
  1491–1506 m
Colossendeis tortipalpis Gordon, 1932 1652–2571
  m
NYMPHONIDAE
Nymphon australe Hodgson, 1902 2476–2677 m
Nymphon compactum Hoek, 1881 2250–2262 m
Nymphon galatheae Fage, 1956 **K** 5340–5850 m
Nymphon inerme Fage, 1956 **K** 4410 m
Nymphon longicoxa Hoek, 1881 1586–1676 m
Nymphon typhlops (Hodgson, 1915) 1932–2619 m
Nymphon uncatum Child, 1998 E 3391 m
Pentanymphon antarcticum Hodgson, 1904 2476
  m

PALLENOPSIDAE
Bathypallenopsis californica (Schimkewitsch,
  1893) 3391 m
Pallenopsis pilosa (Hoek, 1881) 2476–2677 m
PYCNOGONIDAE
Pycnogonum magellanicum Hoek, 1898 2119–
  2182 m

Subphylum CRUSTACEA
Class OSTRACODA
Order MYODOCOPIDA
CYPRIDINIDAE
Bathyvargula sp. 1609 m
Metavargula sp. 1609 m

Class MAXILLOPODA
Subclass THECOSTRACA
Order PEDUNCULATA
EOLEPADIDAE
Vulcanolepas osheai (Buckeridge, 2000) 1572–
  1578 m
LEPADIDAE
Lepas sp. 1705–1930 m
SCALPELLIDAE
Amigdoscalpellum costellatum (Withers, 1935)
  3120 m
Arcoscalpellum novaezelandiae (Hoek) 1930 m
Arcoscalpellum vitreum (Hoek, 1883) 1705 m
Graviscalpellum pedunculatum (Hoek, 1883) 472–
  3948 m
Gymnoscalpellum cf. *tarasovi* Newman & Ross,
  1971 1812–1813 m
Gymnoscalpellum intermedium (Hoek, 1883)
  1730–2505 m
Neolepas sp. 1466–1580 m
Verum novaezelandiae (Hoek, 1883) 2146–2431 m
Verum raccidium (Foster, 1979) 1585–4405 m

Order SESSILIA
PACHYLASMATIDAE
Hexelasma sp. 1091–1697 m
VERRUCIDAE
Verruca sp. 1590 m

Subclass TANTULOCARIDA
DEOTERTHERIDAE
Deoterthron aselloticola Boxshall & Lincoln, 1983
  3250-3340 m

Subclass COPEPODA
Order CALANOIDA
MEGACALANIDAE
Megacalanus sp. 1503–1538 m

Subclass MALACOSTRACA
Order TANAIDACEA
AGATHOTANAIDAE
Paranarthrura fortispina Sieg, 1986 1586–1676 m
APSEUDIDAE
Apseudes galatheae Wolf, 1956 **E K** 4510–6770 m

COLLETEIDAE
Libanius monokanthus (Vanhoeffen, 1914) 1586–1676 m

Mirandotanais vorax Kussakin & Tzareva, 1974 1586 m

NEOTANAIDAE
Herpotanais kirkegaardi Wolf, 1956 **E K** 7150 m

Neotanais serratispinosus hadalis Wolf, 1956 **E K** 7150–8210 m

Neotanais sp. 1586 m

PARATANAIDAE
Bathytanais sp. 1609 m

Paratanais oculatus (Vanhoeffen, 1914) **E K** 5700 m

TYPHLOTANAIDAE
Typhlotanais greenwichensis Shiino, 1970 1676 m

Order AMPHIPODA
AMATHILLOPSIDAE
Amathillopsis grevei Barnard, 1961 3580 m

AMPHILOCHIDAE
Gitanopsis squamosa (Thompson, 1880) 5852 m

AORIDAE
Camacho bathylous Stebbing, 1988 **K** 2470 m–2640 m

ARISTIIDAE
Aristia tacticus Barnard, 1961 **E** 3580 m

CAPRELLIDAE
Pseudoprotomima hurleyi McCain, 1969 1609 m

CEINIDAE
Waitomo manene Barnard, 1972 1609–1642 m

DEXAMINIDAE
Atylus sp. 2526 m

Lepechinella aberrantis Barnard, 1973 1642 m

Lepechinella sucia Barnard, 1961 3580 m

Lepechinella wolffi Dahl, 1959 **K** 6600–6770 m

EPIMERIIDAE
Epimeria bruuni Barnard, 1961 **E K** 2526 m

Epimeria glaucosa Barnard, 1961 **E** 3710 m

EUSIRIDAE
Bathyschraderia magnifica Dahl, 1959 **E K** 6960–7000 m

Rhachotropis sp. **K** 6960–7000m

EURYTHENEIDAE
Eurythenes gryllus (Lichtenstein, 1822) **K** 4400–4630 m

LYSIANASSIDAE
Schisturella robusta (Barnard, 1961) **E** 3580 m

Bruunosa bruuni (Dahl, 1959) **E K** 6660–6770 m

Hippomedon antitemplado Barnard, 1961 **E** 4400 m

Hippomedon concolor Barnard, 1961 **E** 3580 m

Hippomedon tasmanicus Barnard, 1961 **E** 4400 m

Hirondella dubia Dahl, 1959 **E K** 7640–9100 m

Orchomene abyssorum Stebbing, 1888 **K** 8210–8300 m

Orchomenella cavimanus (Stebbing, 1888) 3580 m

Parawaldeckia kidderi Lowry & Stoddart, 1983 2150 m

Schisturella abyssi tasmanensis (Barnard, 1961) E 4400m

Schisturella galathea Dahl, 1959 **K** 6660–6770m

Bruunosa bruuni (Dahl, 1951) **K** 6660–6770 m

Valettiopsis multidentata Barnard, 1961 **E K** 2470 m

OEDICEROTIDAE
Lopiceros forensia Barnard, 1961 **E** 3580 m

Oediceroides wolffi Barnard, 1961 3580 m

PARDALISCIDAE
Pardaliscoides longicaudatus Dahl, 1959 **E K** 6180 m

Princaxelia abyssalis Dahl, 1959 **E K** 6620-8300m

PHOXOCEPHALIDAE
Cephalophoxus regium (Cooper, 1974) 1920 m

Harpinia palabria Barnard, 1961 3253 m

SCOPELOCHEIRIDAE
Scopelocheirus schellenbergi Birstein & Vinogradov, 1958 **K** 8210-9100m

STEGOCEPHALIDAE
Euandandania gigantea (Stebbing, 1888) 4630 m

STILIPEDIDAE
Alexandrella sp. 1730 m

URISTIDAE
Galathella galatheae (Dahl, 1959) **E K** 6960–7000m

Uristes sp. **K**

UROTHOIDAE
Crangolia sp. 2092m

Order ISOPODA
ACANTHASPIDIIDAE
Acanthaspidia sp. 1586–2677 m

CIROLANIDAE
Natatolana honu Keable, 2006 1713–1773 m

Natatolana sp. 1586–2677 m

DENDROTIIDAE
Acanthomunna proteus Beddard, 1886 **E** 1400–2200

Dendromunna mirabile Wolf, 1962 **E K** 5230–5340 m

DESMONATIDAE
Chelator sp. 1586 m

Mirabilicoxa sp. 1586 m

ECHINOTHAMBEMATIDAE
Stylomesus sp. 1586–1676 m

HAPLONISCIDAE
Chauliodoniscus tasmanaeus Lincoln, 1985 **E** 3253–4439 m

Haploniscus kermadecensis, Wolf, 1962 **E K** 4540 m

Haploniscus piestus Lincoln, 1985 **E** 1760–4421 m

Haploniscus saphos Lincoln, 1985 **E** 1760–1799 m

Haploniscus silus Lincoln, 1985 **E** 1457–4439 m

Haploniscus tangaroae Lincoln 1985 **E** 1386–3253 m

Haploniscus sp. **K** 8928–9174 m

Hydroniscus lobocephalus Lincoln, 1985 **E** 3253–3347 m

Mastigoniscys pistus Lincoln, 1985 **E** 2476–4421 m

HEMIONISCIDAE
Scalpelloniscus sp. 1705 m

ISCHNOMESIDAE
Bactromesus sp. 1586–1640 m
Haplomesus sp. 1678 m
Ischnomesus anacanthus Wolf, 1962 3710 m
Ischnomesus birsteini Wolf, 1962 **E K** 4410 m
Ischnomesus bruuni Wolf, 1956 **E K** 7150 m
Ischnomesus spaercki Wolf, 1956 **E K** 6660–7150 m
Ischnomesus sp. Wolf, 1962 3710 m

JANIRIDAE
Jaera sp. 2476 m

JANIRELLIDAE
Janirella sp. 4405 m

MESOSIGNIDAE
Mesosignum sp. 1586–4439 m

MUNNIDAE
Munna sp. 1 2677 m
Munna sp. 2 1586 m

MUNNOPSIDIDAE
Bathybadistes andrewsi Merrin, Malyutina & Brandt, 2009 **E** 3253–3347 m
Bathyopsurus nybelini Nordenstam, 1955 **K** 4400–5900 m
Disconectes madseni (Wolf, 1956) **E K** 7150 m
Eurycope galatheae Wolf, 1956 **E K** 7150 m
Epikopais sp. 1586 m
Ilyarachna kermadecensis Wolf, 1962 **E K** 4540–7000 m
Ilyarachna sp. 1 **E** 1676 m
Ilyarachna sp. 2 **E** 1586–2200 m
Ilyarachna sp. 3 **E** 1586 m
Munnopsis sp. **E** 1676 m
Munneurycope harrietae Wolf, 1962 **E** 4400 m
Munneurycope menziesi Wolf, 1962 **E K** 4540–7000 m
Munnopsis gracilis Beddard, 1886 **E** 2012 m
Notopais zealandica Merrin, 2004 **E** 1386–1640 m
Notopais sp. 2476 m
Paropsurus giganteus Wolf, 1962 4400 m
Storthyngura benti Wolf, 1956 **E K** 5230–7150 m
Syneurycope sp. K 8928–9174 m
Vanhoeffenura abyssalis Wolf, 1962 4400 m
Vanhoeffenura furcata Wolf, 1956 **E K** 5850–6730 m
Vanhoeffenura kermadecensis Wolf, 1962 **E K** 6620–6730 m

NANNONISCIDAE
Austroniscus sp. 1676 m
Nannoniscella sp. 1586 m
Nannoniscus sp. 1676 m

PARAMUNNIDAE
Notoxenoides sp. 1640–2476 m
Pleurosignum sp. 1586–3253 m

PSEUDIDOTHEIDAE
Pseudidotea sp. 2417–2421 m

SEROLIDAE
Acutiserolis sp. 1 1500–2505 m
Acutiserolis sp. 2 1573–2096 m
Caecoserolis sp. 1 2119–2337 m
Caecoserolis sp. 2 2930–3184 m
Cuspidoserolis sp. 1995–2039 m

STENETRIIDAE
Protallocoxa abyssale (Wolf, 1962) **K** 4405–4540 m

Order MYSIDACEA
EUCOPIIDAE
Eucopia sp. 2550–2526 m
LOPHOGASTRIDAE
Gnathophausia sp. 1440–1518 m

Order CUMACEA
BODOTRIIDAE
Gaussicuma kermadecensis Jones, 1969 **E K** 4540 m
Gaussicuma scabra Jones, 1969 **E** 3580 m
DIASTYLIDAE
Makrokylindrus mersus Jones, 1969 **E** 3580 m
Makrokylindrus neptunius Jones, 1969 **E** 3580 m
Makrokylindrus prolatus Jones, 1969 **E** 2470 m
Leptostyloides calcar Jones, 1969 **E K** 4410–4540 m
Leptostylus profunda Jones, 1969 **E** 3580 m

Order EUPHAUSIACEA
EUPHAUSIIDAE
Euphausia similis Sars, 1883 2156–2212 m
Thysanopoda egregia Hansen, 1905 1503–1538 m
Thysanopoda monocantha Ortmann, 1893 1513–1534 m

Order DECAPODA
Infraorder ANOMURA
CHIROSTYLIDAE
Uroptychus bicavus Baba & Saint Laurent, 1992 2340 m
Uroptychus remotispinatus Baba & Tirmizi, 1979 1440–1580 m
Uroptychus cf. *australis* Henderson, 1885 421–1668 m
GALATHEIDAE
Galacantha rostrata A. Milne-Edwards, 1880 1640–3120 m
Munida chathamensis Baba, 1974 E 995–1697 m
Munida endeavourae Ahyong & Poore, 2004 773–2756 m
Munidopsis abyssicola Baba, 2005 **E K** 4410 m
Munidopsis antonii (Filhol, 1884) 2930–3480 m
Munidopsis bairdii (Smith, 1884) 2446–2675 m
Munidopsis crassa Smith, 1885 3580 m
Munidopsis kermadec Cubelio, Tsuchida & Watanabe, 2007 **E** 1649 m
Munidopsis marginata (Henderson, 1885) 2127–2308 m
Munidopsis pilosa Henderson, 1885 2930–3391 m
Munidopsis sonne Baba, 1995 1400–1600 m

Munidopsis valdiviae Balss, 1913 1515–1530 m
Paramunida labis Macpherson, 1996 1714–1720 m
Phylladiorhynchus pusillus (Henderson, 1885) 22–2286 m
LITHODIDAE
Neolithodes sp. 1080–1530 m
Paralomis hirtella Saint Laurent & Macpherson, 1997 1526–1603 m
PAGURIDAE
Bathypaguropsis yaldwyni McLaughlin, 1994 256–1813 m
Diacanthurus rubricatus (Henderson, 1888) 15–2134 m
Lophopagurus cookii (Filhol, 1883) 11–2134 m
Michelopagurus sp. 400–1534 m
Pagurodes inarmatus Henderson, 1888 691–3250 m
Paragiopagurus sp. 1513–1534 m
Parapagurus abyssorum (Filhol, 1885) 3710 m
Parapagurus latimanus Henderson, 1888 413–2675 m
Parapagurus richeri Lemaitre, 1999 **K** 2348–2640 m

Infraorder BRACHYURA
MAJIDAE
Teratomaia richardsoni (Dell, 1960) **E K** 310–7160 m
ATELECYCLIDAE
Trichopeltarion fantasticum Richardson & Dell, 1964 **E** 15–2650 m
Trichopeltarion janetae Ahyong, 2007 830–1506 m
BYTHOGRAEIDAE
Galdalfus puia McLay, 2007 **E** 1647 m
ETHUSIDAE
Ethusina castro Ahyong, 2008 **E** 1216–2776 m
LEUCOSIIDAE
Bellidilia cheesmani Filhol, 1886 **E** 2257 m

Infraorder POLYCHELIDA
POLYCHELIDAE
Pentacheles laevis Bate, 1878 813–1786 m
Pentacheles validus A. Milne Edwards, 1880 1515–2186 m
Stereomastis nana (Smith, 1884) 1573 m
Willemoesia leptodactyla (Willemoes-Suhm, 1875) 3580 m
Willemoesia pacifica Sund, 1920 **K** 2526–5000 m

Infraorder CARIDEA
ALVINOCARIDIDAE
Alvinocaris longirostris Kikuchi & Ohta, 1995 1197–1850 m
Alvinocaris niwa Webber, 2004 **E** 1197–1538 m
Nautilocaris saintlaurentae Komai & Segonzac, 2004 1604–1672 m
CRANGOINIDAE
Parapontophilus junceus (Bate, 1888) 523–2675 m

OPLOPHORIDAE
Acanthephyra quadrispinosa Kemp, 1939 0–2207 m
Acanthephyra sica Bate, 1888 **K** 400–6890 m
Notostomus sp. 1169–2195 m
Oplophorus sp. 944–5050 m
Systellaspis debilis (A. Milne-Edwards, 1881) 2526–2550 m
NEMATOCARCINIDAE
Nematocarcinus hiatus Bate, 1888 486–1642 m
Nematocarcinus serratus Bate, 1888 1216–1705 m
Nematocarcinus sigmoideus Macpherson, 1984 648–1813 m
PASIPHAEIDAE
Pasiphaea notosivado Yaldwyn, 1971 300–2195 m
HIPPOLYTIDAE
Lebbeus wera Ahyong, 2009 **E** 1208–1578 m
Leontocaris amplectipes Bruce, 1990 1377–2182 m

Infraorder DENDROBRANCHIATA
BENTHESICYMIDAE
Benthesicymus cereus Burkenroad, 1936 1739–2000 m
Benthesicymus crenatus Bate, 1881 **K** 6007–6890 m
Benthesicymus howensis Dall, 2001 1287–1975 m
Gennadas gilchristi Calman, 1925 1555–2195 m
ARISTEIDAE
Austropenaeus nitidus (Barnard, 1947) 565–1530 m
Hepomadus tener Smith, 1884, 1530–1934 m
SOLENOCERIDAE
Gordonella kensleyi Crosnier, 1988 1132–2550 m
Haliporoides sibogae (de Man, 1907) 100–2160 m
SERGESTIDAE
Sergestes arcticus Kroyer, 1855 478–2195 m
Sergestes seminudus Hansen, 1919 2195 m

PHYLUM KINORHYNCHA — Mud Dragons
Order CYCLORHAGIDA
ECHINODERIDAE
Fissuroderes papai Neuhaus *in* Neuhaus & Blasche, 2006 **E** 1849–1957 m
Fissuroderes rangi Neuhaus *in* Neuhaus & Blasche, 2006 **E** 2378–3202 m

PHYLUM PRIAPULIDA — Penis Worms
Order PRIAPULOMORPHA
PRIAPULIDAE
Priapulus abyssorum Menzies, 1959 3013 m

PHYLUM NEMATODA — Round worms, eel worms
Class ADENOPHOREA
Subclass ENOPLIA
Order ENOPLIDA
Suborder TRIPYLINA
LEPTOSOMATIDAE

Synonchoides galatheae (Wieser, 1956) **K** 595–4570 m

PHYLUM ECHINODERMATA — Sea lilies, sea stars, sea urchins, etc.
Class CRINOIDEA — Sea lilies
Subclass ARTICULATA
Order MILLERICRINIDA
Suborder BOURGUETICRININA
BATHYCRINIDAE
Bathycrinus australis A.H. Clark, 1907 **K** 8210–8300 m
Bathycrinus volubilis Mironov, 2000 **K** 8185–8400 m
Monachocrinus aotearoa McKnight, 1973 **E** 2150 m

Order COMATULIDA
ANTEDONIDAE
Isometra sp. 1476–1506 m
PENTAMETROCRINIDAE
Pentametrocrinus australis McKnight, 1977 **E** 1500 m
Pentametrocrinus semperei (Carpenter, 1882) 1730–1772 m
Pentametrocrinus varians (P.H. Carpenter, 1888) 1730–1772 m

Class ASTEROIDEA — Sea stars
Order PAXILLOSIDA
ASTROPECTINIDAE
Astromesites compactus Fisher, 1913 1812–1813 m
Dipsacaster magnificus (H.L. Clark, 1916) 1676 m
Dytaster felli H.E.S. Clark, 2000 **E** 2250–3120 m
Dytaster pedicellaris H.E.S. Clark, 2000 **E** 1137–2677 m
Plutonaster ambiguus Sladen, 1889 1520–1677 m
Plutonaster complexus H.E.S. Clark, 2000 **E** 1186–2460 m
Plutonaster fragilis H.E.S. Clark, 1970 **E** 35–2250 m
Plutonaster hikurangi H.E.S. Clark, 2000 **E** 1920 m
Plutonaster jonathani H.E.S. Clark, 2000 **E** 934–2120 m
Plutonaster knoxi Fell, 1958 **E** 59–2748 m
Plutonaster sp. A H.E.S. Clark 2000 1828 m
Plutonaster sp. B. H.E.S. Clark 2000 **E** 55–2476 m
Proserpinaster neozelanicus (Mortensen, 1925) **E** 55–2120 m
Psilaster acuminatus Sladen, 1889 0–2519 m
PORCELLANASTERIDAE
Damnaster tasmani H.E.S. Clark & McKnight, 1994 1647–4714 m
Eremicaster vicinus (Ludwig, 1907) 2104–6730 m
Hyphalaster inermis Sladen, 1883 2505–4540 m
Porcellanaster ceruleus Wyville Thomson, 1877 1222–4670 m
Styracaster armatus Sladen, 1883 3120 m

Styracaster chuni Ludwig, 1907 **K** 4410–4570
Styracaster horridus Sladen, 1883 2104–4540 m
RADIASTERIDAE
Radiaster gracilis (H.L. Clark, 1916) 1687–2039 m
Radiaster rowei H.E.S. Clark, 2000 **E** 1568 m

ORDER NOTOMYOTIDA
BENTHOPECTINIDAE
Benthopecten munidae H.E.S. Clark, 1969 **E** 1491–1530 m
Benthopecten pikei H.E.S. Clark, 1969 **E** 1330–2526 m
Cheiraster ludwigi Fisher, 1913 1828 m
Cheiraster monopedicellaris McKnight, 1973 **E** 1812–1813 m
Cheiraster subtuberculatus (Sladen, 1889) 1491–1506 m
Pectinaster mimicus (Sladen, 1889) 532–2476 m

ORDER VALVATIDA
GONIASTERIDAE
Astropatricia marita McKnight, 2006 **E** 1525–1798 m
Lithosoma novaezealandiae McKnight, 1973 **E** 1713–1773 m
Mediaster arcuatus (Sladen, 1889) 2220–2255 m
Mediaster dawsoni McKnight, 1973 2100 m
Mediaster sp. McKnight 2006 **E** 1491–1506 m
Paragonaster ridgwayi McKnight, 1973 **E** 2113–2150 m
Paragonaster sp. Clark & McKnight 2001 2930 m
Philonaster sp. H.E.S. Clark 2001 **E** 1354–1995 m
Pillsburiaster aoteanus McKnight, 1973 **E** 120–1573 m
Pillsburiaster maini McKnight, 1973 **E** 1491–2008 m
Plinthaster dentatus (Perrier, 1884) 229–2910 m
Pseudarchaster garricki Fell, 1958 56–2598 m
Pseudarchaster macdougalli McKnight, 1973 **E** 1140–2146 m
ODONTASTERIDAE
Hoplaster kupe McKnight, 1973 **E** 1713–2550 m

Order VELATIDA
MYXASTERIDAE
Asthenactis australis McKnight, 2006 1800 m
PTERASTERIDAE
Hymenaster blevgadi Madsen, 1956 **E K** 6606–6770 m
Hymenaster carnosus Sladen, 1882 1009–3391m
Hymenaster pullatus Sladen, 1882 1186–2930 m
Hymenaster estcourti McKnight, 1973 **E** 1029–2810 m
Hymenaster sp. B McKnight 2006 3180 m
SOLASTERIDAE
Crossaster multispinus H.L. Clark, 1916 1491–1773 m

Order SPINULOSIDA

ECHINASTERIDAE
Henricia compacta (Sladen, 1889) 1491–1506 m

Order FORCIPULATIDA
ASTERIIDAE
Psalidaster fisheri McKnight, 2006 **E** 2370 m
PEDICELLASTERIDAE
Hydrasterias sacculata McKnight, 2006 **E** 4066 m
Hydrasterias tasmanica McKnight, 2006 **E** 4405
    m
ZOROASTERIDAE
Zoroaster planus Alcock, 1893 1680–1896 m
Zoroaster singletoni McKnight, 2006 1392–2162
    m
Zoroaster spinulosus Fisher, 1906 97–2150 m

ORDER BRISINGIDA
FREYELLIDAE
Freyastera digitata McKnight, 2006 3118–3120 m
Freyastera mortenseni (Madsen, 1956) **E K** 5850–
    6180 m
Freyella echinata Sladen, 1889 1573–2756 m
Freyella felleyra McKnight, 2006 3180–3184 m
Hymenodiscididae
Hymenodiscus aotearoa (McKnight, 1973) 1440–
    2550 m
Hymenodiscus sp. B McKnight 2006 3391 m
Hymenodiscus sp. C McKnight 2006 3180–3184 m

Class OPHIUROIDEA — Brittle stars
Order EURYALINIDA
ASTERONYCHIDAE
Asteronyx loveni Müller & Troschel, 1842 1522–
    1552 m
ASTEROSCHEMATIDAE
Ophiocreas oedipus Lyman, 1879 1440–1518 m

ORDER OPHIURIDA
AMPHIURIDAE
Amphioplus (*A.*) *ctenacantha* Baker, 1977 **E** 1713–
    1773 m
Amphioplus (*Unioplus*) *cipus* Baker, 1977 **E** 1812–
    1813
HEMIEURYALIDAE
Ophiochondrus sp. 2526–2550 m
OPHIACANTHIDAE
Ophiacantha brachygnatha H.L. Clark, 1928
    1722–2120 m
Ophiacantha composita Koehler, 1906 2526–2550
    m
Ophiacantha sollicita Koehler, 1922 1652–2182 m
Ophiocamax applicatus Koehler, 1922 1476–2550
    m
Ophiolebes sp. 1491–1506 m
Ophiolimna antarctica) Lyman, 1879) 1440–1608
    m
Ophiolimna perfida (Koehler, 1904) 1503–1538 m
Ophioplinthaca amezianeae O'Hara & Stöhr, 2006
    2620–2660 m

Ophioplinthaca bythiapsis (H.L. Clark, 1911)
    1330–2348 m
Ophiotholia spathifer (Lyman, 1879) 2605–2748
    m
Ophiotoma assimilis (Koehler, 1904) 2526–2550
    m
Ophiotoma megatreta Clark, 1911 1400–2217 m
OPHIACTIDAE
Ophiactis abyssicola Sars, 1861 1091–2675 m
OPHIOLEUCIDAE
Ophiernus vallinicola Lyman, 1878 1491–2255 m
OPHIOMYXIDAE
Ophiogeron sp. 2217 m
OPHIONEREIDIDAE
Ophiochiton lentus Lyman, 1879 1503–1538 m
OPHIURIDAE
OPHIOLEPIDINAE
Ophiomusium lymani Wyville-Thomson, 1873
    1491–2363 m
Ophiozonella stellata (Lyman, 1878) 1440–1534 m
OPHIURINAE
Amphiophiura ornata (Lyman, 1878) 1722–2120
    m
Amphiophiura spatulifera Koehler, 1922 1491–
    1506 m
Aspidophiura sp. 2119–2700 m
Ophiambix aculeatus Lyman, 1880 2526–2550 m
Ophiocten hastatum Lyman, 1878 1713–2255 m
Ophiomastus texturatus Lyman, 1883 1722–2120
    m
Ophiophycis johni McKnight, 2003 **E** 1513–2675
    m
Ophiura (*Ophiura*) *spinicantha* McKnight, 2003
    1722–3184 m
Ophiura (*Ophiuroglypha*) *irrorata* (Lyman, 1878)
    1958–2550 m
Ophiura (*O.*) *carinifera* (Koehler, 1901) 2207–
    2675 m
Ophiura (*O.*) *verrucosa* McKnight, 2003 1730–
    2421 m
Ophiura loveni (Lyman, 1878) **K** 6660–6770 m
Ophiurolepis sp. 1420–2348 m
Stegophiura sterilis Koehler, 1922 1722–2120 m

Class ECHINOIDEA — Sea urchins
Order CIDAROIDA
CIDARIDAE
Aporocidaris milleri (Agassiz, 1898) 1586–3250 m
Ctenocidaris aotearoa McKnight, 1974 **E** 1600–
    1829
Notocidaris bakeri McKnight, 1974 3017 m

Order ECHINOTHURIOIDA
ECHINOTHURIIDAE
Hygrosoma luculentum (A. Agassiz, 1879) 1573–
    1773 m
Sperosoma sp. 1515–2748 m
Tromikosoma sp. 1687–3480 m
KAMPTOSOMATIDAE

Kamptosoma asterias (A. Agassiz, 1881) 4077–4954 m

Order DIADEMATOIDA
ASPIDODIADEMATIDAE
Aspidodiadema tonsum A. Agassiz, 1879 1705–1930 m

Order PEDINOIDA
PEDINIDAE
Caenopedina otagoensis McKnight, 1968 **E** 1513–2182 m

Order SALENIOIDA
SALENIIDAE
Salenocidaris hastigera A. Agassiz, 1879 1705–2748 m

Order ECHINOIDA
ECHINIDAE
Gracilechinus multidentatus (H.L. Clark 1925) 1730–1772 m

Order CLYPEASTEROIDA
FIBULARIIDAE
Echinocyamus polyporus Mortensen, 1921 1705–1930 m

ORDER HOLASTEROIDA
URECHINIDAE
Urechinus antipodeanus McKnight, 1974 **E** 1500 m

Order SPATANGOIDA
HEMIASTERIDAE
Hemiaster expergitus Loven, 1874 2810–2849 m

Class HOLOTHUROIDEA — Sea cucumbers
Order MOLPADIIDA
CAUDINIDAE
Paracaudina chilensis (Müller, 1850) 1812–1813 m
MOLPADIIDAE
Heteromolpadia pikei Pawson, 1965 **E** 1491–1915 m
Molpadia abyssicola Pawson, 1977 1730–1772 m

Order ASPIDOCHIROTIDA
HOLOTHURIIDAE
Holothuria sp. 1958–2312 m
STICHOPODIDAE
Pseudostichopus perpatus (Sluiter, 1901) 1713–1773
SYNALLACTIDAE
Bathyplotes sulcatus Sluiter, 1901 1730–1772 m
Mesothuria lactea (Théel, 1886) 3480 m
Molpadiodemas involutus (Sluiter, 1901) 2526–2550 m
Paelopatides quadridens Heding, 1940 2930–3184 m

Pseudostichopus villosus Théel, 1886 **K** 6660–7000 m

Order ELASIPODIDA
DEIMATIDAE
Deima validum validum Théel, 1879 **K** 2640–4670 m
Oneirophanta mutabilis Théel, 1879 **K** 4410–5900 m
Oneirophanta setigera (Ludwig, 1894) **K** 4540 m
ELPIDIIDAE
Achlyonice ecalcarea Théel, 1879 **K** 4410 m
Amperina robusta (Théel, 1882) **K** 2640 m
Ellipinion bucephalum Hansen, 1975 **K** 4410 m
Ellipinion sp. **K** 5230–5340 m
Elpidia birsteini Belyaev, 1971 **K** 8185–8400 m
Elpidia glacialis kermadecensis Hansen, 1956 **K** 6620–8300 m
Elpidia ninae Belyaev, 1971 7694–7934 m
Elpidia theeli Hansen, 1956 4510 m
Peniagone azorica von Marenzeller, 1893 **K** 2640–8300 m
Peniagone diaphana Théel, 1882 4670 m
Peniagone humilis Hansen, 1975 **K** 4410 m
Peniagone sp. 6660–6770 m
Scotoplanes globosa Théel, 1879 **K** 2470–6770 m
LAETMOGONIDAE
Apodogaster sp. **K** 4410–6730 m
Laetmogone wyvillethomsoni Théel, 1879 **K** 4410 m
PELAGOTHURIIDAE
Enypniastes eximia Théel, 1882 1812–1813 m
PSYCHROPOTIDAE
Benthodytes incerta Ludwig, 1894 1730–1813 m
Benthodytes sanguinolenta Théel, 1882 **K** 3580–4410 m
Benthodytes typica Théel, 1882 2640–3710 m
Benthodytes sp. 2470–4540 m
Psycheotrephes magna Hansen, 1975 **K** 4410 m
Psychropotes longicauda Théel, 1882 **K** 3710–4410 m
Psychropotes loveni Théel, 1882 **K** 2640–4410 m
Psychropotes verrucosa (Ludwig, 1894) **K** 3710–6730 m

PHYLUM TUNICATA — Sea squirts
Class ASCIDIACEA
Order ENTEROGONA
Suborder APLOUSOBRANCHIA
CLAVELINIDAE
Distaplia galatheae Millar, 1959 **E K** 4410 m
POLYCITORIDAE
Millarus diogenes Monniot & Monniot, 1987 **E** 1386–1676 m
POLYCLINIDAE
Aplidium pseudoradiatum Millar, 1982 5460–5760 m
Polyclinum sp. Monniot & Monniot 1987 1586 m
RITTERELLIDAE

Phayngodictyon elongatum Millar, 1982 **E** 500–
 1586 m
Pharyngodictyon sp. Sanamyan and Sanamyan
 1999 2010 m

Suborder PHLEBOBRANCHIA
AGNEZIIDAE
Adagnesia antarctica Kott, 1969 5460–5760 m
Adagnesia charcoti Monniot & Monniot, 1973
 5410–5450 m
CORELLIDAE
Abyssascidia wyvilii Herdman, 1880 **K** 5850–5900
 m
OCTACNEMIDAE
Dicopia fimbriata Sluiter, 1905 1210 m
Octacnemus bythius Moseley, 1876 **K** 2640 m
Octacnemus vinogradovae Sanamyan & Sanamyan,
 1999 5400 m

Order PLEUROGONA
HEXACROBYLIDAE
Oligotrema lyra (Monniot & Monniot, 1973)
 2000–5000 m
Oligotrema psammites Bourne, 1903 4400 m
MOLGULIDAE
Minipera macquariensis Sanamyan & Sanamyan,
 1999 5410–5450 m
Molguloides monocarpa (Millar, 1959) **K** 825–
 4420 m
Molguloides? *vitreus* Sluiter, 1904 40–4000 m
Molguloides sp. Monniot & Monniot 1987 1586 m
PYURIDAE
Culeolus anonymus Monniot & Monniot, 1976
 5460–5760 m
Culeolus recumbens Herdman, 1881 680–2010 m
Culeolus suhmi Herdman, 1881 **K** 2640–5340 m
Fungulus perlucidus (Herdman, 1881) 5400 m
STYELIDAE
Bathystyeloides enderbyanus Michaelsen, 1904
 1373–4390 m
Cnemidocarpa bythia Herdman, 1881 **K** 4360–
 7000 m
Dicarpa simplex Millar, 1955 **K** 2740 m
Monandrocarpa abyssa Sanamyan and Sanamyan,
 1999 4330–4370 m
Styela crinita Monniot and Monniot, 1973 5410–
 5450 m
Styela sericata Herdman, 1888 4360–4670 m

PHYLUM CHORDATA — Vertebrates
Class CHONDRICHTHYES — Cartilaginous
 fishes
Subclass HOLOCEPHALI
Order CHIMAERIFORMES
RHINOCHIMAERIDAE — Longnose chimaeras
Harriotta haeckeli Karrer, 1972 1400–2600 m
 smallspine spookfish
CHIMAERIDAE — Shortnose chimaeras
Chimaera lignaria Didier, 2002 600–1800 m giant
 chimaera.

Chimaera sp. C 800–1514 m brown chimaera
Hydrolagus trolli Didier & Séret, 2002 610–1700
 m pointynose blue ghost shark
Hydrolagus homonycteris Didier, 2008 900–1530
 m black ghost shark

Subclass ELASMOBRANCHII
Order CARCHARHINIFORMES
PSEUDOTRIAKIDAE — False cat sharks
Pseudotriakis microdon de Brito Capello, 1868
 100–1890 m false cat shark

Order HEXANCHIFORMES
HEXANCHIDAE — Cow sharks
Hexanchus griseus (Bonnaterre, 1788) 0–2500 m
 sixgill shark

Order SQUALIFORMES
SOMNIOSIDAE — Sleeper sharks
Centroscymnus coelolepis Barbosa du Bocage & de
 Brito Capello, 1864 270–3700 m Portuguese
 dogfish
Zameus squamulosus (Günther, 1877) 550–2000 m
 velvet dogfish

Order RAJIFORMES
RAJIDAE —Hardnose skates
Amblyraja hyperborea (Collett, 1879) 980–2500 m
 boreal skate
ARHYNCHOBATIDAE — Softnose skates
Bathyraja richardsoni (Garrick, 1961) 1370–2990
 m Richardson's skate

Class ACTINOPTERYGII — Bony fishes
Division TELEOSTEI
Order ALBULIFORMES — Bonefishes
HALOSAURIDAE — Halosaurs
Aldrovandia affinis (Günther, 1877) 730–2560 m
Halosauropsis macrochir (Günther, 1878) 1000–
 3200 m abyssal halosaur
NOTACANTHIDAE — Spiny eels
Lipogenys gillii Goode & Bean, 1895 400–2000 m
Notacanthus chemnitzii Bloch, 1788 ?–3200 m
Polyacanthonotus challengeri (Vaillant, 1888)
 905–4560 m

Order ANGUILLIFORMES
SYNAPHOBRANCHIDAE — Cutthroat eels
Diastobranchus capensis Barnard, 1923 700–1600
 m basketwork eel
Histiobranchus australis (Regan, 1913) 950–3001
 m
Histiobranchus bruuni Castle, 1964 3493–4974 m
Ilyophis brunneus Gilbert, 1891 450?–3120 m
Synaphobranchus affinis Günther, 1877 290?–
 2400 m
NETTASTOMATIDAE — Duckbill eels
Venefica proboscidea (Vaillant, 1888) 1400–2200
 m

Order ARGENTIFORMES
MICROSTOMATIDAE — Pencilsmelts
Melanolagus bericoides (Borodin, 1929) 1000–1700 m
ALEPOCEPHALIDAE — Slickheads
Alepocephalus antipodianus (Parrott, 1948) 600–1700 m small-scaled brown slickhead
Alepocephalus australis Barnard, 1923 600–1700 m big scaled brown slickhead
Asquamiceps hjorti (Koefoed, 1927). 800–1500 m
Bajacalifornia megalops (Lütken, 1898) 1000–2000 m
Herwigia kreffti (Nielsen & Larsen, 1970) 990–1800 m
Talismania longifilis (Brauer, 1902) 560–1638 m

Order AULOPIFORMES
IPNOPIDAE — Deep-sea tripod fishes
Bathymicrops brevianalis Nielsen, 1966 **K** 4810–5900 m
Bathypterois filiferus Gilchrist, 1906 802–2835 m
Bathypterois longicauda Günther, 1878 4663–5900 m
Bathypterois longipes Günther, 1878 2615–5610 m
Bathypterois oddi Sulak, 1977 **E** 4400–5550 m
BATHYSAURIDAE
Bathysaurus ferox Günther, 1878 1000–2600 m deep-sea lizardfish.

Order GADIFORMES
BATHYGADIDAE — Bathygadids, grenadiers
Bathygadus cottoides Günther, 1878 **K** 950–1610 m
MACROURIDAE — Macrourids, grenadiers, rattails
Coelorinchus trachycarus Iwamoto, McMillan & Shcherbachev, 1999 980–1610 m
Coryphaenoides armatus (Hector, 1875) 2000–4000 m
Coryphaenoides microstomus McMillan, 1999 **E** 1550–1720 m
Coryphaenoides murrayi Günther, 1878 1146–2000 m

Coryphaenoides rudis Günther, 1878 **K** 1100–3500 m
Coryphaenoides striaturus Barnard, 1925 1100–2000 m
Haplomacrourus nudirostris Trunov, 1980 800–1600 m
MACROUROIDIDAE — Macrouroids, grenadiers, rattails
Squalogadus modificatus Gilbert & Hubbs, 1916 600–2100 m
TRACHYRINCIDAE — Trachyrincids, grenadiers, rattails
Idiolophorhynchus andriashevi Sazonov, 1981 1030–1610 m
MORIDAE — Deep-sea cods
Antimora rostrata (Günther, 1878) 500–2800 m
Guttigadus globosus (Paulin, 1985) 1100–1600 m
Guttigadus kongi (Markle & Meléndez C.,1988) 690–1500 m
Halargyreus johnsonii Günther, 1862 700–1700 m

Order OPHIDIIFORMES
OPHIDIIDAE — Cusk-eels
Abyssobrotula galatheae Nielsen, 1977 **K** 5230–5340 m abyssal cusk-eel
Bassozetus robustus Smith & Radcliffe, 1913 1069–1922 m
Spectrunculus grandis (Günther, 1877) 800–4255 m warty cusk-eel
APHYONIDAE — Aphyonids
Sciadonus galatheae (Nielsen, 1969) **K** 2250–4410 m

Order SCORPAENIFORMES
LIPARIDAE — Snailfishes
Notoliparis kermadecensis (Nielsen, 1964) **E, K** 6660–6890 m Kermadec snailfish

Order PERCIFORMES
ZOARCIDAE — Eelpouts
Pachycara garricki Anderson, 1990 **E** 2602–2619

3.   ASSEMBLAGE STUDIES

There have been few published New Zealand deep-sea assemblage studies undertaken, and these generally have low taxonomic resolution and/or are restricted to particular habitats, namely the Chatham Rise slope and the Kermadec and Tonga trenches. As a consequence, there are no detailed descriptions of benthic faunal (macroinvertebrates and demersal fish) assemblages from representative deep-sea habitats in the New Zealand region. This deficiency contrasts with international studies in which different types of deep-sea environments have been investigated more thoroughly, with some areas receiving considerable attention in the form of long-term time-series and experimental studies (e.g., Porcupine Abyssal Plain, northeast Atlantic Ocean). Because of this discrepancy regarding the state of knowledge between New Zealand and overseas, the following synthesis of existing information is provided separately for New Zealand and other regions.

3.1   Global assemblage studies

3.1.1   Diversity patterns

Deep-sea ecosystems were perceived initially to be characterised by depauperate benthic assemblages, but advances in sampling techniques and increased sampling effort have changed this perception and led to the recognition that they support high biodiversity at local and regional scales (Hessler & Sanders 1967; Rex 1981; see review in Snelgrove & Smith (2002)). For example, extensive quantitative sampling of benthic fauna between 1500 and 2500 m depth in the northeast Atlantic revealed remarkably high local diversity of 798 species (representing 17 families and 14 phyla), which increased to 1597 species on a regional (100s kilometres) scale (Grassle & Maciolek 1992). Similar high-diversity values from other areas suggest that deep-sea biodiversity is equally high on a global scale as it is on local and regional ones (Snelgrove & Smith 2002). Recent research in the Southern Ocean for example, showed that this largely under-studied region is characterised by high diversity, evident in the meio-, macro- and megafaunal components of the benthic assemblages (Brandt et al. 2007a,b).

Diversity patterns have been examined across a number of different geographical regions, predominantly in the North Atlantic and North Pacific Oceans, with early studies focused on general trends in species diversity (e.g., Hessler & Jumars 1974). Over time, studies have become more complex, examining assemblage patterns in detail and incorporating ecological factors that may influence benthic assemblage compositions (e.g., Galéron et al. 2001; Soltwedel et al. 2009). The most obvious environmental factor to receive attention has been water depth, with many studies examining diversity trends from relatively shallow waters (10s to 100s m) to greater depths (1000s m) (e.g., Grassle et al. 1979; Soltwedel 1997; Flach & de Bruin 1999); and although the number of individuals and biomass generally show a drastic decline from shallow to deep water (Rowe et al. 1982), diversity patterns do not consistently follow this trend. For a number of taxa, the relationship between diversity and depth is parabolic, in that diversity values increase with the descent from shallow to intermediate depths (about 2000–3000 m) before declining to lower values as water depth increases (see review in Rex (1981)). This diversity pattern has been documented for macro- and megafauna (including fish), with the highest diversity values between 2300–2800 m and 1900–2300 m respectively (Rex 1981 and references therein). For the less-studied meiofaunal benthic component, peak diversity appears to be at depths below those of macrofauna (e.g., for copepods at 3000 m depth, Coull 1972).

A number of deep-sea studies have also examined the sequential pattern of species replacement from relatively shallow to deep waters that is apparent in overall changes in faunal assemblage compositions, also termed 'zonation' (see review by Carney (2005)). Depth-related species replacement has been documented for macro- and megafaunal (including fish) assemblages, and species turnover can be continuous, with successive assemblages sharing a substantial proportion of species, or discontinuous, resulting in disparate assemblage compositions. The depths at which

assemblage changes are discernible vary depending on the faunal group (or species) examined. For example, for meiofaunal nematode assemblages two distinct groups have been documented, with one 'shelf-break' (to 206 m depth) and one 'down-slope' group (1034–2760 m depth), and a broad transition between the two (Vanaverbeke et al. 1997). Macrofauna appears to be characterised by three distinct assemblage groups, one of each characterising the shelf (to 670 m depth), the slope (670–2200 m), and the abyss (below 3500 m) (Flach & de Bruin 1999). For megafauna, there seems to be a continuous species change with more rapid transitions at particular depth intervals, such as for demersal fish at 750–1900 m depth (Gordon et al. 1996). As water depth increases, the deep-sea environment becomes more uniform and the rate of faunal turnover decreases (Rex 1981; Gordon et al. 1996). Abyssal and hadal depths are generally characterised by a low diversity of scavengers and predators (e.g., megafaunal gastropods, amphipods and fish) (King et al. 2008; Jamieson et al. 2009a).

In addition to depth differences in deep-sea biodiversity, Rex et al. (1993) proposed a latitudinal diversity gradient for several taxonomic groups, i.e., a decrease in diversity for gastropods, bivalves and isopods with increasing latitude. They considered this gradient to be particularly pronounced in the Northern Hemisphere (North Atlantic and Norwegian Sea), but studies on other taxonomic groups do not support this notion (e.g., Lambshead et al. 2002), and there appears to be no benthic latitudinal diversity gradient in the Southern Hemisphere (Gray 2002; Gage et al. 2004). Similarly, the recently mooted notion that abyssal biodiversity is based on a bathyal–abyssal source-sink relationship, with abyssal assemblages depending on immigration from bathyal populations (Rex et al. 2005), has met with criticism (Smith et al. 2008). Although this hypothesis may be applicable to abyssal molluscs with a planktonic larval stage, it remains to be tested. Furthermore, it does not consider that the majority of invertebrate groups that determine abyssal species richness generally lack dispersing larvae, and that distances between the slope and the abyss in some regions (e.g., Pacific Ocean) are too great to facilitate this kind of larval supply (Craig et al. 2008).

3.1.2 Assemblage composition

Descriptions of deep-sea benthic assemblages are available from various regions, including the Arctic and the Antarctic. Most sampling effort has been concentrated in the northern Atlantic (i.e., the Porcupine Abyssal Plain) and northern Pacific oceans (e.g., Smith & Druffel 1998; Billett et al. 2001, 2010; Ruhl & Smith 2004). Most studies have focused on a particular faunal component (i.e., meio-, macro- or megafauna) and not on the benthic community as a whole, with arbitrary distinctions between components (usually based on size, e.g., Lauerman et al. 1996; Flach & de Bruin 1999; Danovaro et al. 2002). The majority of studies are not exclusively abyssal and make comparisons across a depth gradient that includes relatively shallow sites (less than 200 m deep), with considerably fewer studies considering sites exclusively below 1500 m depth. Sampling effort and methods and taxonomic resolutions can also vary considerably between studies and faunal groups, with meiofaunal assemblages frequently identified to major taxonomic groups only (e.g., Galéron et al. 2001). In addition, sampling sizes are frequently small so that data are suitable for basic descriptions, but not for formal assessments of assemblage patterns (but see, for example, Hilbig et al. (2006) and Fodrie et al. (2009)). More recently, however, an increasing number of ecological studies have incorporated environmental variables into descriptions and assessments to explain regional assemblage patterns and observed differences. Because of the dependency of deep-sea fauna on organic matter supplied by primary production in surface waters (Gage & Tyler 1991), surface productivity has become an important consideration in spatial and temporal comparisons of assemblage structures (Ruhl & Smith 2004; Billett et al. 2010).

3.1.3 Benthic invertebrates

3.1.3.1 Soft substrata

Meiofaunal organisms are a ubiquitous component of soft-sediment communities (Soltwedel 2000), with greater or proportionally greater biomass than macro- and megafaunal invertebrates in deep-sea

sediments (Pequegnat et al. 1990; Rowe et al. 1991). Meiofaunal biomass values (combined with bacteria) can be greater than 90% of total benthic biomass (Danovaro et al. 2002), and this group represents an important link between primary and secondary production and higher trophic levels (Montagna 1984). A global review of deep-sea benthic meiofauna encompassed studies from northern and southern polar regions, northern temperate, subtropical, tropical and arid regions, with most studies encompassing a wide range of sampling depths, from shallow sites to 7460 m depth (Soltwedel 2000). In all regions, nematodes dominate metazoan assemblages, reflecting approximately 80% of overall abundance, with harpacticoid copepods contributing approximately 12% of individuals. Other taxa, such as polychaetes, ostracods, kinorhynchs, tubellarians and molluscs, occurred in only small numbers, but were present at most water depths. There was a general trend of decreasing abundance and biomass with increasing water depth, which the author attributed to decreasing food availability. Furthermore, highest abundance levels were documented for highly productive areas, such as upwelling regions off West Africa. In these productive regions, meiofaunal abundances also declined with increasing depth to a lesser extent than in less productive areas. When relating meiofaunal abundance data to organic matter input (via phytodetritus) on a global scale, there was a uniform increase in meiofauna as a function of organic matter input, indicating close pelago-benthic coupling (Soltwedel 2000).

Deep-sea macrofaunal assemblages are generally characterised by low densities, but high diversity, with biomass and abundance generally dominated by polychaetes (Paterson & Lambshead 1995; Smith & Demopoulos 2003). Assemblage patterns have been described from a number of different regions, with a prevalence of studies based on comparisons across depth gradients and/or across regions that differ in productivity (Flach & de Bruin 1999). Flach and de Bruin (1999) compared macrofaunal assemblage patterns across the continental slope in the northeast Atlantic, with sites spanning from about 200 to about 4500 m depth and including the Goban Spur and the Porcupine Sea Bight. They found that species diversity increased with increasing water depth, with almost twice as many species on the abyssal plain as on the shelf. Species evenness exhibited the same trend, but the trend was reversed for species dominance. Overall, assemblages differed from the shelf and slope to the abyss, with the latter exhibiting distinctly different assemblage compositions to shelf and slope stations (670–2200 m depth). Abyssal faunal densities were low with intermediate species richness and crustaceans the most abundant group (compared with polychaetes at the shallower sites). Inter-site differences in species composition between abyssal Porcupine Bight and Goban Spur sites were linked tentatively to differences in physical and chemical variables between the two areas (Flach & de Bruin 1999).

Megafaunal organisms are the most conspicuous component of benthic communities and are dominated by echinoderms (holothuroids, asteroids, ophiuroids), but also actiniarians and natant decapods in some regions (Smith & Demopoulos 2003), with studies frequently including fish with benthic invertebrates in this group. In comparison with meio- and macrofauna, megafaunal invertebrates are generally less abundant and diverse, but represent a substantial proportion of benthic biomass, and are also pivotal (i.e., holothurians) for organic matter recycling (Smith et al. 1993; Ruhl & Smith 2004). Megafaunal assemblages in the northeast Atlantic exhibit clear zonation patterns among sites between 40 and 5000 m depth, with distinct assemblages characterising a range of zones below 1500 m depths (Haedrich et al. 1980). In addition to differences across shallower depth zones, megafaunal diversity and species dominance vary markedly across zones from the lower continental slope (1380–1947 m), the slope to the rise (2116–2481 m), the upper continental rise (2504–3113 m), the middle continental rise (3244–3470 m) and the lower continental rise/abyssal plain (3879–4986 m). Diversity is lowest at greater depths, with decapod crustaceans, echinoderms and fish being the main taxa with differences in their prevalence and diversity within and across zones (Haedrich et al. 1980).

Fodrie et al. (2009) studied megafaunal density and assemblage structure between 2000 m and 4200 m depth along the Aleutian margin and found uncharacteristically high epibenthic densities, which they attributed to environmental factors including high productivity. Diversity and richness were highest at the shallowest sites, whereas evenness was greatest at deep sites, which were similar in richness and

evenness. Within assemblages, echinoderms were the most abundant phylum across depths, with ophiuroids prevalent at 2000 m (89% of individuals), echinoids at 3200 m (39%) and holothuroids at 4200 m (47%) (Fodrie et al. 2009).

The relationship between environmental variables, faunal biomass and assemblage structure was also the focus of a study in the northeast Atlantic, which integrated meio-, macro- and megafaunal data. The sampling design included three sites (1600 to 4500 m depth) characterised by different levels of primary productivity (eutrophic, mesotrophic, and oligotrophic), indicating different levels of food supply, with faunal data collected across three seasons (winter to spring). There was no seasonal variation in faunal measures, but sites differed substantially in assemblage structure and biomass, with each faunal component displaying spatial variation in relation to food supply. Total faunal biomass and abundance decreased with increasing depth and lower food availability, and this trend was consistent for each faunal component. The relative contribution of each component to overall biomass, however, varied across sites and with depth. At the eutrophic site, biomass was dominated by megafauna, whereas macrofauna was prevalent in mesotrophic conditions, and meiofauna at the oligotrophic site and at the greatest depths. Although these patterns were consistent for each component, some taxa within each group showed inconsistent responses to food availability, suggesting that other physical and biological factors also play an important role in determining assemblage compositions in abyssal habitats (Galéron et al. 2000).

Availability of a comprehensive data set from the northern Gulf of Mexico (175–3750 m depth) enabled a broad-scale modelling approach to examine species richness in benthic macro- and megafauna (Haedrich et al. 2008). Aimed at establishing whether assemblage patterns (i.e., depth distributions) are random or related to environmental factors, this study incorporated a suite of variables, grouped into food, habitat, pollution, and location categories. Different combinations of 18 of these factors were significantly related to richness patterns, dependent on the phylum examined; there were no universal predictors for species richness in these deep-sea assemblages, leading the authors to recommend that richness be examined separately for each taxonomic group (Haedrich et al. 2008).

3.1.3.2   Hard substrata

In comparison with the number of studies concerned with soft-sediment assemblages, there have been markedly fewer investigations of deep-sea faunal assemblages associated with hard substrata. Hard substrata range in scale from relatively small polymetallic nodules and biogenic features (such as glass-sponge stalks) to rocky outcrops and relatively large geomorphic features such as seamounts and ridges (Beaulieu 2001a; Stocks 2004). Seamounts have been recognised as important deep-sea habitats that can support high biodiversity and productivity (Rogers 1994), and are also considered to reflect apparently high species endemism and endemic populations (Richer de Forges et al. 2000). For the purposes of the present study, descriptions of seamount assemblages are predominantly based on samples collected above 1500 m; if samples from depths below 1500 m were obtained, data are combined with those from shallower depths to characterise faunal assemblages. There are no seamount studies that exclusively examine benthic assemblages at water depths below 1500 m, except for those associated with microhabitats, such as deep-sea nodules (e.g., Mullineaux 1987; see below).

Hard substrata, including those represented by seamounts, are considered 'island habitats' in a predominantly sedimentary environment (Beaulieu 2001a). They also enable suspension feeders to exist in a sediment-dominated environment by providing suitable habitat above the sediment surface, which allows the interception of food in the benthic boundary layer flow (Barthel et al. 1991; Beaulieu 2001a; Etter & Mullineaux 2001). As a consequence, hard substrata are frequently characterised by higher species diversity than ambient sediments (e.g., Beaulieu 2001a).

Hard substrata in the form of ferromanganese nodules are widespread on the deep seafloor, i.e., the Pacific Ocean (Thistle 2003). Faunal studies at nodule sites in the North Pacific Ocean (deeper than

4000 m) reveal diverse and abundant assemblages associated with nodules, which are distinctly different to those in surrounding sediments (Mullineaux 1987; Thiel et al. 1993; Veillette et al. 2007). Epifaunal assemblages on the nodules are dominated by foraminifera, but also include metazoan groups such as ascidians, brachiopods and turbellarians, with more than 62 taxa identified on nodule surfaces (Veillette et al. 2007). The nodules provide microhabitat for epifaunal species that are not present in ambient sediment, resulting in assemblages that are characterised by suspension feeders (Mullineaux 1987). In addition to distinct epifaunal assemblages on the surface, nodules also appear to contain distinct assemblages within sediment-filled crevices (Thiel et al. 1993). Examination of crevice fauna of 26 nodules from abyssal sites (4150 m depth) in the SE Pacific Ocean revealed a faunal composition that was markedly different to ambient sediments, and included nematodes, harpacticoid copepods and nauplii, polychaetes, tanaids, tardigrades, isopods, echiurids and sipunculids; several of these taxa were represented by a large number of specimens and a number of different species (Thiel et al. 1993).

Biogenic features in the form of epifaunal tubes and stalks also support abundant and diverse abyssal assemblages. For example, stalks that are part of glass (hexactinellid) sponges are used by encrusting epifauna and provide habitat for dense assemblages of mostly suspension-feeders, with large mobile representatives such as anemones and echinoderms (crinoids and ophiuroids) found at the top of the stalks, but other feeding guilds including scavengers and mobile predators are also present. As a consequence, these deep-sea sponges support exceptionally high macrofaunal diversity (greater than 100 species, Beaulieu 2001b).

Plant/wood deposits, large-mammal carcasses and kelp falls are chemosynthetic systems (see under 3.1.3.4 below) that also provide suitable microhabitats for species that are dependent on hard substrata, attracting a large biota by supplying massive amounts of organic matter to the seafloor (e.g., Wolff 1979). The combination of these factors leads to distinct species-rich communities across different trophic levels (i.e., bacteria to scavengers) that use such 'food falls' for habitat and nutrition (Turner 1973; Gage 2003). Algal and seagrass material that sinks to the seafloor is colonised rapidly by deep-sea species, including echinoids and amphipods that are able to locate these food falls quickly (Gage 2003). Similarly, terrestrial plant material is also used by numerous species, and although the presence of lignin and cellulose limits its food value to marine metazoans, specialised wood-boring bivalves and ostracods facilitate carbon flow from these sources to other deep-sea organisms (Turner 1973; Maddocks & Steineck, 1987).

3.1.3.3   Canyons and trenches

Deep-sea soft-sediment habitats also include submarine canyons, which accumulate sediment particles and organic matter via lateral transport and have a consequent affect on species diversity and biomass (Duineveld et al. 2001). Studies of canyon systems show inconsistent patterns regarding biodiversity and species abundance, however, with some canyons characterised by distinct assemblages and others with similar faunal compositions to adjacent non-canyon areas, but with elevated abundance and biomass (Rowe 1971; Rowe et al. 1982). The underlying causes for these patterns has been related to sediment accumulation, instability and organic enrichment in canyon systems, especially in environments that are close to the coast (Rowe 1971; Escobar Briones et al. 2008).

Rowe (1971) compared epifauna in the western Atlantic Ocean along a depth gradient from 200 m to deeper than 2000 m in the Hatteras Submarine Canyon system to non-canyon epifauna at similar depths, and observed markedly different assemblages between the canyon sites and the adjacent continental slope. Some common species were present only in the canyon (where they occurred at high densities), whereas others were abundant on the slope but absent or at significantly lower densities in the canyon; a third group was present at low densities in both types of habitats at deeper sites. The unique canyon fauna seemed to be related to the different sedimentary environment in the canyon, which was characterised by high sedimentation rates and high organic matter influx (Rowe 1971).

Other studies have failed to detect differences in the species present, but found increased densities and biomass in canyon macrofauna as opposed to non-canyon habitats (Haedrich et al. 1980; Rowe et al. 1982). The latter appears also to be the case for demersal fish. King et al. (2008), for example, did not identify a distinct canyon fauna in the Nazaré Canyon system, northeast Atlantic Ocean, as the same scavenging species dominated canyon sites and abyssal ones on the open continental margin. Fish abundances estimated in the canyon were similar to those from regions further to the north that are more productive, and seemed to indicate that bathyal and abyssal fish populations within the canyon were enhanced by increased coastal productivity and deposition of organic matter (King et al. 2008).

High levels of organic matter deposition have also been implicated in observations of high meiofaunal densities and distinct assemblages in trenches in the South Pacific Ocean and the Mediterranean Sea (Danovaro et al. 2002; Tselepides & Lampadariou 2004). A ten-fold higher meiofaunal abundance was detected in the Atacama Trench at 7800 m depth compared to sediments at shallower bathyal depths. Differences were likewise discernible in assemblage structure between bathyal and hadal depths. Although nematodes consistently reflected greater than 80% of total density, the proportion of harpacticoid copepods showed marked variations, increasing from 2–7% at bathyal sites to about 17% at 7800 m depth. Differences in food quality seem to explain the observed patterns. Organic matter content was similar at all depths, with concentrations comparable to those in shallow, eutrophic sediments, but detailed analysis showed that it was of considerably higher nutritional value in trench sediments. The high-quality organic matter was derived from relatively fresh detritus and appeared to have been deposited by lateral flux down the steep slopes before being captured in the trench (Danovaro et al. 2002).

3.1.3.4   Chemosynthetic ecosystems

Chemosynthetic ecosystems in the deep-sea range from cold seeps and hydrothermal vents to whale and plant/kelp falls (which also provide hard substrata, see 3.1.3.2 above), with most research focussing on the former systems rather than the latter. Although differing in their origin (geological versus biological) and some physical characteristics, chemosynthetic ecosystems are characterised by distinct assemblages, with some species shared between them (Smith & Baco 2003; Levin 2005).

Whale falls are common hard substrata on the seafloor, and the abundance of sulphide-rich whale skeletons has been estimated to be in excess of 500 000 skeletons at any one time (Smith & Baco 2003). With their ecological significance enhanced greatly by chemosynthetic activity, whale-fall sites influence faunal community patterns, including microbial assemblages. Comparing macrofaunal species richness of three whale skeletons (1240–1910 m depth) on the California slope with diversity values from a range of hard-substratum habitats (including intertidal ones), Baco & Smith (2003) showed that the average local diversity on single whale skeletons was similar to that reported globally for cold-seep assemblages (185 species versus 229 species) and comparable to biodiversity in deep-sea soft sediments. The dominant macrofaunal component was polychaetes, which contributed most species. Moreover, whalebone diversity was higher than that of vent fields (121 species) and other deep-sea and some shallow-water hard-substratum habitats (e.g., intertidal mussel beds, shallow-water corals). The high species richness was attributed to the exceptionally high trophic diversity of the skeletons, which support sulphophilic species such as bacterial mat grazers and those with chemosynthetic endosymbionts, direct consumers and suspension- and deposit-feeders that respond to organic enrichment (Baco & Smith 2003).

Cold seeps and hydrothermal vents are geological features that represent complex deep-sea ecosystems, with faunal communities sustained by energy supplied by chemosynthetic processes via free-living and symbiotic bacteria. Their specialised faunal assemblages exhibit low diversity and often include a number of endemic species.

One of the main differences between the two chemosynthetic systems is the temperature of the effluxing fluids, which affects the associated biota, i.e., while fluid efflux from cold seeps is relatively

constant at approximately ambient temperatures, that from hydrothermal vents varies greatly and can reach temperatures exceeding 100°C (Kaiser et al. 2005). Although they are predominantly soft-sediment environments, these deep-sea features also provide a hard substratum, either directly by precipitating minerals   (e.g., carbonates at cold seeps, massive sulphides at hydrothermal vents) or through their conspicuous chemoautotrophic megafauna, e.g., vestimentiferan tubeworms, bathymodiolin mussels and vesicomyid clams (Levin 2005). Representatives of these groups provide physical structure and considerable habitat complexity above and below the sea-floor, in addition to influencing geochemical processes (Levin 2005). Since these animals are not limited by food supplied from surface waters (or from lateral sources), individuals can reach large sizes (tens of centimetres for mussels and clams, more than two metres for tubeworms) (Bergquist et al. 2003; van Dover et al. 2003), resulting in substantially higher biomass at seep and vent sites compared to surrounding sediments.

Although there are few quantitative assessments of their hard-substratum faunas, hydrothermal-vent and cold-seep assemblages have been described in a number of studies and reviews (e.gTunnicliffe et al. 2003; Levin 2005), covering the wide geographical and depth distributions of these systems, from shallow waters to hadal trenches (below 7000 m depth; Fujikura et al. 1999). One important difference in hydrothermal-vent megafauna has been observed between two main regions: the dominant tubeworms (and alvinellids) on Pacific Ocean hydrothermal vents are replaced by abundant caridean shrimps in the Atlantic Ocean (Desbruyères et al. 2001). In addition to the characteristic megafaunal groups and associated commensals, less dominant epifauna on cold seeps includes pogonophorans (siboglinid polychaetes), sponges, gastropods and shrimps (see Levin 2005 and references therein). Faunal comparisons between cold seeps and hydrothermal vents have shown that the former contain almost twice the number of species than the latter (Tunnicliffe et al. 2003). At the same time, some species occur across the different chemosynthetic habitat types (including whale falls), with cold seeps in the northeastern Pacific Ocean sharing 11 and 20 species with hydrothermal vents and whale falls, respectively (Smith & Baco 2003). Both vent and seep habitats are inhabited by diverse meio- and macrofaunal assemblages, each containing endemic species (Desbruyères et al. 2001; Levin 2005). At cold seeps, for example, assemblages are distinctly different from non-seep infauna at 2000–3000 m depth, evident in the species compositions, but also in higher densities and lower diversity of seep assemblages (Levin 2005). Furthermore, assemblage heterogeneity is evident between particular seep habitats, such as microbial mats, clam and mussel beds and tube-worm aggregations, which reflect specialised infaunal assemblages.

3.1.4   Demersal fish

Following early studies that were restricted to small numbers of fish specimens trawled from particular depths (e.g., Wolff 1961a,b) the use of modern technology (i.e., baited cameras that are remotely operated on towed equipment and on landers) has greatly enhanced knowledge of abyssal demersal-fish assemblages (Bailey et al. 2006b; Jamieson et al. 2009a). The majority of studies have examined fish abundance and assemblage composition in relation to depth. Most of the studies compare shallow and deep-water fish assemblages, but the boundary between these zones differs greatly across studies. Nevertheless, data from different geographical regions show that the abundance, diversity and biomass of demersal fish species generally decline with depth, with few species recorded below 1500 m and frequently only one or two species at abyssal depths below 3000 m (e.g., Snelgrove & Haedrich 1985; King et al. 2008).

In a global comparison of the depth distribution of cartilaginous and bony fishes, Priede et al. (2006a) used a range of sampling techniques (baited cameras, long-lines with baited hooks, demersal trawling) in the Atlantic and Pacific oceans and also analysed a global data set. They found that cartilaginous fishes are rare at depths exceeding 3000 m, with only seven species recorded below 2500 m, and that this group is generally absent below 4000 m. In contrast, 260 species of bony fishes are found below 2500 m, including several species whose minimum depth is below 3000 m. Both types of fish showed a decline

in species numbers with increasing depth, but this decrease was more rapid for Chondrichthyes (Priede et al. 2006b).

In a regional study in the northwestern Atlantic Ocean (off Newfoundland), trawling between 204 and 2325 m depth revealed markedly higher abundance and biomass of demersal fish species at shallower (less than 1500 m) than at deeper sites (greater than 1500 m), with the number of species showing a similar decrease (33 versus 10 species, respectively), even though species diversity was the same in both zones, and evenness was slightly greater in the deeper zone (Snelgrove & Haedrich 1985). Moranta et al. (1998) documented similar patterns for demersal fish on the continental slope in the Mediterranean Sea, with abundance, species richness and diversity being lowest between 1200–1800 m depth, and similar evenness values obtaining at deep and shallow sites. Below 3000 m depth, a low diversity of only one or two species is not unusual, frequently including a macrourid species (Priede et al. 1994; King et al. 2008).

In addition to overall trends in community parameters and biomass, differences in the vertical distribution of demersal deep-sea species are also reflected in zonation patterns (see Koslow 1993; review of North Atlantic deep-sea fish assemblages). The strength of the zonation, or the rate of change with depth, appears to vary depending on the fish community and/or the region involved. For example, Snelgrove & Haedrich (1985) observed a uniform addition of species with increasing depth, but their data did not show a pronounced zonation, even though faunal compositions at shallow and deep sites were markedly different. In contrast, Moranta et al. (1998) distinguished four fish assemblages between 200 and 1800 m depth, with one group in the zone below 1400 m depth. On the Mid-Atlantic Ridge, King et al. (2006) also documented distinct demersal fish assemblages at different depth zones. They found discernible differences in the composition of shallow (92–1198 m), intermediate (1569–2355 m), and deep (2869–3420 m) assemblages, with each assemblage dominated by a different single species and zonation patterns best explained by depth and temperature. In addition, latitudinal differences in the estimated abundance of the three dominant species and in average species richness seemed to indicate a faunal change between 50–52°N. This latitude coincides with the Subpolar Front, the boundary between cold productive waters in the north and warmer, lower-productivity waters in the south, and the authors suggested that these differences in surface productivity result in the observed differences in deep-sea fish distribution and abundance at different latitudes in this region (King et al. 2006).

The notion of productivity-related changes in assemblages has previously been proposed in other studies that examined deep-sea fish assemblages in regions with different levels of productivity (Merrett 1987; Henriques et al. 2002). Merrett (1987) suggested that discernible differences in deep-sea demersal fish assemblages in the northeastern Atlantic Ocean were linked to patterns of productivity along a latitudinal division, with assemblages dominated by large macrourids reflecting highly productive conditions in northern temperate areas and smaller species prevalent in tropical areas with non-seasonal, low-productivity conditions. Deep-sea fish assemblages in other parts of the Atlantic Ocean did not follow this latitudinal pattern, but differences in composition still appeared to be related to differences in surface productivity (Henriques et al. 2002). Comparing upwelling areas in the northeastern Atlantic Ocean (Canaries, Cape Verde Terrace, Cape Verde Abyssal Plain) with eutrophic (Porcupine Abyssal Plain) and oligotrophic (Madeira Abyssal Plain) areas indicated that the abundance of demersal fish species below 3000 m depth (3200–4040 m) was greatly influenced by differences in surface productivity. Large macrourid species were highly abundant in the upwelling region, and the relatively abundant assemblage of deep demersal fish appeared to be supported by the high and seasonal productivity in this region (Henriques et al. 2002). In addition to abundance and size structure, the behaviour and swimming speed of abyssal fishes has also been linked to spatial and temporal variations in surface-water productivity (Priede et al. 1994), although the underlying mechanisms remain unclear.

3.2   Assemblage-based studies in New Zealand waters

There is little information on the diversity and composition of invertebrate or fish assemblages in New Zealand deep waters, i.e., below 1500 m depth. Data are generally restricted to species lists and

taxonomic descriptions from early scientific expeditions, such as the *Challenger* and *Galathea* (see section 2). In contrast to global studies, patterns of species diversity in relation to depth are largely unexplored, with too few samples collected below 1500 m depth to distinguish diversity patterns across this depth (Rowden et al. 2004). There are some assemblage descriptions for fauna below 1500 m depth, but these are generally a component of soft-substratum assemblage studies that encompass a wide and predominantly shallower depth range (e.g., McKnight & Probert 1997), and/or are part of interdisciplinary studies examining particular ecosystem processes (e.g., Nodder et al. 2003; Grove et al. 2006). Studies of the assemblages of hard substrata found below 1500 m, such as seamounts, have yet to be published in the peer-reviewed literature (Clark 2004), or do not distinguish samples taken from shallower depths to describe assemblage patterns (Rowden et al. 2004). Comprehensive investigations of chemosynthetic ecosystems in New Zealand waters, such as cold-seep and hydrothermal-vent assemblages, have been conducted, but are exclusively for sampling sites shallower than 1500 m depth (e.g., Baco et al. 2010). Assemblage studies that have sampled canyon habitats have done so to water depths of only a few hundred metres (e.g., Probert et al. 1979). Ecological research exclusively focused on fauna below 1500 m is limited to the Kermadec and Tonga Trenches (e.g., Blankenship et al. 2006; Jamieson et al. 2009a).

3.2.1   Chatham Rise slope

Of the few studies of benthic assemblages that include data from below 1500 m, the majority have focussed geographically on the Chatham Rise. These studies often include data from more than one sampling occasion and sometimes contain comprehensive datasets regarding physical and biogeochemical variables and soft-sediment benthic assemblages (meio- and macrofauna). Although these studies present valuable data from a New Zealand deep-sea habitat, their low taxonomic resolution has sometimes prevented detailed analysis of assemblage patterns (e.g., Nodder et al. 2007).

The Chatham Rise lies beneath the Subtropical Front, where subtropical water from the north encounters subantarctic water from the south, making this region highly productive, with frequently elevated primary productivity on the southern side of the rise (Bradford-Grieve et al. 1999). Owing to its high productivity, this region is also important in economic terms as it supports substantial deep-sea fisheries, i.e., for orange roughy (*Hoplostethus atlanticus*) and hoki (*Macruronus novaezelandiae*) (Bull et al. 2001).

McKnight & Probert (1997) examined epibenthic macrofauna that was sampled by sled trawl along several transects across the rise. Of a total of 40 stations sampled between 237 and 2039 m depth, five were below 1500 m. Faunal samples were sieved on 1-mm mesh and most were identified to species, before inclusion of 85 (of a total of 218) common taxa (present in two or more samples) in community analyses based on presence/absence data. The dominant taxa across all depths were echinoderms (52 species), followed by crustaceans (44 species) and molluscs (36 species), but there was no proportional breakdown or list of taxa for sites below 1500 m only.

Similarly, community analyses were conducted across the entire depth range sampled; these revealed three distinct epibenthic assemblages, two of which encompass 10 sites each and include the five deeper sites. One assemblage (termed 'Community B' by the authors) was present at sites between 462–1693 m and included one site below 1500 m (1660–1693 m depth, northern flank of the rise), whereas the other assemblage ('Community C') ranged between 799–2039 m and included the remaining four sites below 1500 m (two northern (1491–1915 m and 1687–2039 m) and two southern sites (1932–1963 m and 1600–1706)) in addition to shallower sites. Community B was represented by 42 species, of which eight were dominant in this assemblage, including six echinoderm (three ophiuroids, two holothurians, one echinoid) and two molluscan species (gastropods). Of a total of 49 species, Community C was characterised by 16 dominant species, which included 13 echinoderm species (five ophiuroids, five asteroids, three echinoids) and three molluscan species (two gastropods and one scaphopod). Since Community C included the deep-sea echinoderm taxa *Ophiomusium lymani*, *Porcellanaster* and *Urechinus*, the authors considered this assemblage to be abyssal. In their

interpretation of the observed species distributions, McKnight and Probert (1997) speculated that the observed differences in assemblages (including different depth ranges on either side of the rise) may be related to variation in seawater temperature and organic matter flux.

A meiofaunal study on the Chatham Rise investigated abundance and biomass between 350 and 2600 m depth in relation to physical and biogeochemical variables across the rise (Grove et al. 2006). Sampling was conducted on three occasions (autumn and spring 1997, summer 2000), and included sediment variables that potentially influence benthic meiofauna (e.g., grain size, water content, and potential food sources such as organic matter (in different forms), chloroplastic pigments, and bacteria). Mean meiofaunal densities ranged from 93 to 1454 individuals 10 cm^{-2} and mean biomass from 10.4 to 435.3 µg 10 cm^{-2} across the sampling sites. Lowest densities and volumes were at the deepest sites either side of the crest (2300 m North and 2600 m South) compared with highest values on top of the crest, usually at 450 m South. Both meiofaunal abundance and biomass estimates were generally higher on the southern side than at equivalent depths on the northern side of the crest. Between seasons, abundance values varied little, but biomass was considerably higher at all sites in autumn compared with spring and summer. In terms of assemblage composition, nematodes were numerically dominant at all sites (77–95% of all individuals), followed by harpacticoid copepods (3–12%) and nauplii (less than 10%); polychaetes and ostracods constituted fewer than 1–3%, with all other taxa reflecting fewer than 1% of the total number of individuals. Within the sediment (top 5 cm), meiofaunal abundance declined with increasing depth, with a concomitant shift in assemblage composition: whilst the top 1 cm on average contained 80% of non-nematode meiofaunal individuals, nematodes averaged 97% of all individuals in the 3–5 cm depth layer. Combining data from all sampling occasions resulted in significant negative correlations between meiofaunal parameters (e.g., total meiofaunal and total nematode density and biomass) and water depth, median grain size, and sediment carbonate content; there were positive correlations between meiofaunal variables and chlorophyll *a* concentrations. Nevertheless, when data were analysed separately for each season, the relationships between meiofaunal and sediment variables were inconsistent, providing no conclusive link between potential food sources (i.e., sediment organic matter content) and assemblage patterns. The authors suggested that the lack of a clear link may have been related to an inadequate assessment of food supply (as the measured organic matter variables were not synonymous with bioavailable and digestible organic matter), but also noted that it could reflect the complexity of the region in terms of bathymetry and hydrology (Grove et al. 2006). A companion study examined benthic processes associated with deep-sea ecosystem productivity in this region (see below under 4.4).

3.2.2 Kermadec and Tonga trenches

The *Galathea* reports include lists of species that were sampled from the Kermadec Trench and constitute the first and only records of a range of deep-sea organisms (below 1500 m water depth) from the New Zealand region, but they do not provide descriptions of assemblage composition. In a general study of hadal fauna, Wolff (1960) considered data from 15 trenches in the Pacific, Indian and Atlantic oceans, including the Kermadec and Tonga Trenches, to describe hadal communities (including hadopelagic fauna) below 6000 m water depth. His study included information from Russian expeditions that is generally difficult to access as it is either unpublished or published only in Russian reports. Although it did not present an overall analysis of assemblage structures within or between trenches, his report presented an overview of hadal fauna and environmental conditions (sediment, pressure, oxygen, salinity, temperature, food supply) encountered in trenches. Data were summarised across trenches for which there was sufficient information and appendices provided a comprehensive species list (by phylum for all trenches combined) and species data for each trench. The latter were presented by sampling depth (as dictated by the sampling at the time) with some overlap between depth of stations, but there was no overall assemblage description per trench. Further, there are some discrepancies between the total number of species listed and the breakdown of individual phyla, and as sampling effort varied greatly between and sometimes within trenches (across depths and expeditions), Wolff's (1960) comparisons need to be viewed with caution.

For the Tonga Trench (sampled by *Vitjaz* in the 1950s using a sled/trawl), 20 metazoan species (and one species of foraminiferan) were recorded from two stations between 9700 and 10 415 m, including polychaetes, porifera, nematodes, crustaceans (isopods, amphipods), molluscs (gastropods, bivalves) and echinoderms (holothurians). In the Kermadec Trench (sampled by both the *Galathea* and *Vitjaz* in the 1950s by sled/trawl), samples were collected at eight stations between 6180 m and 10 005 m. The highest number of metazoan species (32) was at 6660–6770 m depth, with 15 species (and one species of foraminiferan) collected at the deepest station at 9995–10 002 m depth. Species collected in the Kermadec–Tonga Trench system also represent a wide range of taxa, including actiniarians, scyphozoans, octocorals, asteroids, echiuroids, ophiuroids, hydrozoans, tunicates, tanaids, fish, bryozoans and barnacles. Comparing the distribution of hadal species faunal among trenches, Wolff (1960) highlighted that the Kermadec Trench has a considerably higher number of isopod and amphipod species than all other trenches investigated on the *Galathea* expedition, with the opposite case for echinoderms and polychaetes. Wolff (1960) also made special mention of highly abundant waterlogged lumps of pumice in the Kermadec Trench that bore an attached fauna of different species of hydroids, but the ecological significance of these hard substrata remains to be investigated.

More recently, sampling of the Kermadec and Tonga trenches took place as part of a series of ecosystem process studies (see below under 4.4)

4   ECOSYSTEM-PROCESS STUDIES

4.1   Global ecosystem-process studies

The collection of time-series and long-term datasets (over several years) and the inclusion of environmental variables (primary productivity, climate) and experimental manipulations (in situ and laboratory studies) have enabled the identification of some of the factors that influence deep-sea benthic communities and associated ecosystem processes. Food limitation plays a major role in deep-sea ecosystems, where benthic communities are greatly dependent on food input from overlying water, i.e., phytodetritus from primary production in the euphotic zone (Gage & Tyler 1991; Kaiser et al. 2005). In this context, surface productivity has received considerable attention in studies aimed at elucidating the role of pelagic-benthic coupling in determining the composition and functioning of abyssal communities (e.g., Billett et al. 1983, 2010; Ruhl & Smith 2004; Kalogeropoulou et al. 2009). Seasonal phytoplankton blooms are particularly important as they result in significant phytodetritus deposition events on the seafloor, and this particulate organic carbon influx represents a substantial (often episodic) food supply for abyssal organisms (Billett et al. 1983, see reviews by Gooday et al. 1990; Beaulieu 2002). As this supply is readily exploited by benthic fauna, episodic events have been shown to affect the recruitment, abundance and biomass of different components of the benthic community (e.g., Smith et al. 1993; Billett et al. 2001; Wigham et al. 2003). Epibenthic and infaunal deposit-feeders respond quickly to elevated food levels, and drastic increases in their densities result in the rapid processing of large quantities of organic matter (Witte et al. 2003; Bett et al. 2001). For example, on the Porcupine Abyssal Plain, increased abundance of megafaunal deposit-feeders and their sediment reworking reduced sediment turnover times from 2.5 years to under six weeks (Bett et al. 2001). This processing of substantial amounts of organic matter by deposit-feeders has important consequences for nutrient cycling in abyssal communities and associated trophic groups.

4.1.1   Pelagic-benthic coupling

In the northeastern Atlantic and northeastern Pacific Oceans, long-term time-series data have been collected since 1989 to assess the variability of abyssal fauna in relation to downward organic matter flux (e.g., Smith & Druffel 1998; Billett et al. 2010). A series of long-term studies on the Porcupine Abyssal Plain (northeastern Atlantic Ocean) investigated the impact of seasonal pulses and inter-annual variation of detrital material to abyssal depths, including different components within the benthic community (e.g., meiofauna: Kalogeropoulou et al. 2009; polychaetes: Soto et al. 2009). Observations between 1989 and 2005 show that this area is characterised by regular, strong seasonal

input of organic matter to the seafloor, with significant long-term and large-scale effects evident in the benthic community (Billett et al. 2010). Abundance of megafaunal species (actiniarians, annelids, pycnogonids, tunicates, ophiuroids, and particularly holothurians) showed drastic increases in 1996, with two holothurian species increasing in abundance by more than two orders of magnitude (Billet et al. 2001). The spectacular and long-lasting increase in one holothurian species, *Amperima rosea*, which became dominant over a wide area, prompted the authors to term the observed shift within the megafaunal assemblage the '*Amperima* event'. Total megafaunal biomass did not show a corresponding increase — the dominant holothurian species exhibited discernible decreases in body size — indicating that the higher densities resulted from increased recruitment because of elevated food availability (Billett et al. 2001). Similar population effects were observed for meio- and macrofaunal assemblages in the area, indicating that the change was uniform, affecting the entire benthic community at the same time (Galéron et al. 2001; Vanreusel et al. 2001; Kalogeropoulou et al. 2009; Soto et al. 2009). The underlying causes for these major changes appeared to be linked to environmental factors, particularly large-scale changes in the flux of organic matter to the seafloor, which were recorded at different times over the study period (Billett et al. 2010).

Similar to the findings from the northeastern Atlantic Ocean, abyssal megafauna in the northeastern Pacific Ocean also underwent major changes in assemblage structure, which coincided with a significant El Niño/La Niña event between 1997 and 1999 (Ruhl & Smith 2004). Analysis of data collected over a 14-yr period from 1989 to 2002 showed a drastic decline (2–3 orders of magnitude) in the abundance of two echinoderm species (holothurians) and a concomitant increase (1–2 orders of magnitude) of several other echinoderms (holothurians, echinoids, ophiuroids) after 1998. The changes in densities appeared to be related to food supply, with species-specific positive or negative responses to the amount of particulate organic carbon present. The latter varied in relation to seasonal and inter-annual variations in surface productivity, which in turn were influenced by climate, thereby establishing a link between climatic variations and abyssal assemblages (Ruhl & Smith 2004). The recognition of this link has prompted warnings that climate change and human-induced modifications to the productivity of surface waters (i.e., ocean fertilisation) will impact on the biodiversity, structure, and function of abyssal ecosystems (Smith et al. 2008).

4.1.2   Trophic interactions and food-web studies

Following the general grouping of different organisms into broad feeding types, in situ observations and the development of chemical and molecular techniques (e.g., stable-isotope signatures, fatty-acid compositions, genetic markers) have allowed more precise assessments of trophic pathways and interactions in abyssal food webs. A long-term study of trophic interactions in the northeastern Pacific Ocean between 1989 and 2004 examined temporal changes in abyssal benthopelagic fish abundance (Bailey et al. 2006b). Towed camera-sled surveys at 4100 m documented fluctuations in the density of the dominant macrourids (*Coryphaenoides* spp.) with a substantial overall increase (more than 100%) in annual mean density over the study period, but no seasonal variation in fish numbers. Analysis of 15-yr time-series data of climate, productivity, particulate flux and abundance of primary and secondary consumers (mostly echinoderms and fish, respectively) showed that *Coryphaenoides* spp. abundances were significantly correlated with the total abundance of epibenthic infauna (echinoderms), but not surface climate nor particulate flux. Changes in macrourid density corresponded with those in echinoderm density and appeared to be caused by macrourids migrating to and from the study area in response to changing availability of echinoderm prey. This link between benthic invertebrate and benthopelagic fish indicates bottom-up control on animal abundance in the abyssal system. Furthermore, as producers in the photic zone are not directly available to consumers, and both primary and secondary consumers are dependent on allochthonous food sources, the authors concluded that abyssal systems are more similar to terrestrial systems than to other marine ones (Bailey et al. 2006a).

Iken et al. (2001) examined trophic interactions and food-web structure in the benthic community on the Porcupine Abyssal Plain during the *Amperima* event in 1996 and 1997. Using stable-isotope

signatures, they analysed meio-, macro- and megafaunal samples to identify different trophic groups and their food sources. The majority of macro- and megafaunal organisms were deposit-feeders, followed by scavengers/predators and suspension feeders. The latter trophic group fed on resuspended matter and also on pelagic prey, whereas benthic deposit-feeders, in particularly holothurians, used different feeding strategies to exploit the organic matter resource: highly mobile species were able to detect and exploit high-quality phytodetritus efficiently, whereas less mobile holothurians consumed more refractory material. Predators/scavengers were split into two main trophic pathways, with one group of invertebrate predators preying on deposit-feeders, representing end consumers in an exclusively benthic food web, whereas the second group consisted of highly mobile benthopelagic species, which feed on pelagic prey and represented a link to the benthopelagic food web.

4.1.3   Sediment community respiration and carbon models

Assessments of sediment community oxygen consumption (SCOC, also called community respiration) rates provide an important link between surface water and benthic productivity, and are crucial for the development of carbon models to establish pathways between different trophic levels. SCOC is a measure of biotic activity by aerobic bacteria, protozoans and metazoans (meio- and macrofauna), and is used as a proxy for organic-carbon remineralisation. It has been part of a number of ecological deep-sea studies, with measurements obtained via in situ respirometers (e.g., used at abyssal northeastern Pacific sites, Smith 1992) or benthic incubation chambers (in situ and/or shipboard, e.g., Duineveld et al. 2001; Nodder et al. 2007). Using this measure, Rowe et al. (2008a) established that sediment-oxygen consumption rates on the Sigsbee Abyssal Plain (NE Gulf of Mexico, approximately 3500 m) were two orders of magnitude lower than on the adjacent continental slope (450–2750 m). As the observed rates in the abyss were substantially higher than sustainable by organic carbon input from surface waters, a significant proportion of organic matter to the abyssal communities seemed to be imported laterally from the continental margin (Rowe et al. 2008a). Using SCOC data in association with biomass estimates for different benthic community components at this site also enabled an estimation of carbon flow through the abyssal food web via a composite carbon model (Rowe et al. 2008b). Model estimates showed that total amount of carbon and associated fluxes decreased with increasing depth, which was more pronounced in larger faunal groups (fishes and megafaunal invertebrates) leading to a predominance of small-sized biota (bacteria and meiofauna) (Rowe et al. 2008b).

4.1.4   Disturbance and (re)colonisation

Biogenic disturbance (bioturbation) is considered a key ecosystem process in low-energy depositional environments such as the deep sea, where it has been recognised as a potentially important determinant of biodiversity (Dayton & Hessler 1972; Smith & Demopoulos 2003). It has a direct impact on physical, chemical and biological processes, as it influences nutrient fluxes between the sediment and overlying water, and greatly enhances erosion potential on steep slopes and canyons (Gage & Tyler 1991; Lohrer et al. 2004). In deep-sea environments, bioturbation rates have been measured in relation to particle size and the presence of different bioturbating taxa (e.g., Wheatcroft 1992; Turnewitsch et al. 2000), but its ecological repercussions remain largely understudied.

The first large-scale, long-term impact assessment of disturbance associated with manganese-nodule mining was in the abyssal Pacific Ocean (4160 m, Peru Basin) (see summary in Thiel et al. 2001). Repeated experimental disturbance of a large area (3.6 km diameter) was followed by a long-term (12-yr) monitoring programme to assess infaunal recoveries over different periods of time after the simulated mining activities. Lateral migration facilitated infaunal recovery over a small spatial scale (1 m) within three years, with densities returning to similar values as those of undisturbed sediment (Borowksi & Thiel 1998). Infaunal species diversity, however, did not exhibit similar recovery and the large-scale nature of mining operations make it likely that recovery times of infaunal communites may be decades. A follow-up study of this project is ongoing (Thiel et al. 2001).

Colonisation and recolonisation experiments have also been conducted on a smaller scale by placing azoic sediment (review in Smith & Hessler 1987) and artifical (e.g., glass-sponge mimics, Beaulieu 2001b) and natural substrata/food sources (whale carcasses, plant material, e.g., Baco & Smith 2003) on the seafloor. These experiments have been aimed at determining assemblage compositions associated with these substrata (as discussed above under 3.3) and colonisation/succession rates in deep-sea habitats. In general, deep-sea colonisation rates in soft-sediment communities are slow and succession rates unpredictable, whereas those of hydrothermal-vent communities seem strongly influenced by physical processes. The complex nature of these processes requires further study to determine their importance in structuring deep-sea communities (Smith & Hessler 1987).

4.2   Ecosystem-process studies in New Zealand waters

4.2.1   Pelagic-benthic coupling

A multidisciplinary study in the Chatham Rise region examined benthic processes associated with deep-sea ecosystem productivity, using comprehensive datasets for a range of biological and environmental variables (Nodder et al. 2003). Based on an extensive sampling regime over three different seasons between 1997 and 2000, Nodder et al. (2003) give a detailed description of the sedimentary environment, benthic biomass and benthic activity across the Chatham Rise. They assessed meio-, macrofaunal (autumn only) and bacterial biomass and a range of sediment parameters, with sites ranging from 350 m depth on the crest of the rise to 2300 and 2600 m on its northern and southern side, respectively. In addition to benthic sampling, shipboard incubations were used to determine bacterial productivity and oxygen consumption of the sediment community (SCOC), which also facilitated the development of a simple carbon-budget model. Their findings showed that sediment properties were relatively uniform at the shallower sites (less than 1200 m water depth) across the rise and consisted of silty sand with moderate carbon and organic contents. Benthic biomass was highest on the crest and on the shallow (above 1200 m) southern flank of the rise, compared with sites at equivalent depths on the northern side. Oxygen consumption and bacterial production rates followed a similar trend, although the spatial patterns of the latter varied across seasons. The observed spatial variability appeared to be related to the flux of increased labile organic matter from the productive Subtropical Front to the seafloor at the upper southern sites. The deepest sites were distinctly different from the shallower sites, with benthic patterns reversed across the rise: at the southern sites (2300 and 2600 m), low benthic biomass was associated with carbonate-dominated muddy sands and low organic content, whereas the deepest northern site (2300 m) had uncharacteristically high macrofaunal biomass, low meiofaunal biomass and organic-rich muddy sediments. Organic-matter remineralisation rates and bacterial production were moderately high at northern sites, reflecting relatively high organic sediment content, compared with low values in the south. These deeper sites appear to be less influenced by the Subtropical Front than by mesoscale eddies (e.g., Southland Front, Wairarapa Eddy), bottom currents and geomorphic processes (i.e., slope mass wasting) in the North and carbonate sedimentation in the South.

4.2.2   Trophic interactions and food-web studies

In New Zealand waters, there have been four recent studies in the Kermadec and Tonga trenches that considered trophic interactions in deep-sea systems. Two companion studies conducted in the Kermadec and Tonga trenches examined the vertical zonation and foraging strategies of scavenging amphipods between 5155 and 10 787 m depth (Blankenship et al. 2006; Blankenship & Levin 2007). The scavenging amphipod assemblages were similar between the two trenches and dominated by four species (*Eurythenes gryllus*, *Hirondellea dubia*, *Scopelocheirus schellenbergi*, and *Uristes* n. sp.) that were captured in baited traps at different sites along the trenches. Their distributions revealed clear vertical partitioning of the trench habitat, with each species occupying a distinct vertical zone. The species occurring at greatest depth, *Hirondellea dubia* and *Scopelocheirus schellenbergi*, also showed

an ontogenetic shift in depth preference, with early instars exclusively found at the shallowest depth of each species' vertical zone. Species diversity and evenness were highest between 7349 and 8732 m, and only *Hirondellea dubia* was captured at depths below 9273 m (Blankenship et al. 2006). A companion study used DNA analysis and stable-isotope signatures to examine the foraging strategies and diet of the captured amphipod species in these trenches (Blankenship & Levin 2007). The findings show that the amphipods were not restricted to scavenging, but each species also employed other foraging strategies, such as detritus-feeding and predation (e.g., on other amphipods). Feeding strategies also varied with depth, which seemed to be driven by interspecific competition at depths where species co-existed. One species (*Hirondellea dubia*) also switched feeding mode between trenches, possibly owing to the different food supply driven by differences in productivity in the water overlying each trench. In addition, both *Hirondellea dubia* and *Uristes* sp. nov. showed ontogenetic shifts in diet, with detritus-feeding prevalent in juveniles. Based on these data, the authors developed conceptual hadal food webs for this trench system, differing in relation to depth zones and the trench involved (Blankenship & Levin 2007). These two studies are the first ecological investigations that have been focused on the hadal ecosystem. The subsequent use of baited video landers at hadal depths (at around 7000 m) in these trenches (and other trench environments) provides a direct link between the food web proposed by Blankenship and Levin (2007) and higher trophic levels (Jamieson et al. 2009a, b). The first in situ observations of feeding and activity of hadal fish below 6000 m in the Kermadec and Tonga Trenches document that the snailfish *Notoliparis kermadecensis* predominantly feeds on scavenging amphipods, implicating this species as a top predator in the trench food web (Jamieson et al. 2009a). Even though decapods are known from these depths (see chapter 2.3) Jamieson et al. (2009b) provided the first data via baited camera landers. The prawn *Benthesicymus crenatus* was observed at depths between 6007 and 7703 m in different trenches, including Kermadec, where the caridean prawn *Acanthephyra* sp. was also observed at 6007 and 6890 m depth. *Benthesicymus crenatus* represents another important top predator in the hadal system as it appears to prey on scavenging amphipods, which in turn constitute the main component of the food web at these depths (Blankenship & Levin 2007; Jamieson et al. 2009b).

4.2.3   Sediment community respiration and carbon models

Through the application of a simple carbon budget model, Nodder et al. (2003) were able to estimate the carbon requirements of the benthic communities that they studied on the Chatham Rise and compare them to particle-flux data collected in the study region by Nodder & Northcote (2001). This comparison highlighted carbon-input deficiencies for benthos on the southern Chatham Rise in autumn and summer, with a discrepancy of more than 80% between carbon demands and organic particles supplied from surface waters. As a consequence, carbon requirements of the benthic community on this side of the rise are either met by organic matter supplied from other sources (lateral), or the benthic fauna is adapted to persist on a low food supply for extensive periods of time (Nodder et al. 2003).

4.2.4   Disturbance and (re)colonisation

There have been no studies in New Zealand waters that have examined the effects of biogenic or anthropogenic disturbance on deep-sea ecosystems. The latter type of disturbance is particularly relevant in view of the extensive occurrence of polymetallic nodules in the New Zealand region and their potential for exploitation.

5. INCIDENTAL STUDIES

On occasion, non-ecological studies mention the presence of deep-sea fauna and/or contain images of the sediment surface that include benthic animals. These incidental records are of limited value, but in some areas provide the only information concerning deep-sea animals. In New Zealand, two published geological studies in the Campbell Plateau area beneath the Pacific Deep Western Boundary Current provide such records of deep-sea fauna in seafloor images (Carter & McCave 1997; Wright et al. 2005). Images taken at 4400 m in the Bounty Fan showed a single ophiuroid on a bioturbated sediment surface; in another image, faecal material on top of the sediment (at 5100 m depth) was attributed to holothurians by Carter & McCave (1997). Similarly, images taken by Wright et al. (2005) showed single holothurians at sites between 4000 and 5000 m depth and evidence of bioturbation. In addition to these published images, there are a large number of unpublished images of nodule fields that were taken during geological surveys. These images have yet to be analysed for the presence of epifauna at the sediment surface and on nodules.

Data on bacterial biomass and productivity, meiofaunal and macrofaunal biomass, sediment community oxygen consumption (SCOC, using in situ benthic-lander incubation chambers) and sediment parameters have been collected at two deep-water sites on the southern side of the Bounty Trough (approximately 2800 m water depth, 46°40' S, 178°30' E) and on the Hikurangi Plateau (approximately 3100 m water depth, 41°00' S, 178°30' E). The data were collected in 2001, in an ongoing collaboration between NIWA, the Royal Netherlands Institute for Sea Research (NIOZ, Texel), University of Waikato and University of Otago, but are presently unpublished. There are also unpublished video-image, near-bed current-meter, transmissiometer and fluorometry, downward particle flux and SCOC data collected at these same sites over the period of a year (2001–2002). Recently (2007–2008), NIWA researchers and collaborators have begun sampling the sediment communities (bacteria, meiofauna, macrofauna) at these sites on periodic voyages to recover and redeploy the deep-ocean moorings.

## 6. AVAILABILITY OF DATA THAT HAVE NOT BEEN ANALYSED

In this section we evaluate metadata from the NIWA Invertebrate Collection and Te Papa collection and databases and NIWA's image holdings to assess the availability of data from depths below 1500 m that have not so far been analysed for biodiversity or studies of ecosystem processes.

6.1 NIWA Invertebrate Collection — *Specify* database

The NIWA Invertebrate Collection (NIC) *Specify* database currently holds 2348 records of deep-sea invertebrates found at depths ranging from 1500–9520 m. Of these, 1637 records were found inside the New Zealand region, and 608 were from the Ross Sea in the Ross Dependency (see Figures 13 and 14).
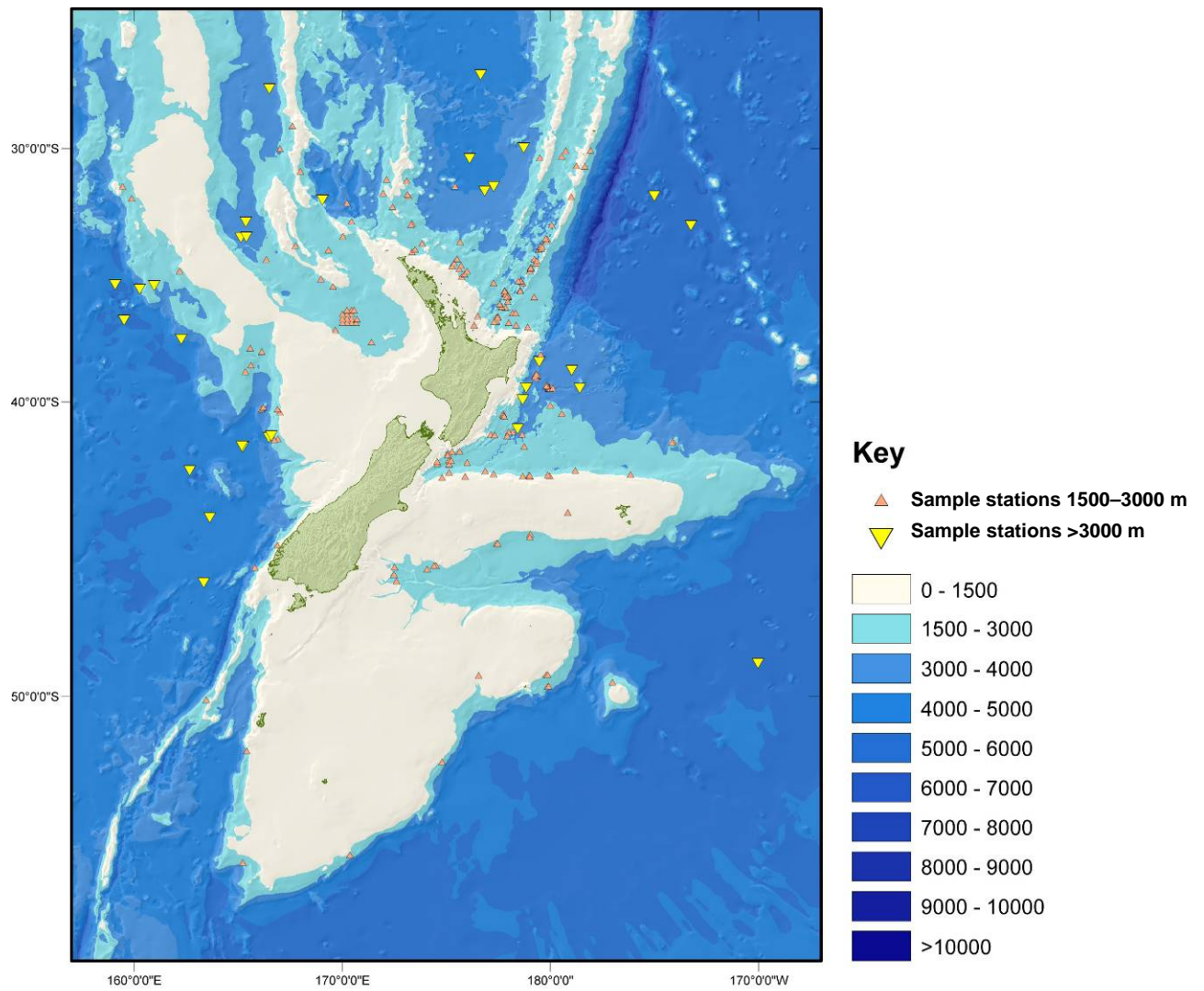
Figure 13: Benthic invertebrate samples below 1500 m in the New Zealand region taken from the NIWA *Specify* database.
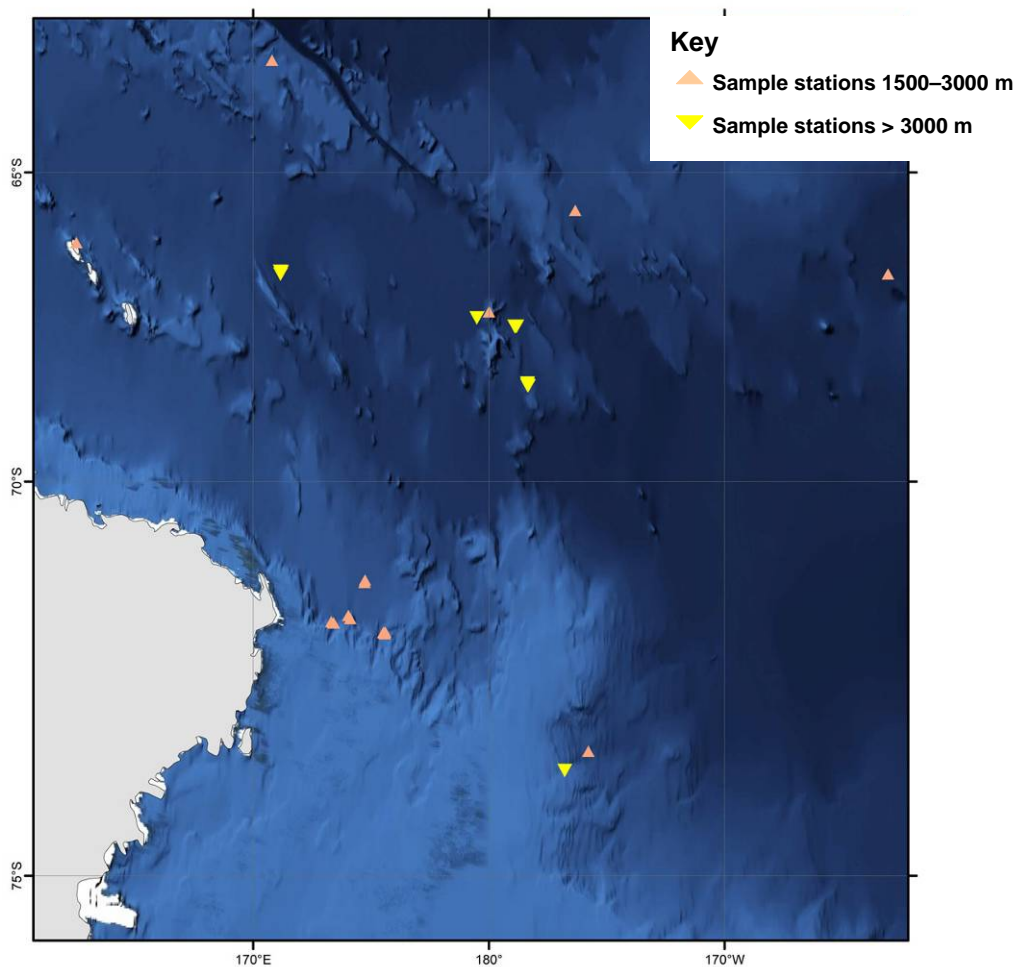
Figure 14: Invertebrate samples from below 1500 m in the Ross Sea from the NIWA *Specify* database.

From the New Zealand museum data, 19 phyla are represented, with most records from 1500–1999 m (Table 6). The deepest station in the New Zealand region was at 5852 m; only the amphipod *Gitanopsis squamosa* (Thompson, 1880) was recorded there. Arthropods comprise the majority of the records, followed closely by echinoderms (Table 7).

Table 6: Number of records of abyssal (below 1500 m) invertebrates in the NIWA Invertebrate Collection *Specify* database and the number of phyla these represent.

Depth strata (m)	No. of invertebrate records	No. of phyla
1 500–1 999	876	18
2 000–2 999	615	10
3 000–3 999	88	9
4 000–4 999	52	5
5 000–5 999	7	2
6 000–6 999	0	0
7 000–7 999	0	0
Totals	1637	19

Table 7:   **Number of records in the NIWA Invertebrate Collection *Specify* database of phyla from abyssal depths (below 1500 m) found in New Zealand waters.**

Phylum	No. of records in *Specify*	No. of records identified to species level
Annelida	49	9
Arthropoda	610	142
Brachiopoda	3	1
Chaetognatha	3	0
Cnidaria	166	23
Entoprocta (Bryozoa)	42	22
Echinodermata	529	112
Hemichordata	1	1
Kinorhyncha	4	1
Mollusca	103	37
Nematoda	1	0
Nemertea	1	0
Platyhelminthes	2	0
Porifera	79	14
Priapulida	1	0
Protozoa	22	8
Sipunculida	9	0
Urochordata (Ascidiacea and Thaliacea)	6	1
Totals	1637	370

Invertebrate data in *Specify* represent only a small proportion of sample lots housed in the NIWA Invertebrate Collection (NIC). It is estimated that only one third of all samples held in the collection are currently registered, hence a significant amount of data on the deep-sea benthos remains unavailable for the purpose of this study.

Table 7 shows the small number of samples, split by phylum, that have been identified to species-level. Only about 20% of Annelida, Arthropoda, Porifera and Echinodermata have been identified to species. The Mollusca are the best-studied group, with 36% of the samples identified to species. No Chaetognatha, Nematoda, Nemertea, Priapulida or Sipuncula are known to species level.

Of the total of 1637 lots in the NIC registering below 1500 m from New Zealand waters, only 370 lots have registered species names. Consequently, nearly 80% of the currently available samples remain incompletely identified; of these, 771 samples are identified only to genus. A total of 404 samples are identified to family level only, 205 to order, 82 to class, and 26 lots remain identified only to phylum. These existing specimen collections provide a valuable resource and further identification of this available material will provide additional information for questions related to New Zealand's deep-sea fauna.

6.2   NIWA image and video archives

NIWA's *Tsunami* and MFish's *Trawl* databases were searched to identify the number and location of stations within the New Zealand region at depths below 1500 m where cameras had been deployed to recover still and video images of the seabed. A comprehensive search of hard-copy and digital images of the New Zealand seabed below 1500 m was also made of NIWA archives at Greta Point,

Wellington. Because images referenced from these databases span several decades, a number of different camera systems and many different research programmes, finding the actual images for the present review was not always straightforward. Since NIWA's Deep Towed Imaging System (DTIS) became operational in 2006, video and still images have been archived centrally, either on network servers (for still images), or in a physical archive at Greta Point (video tapes), with backups and working copies on local hard-disc drives (HDD). Previously, surviving research images, often recorded on conventional silver halide film either as negatives or prints or both, were stored independently by the groups or individuals responsible for particular projects. The legacy of inadequate coordination of storage is a significant problem for tracing older photographic material and one that is being addressed by the development of the NIWA image database *Atlas*. A problem remains concerning the resources required to locate, digitise and load historical images and metadata into *Atlas,* but projects such as this provide an impetus to achieve at least the first of these steps.

6.2.1 Still images

A total of 8012 still images (prints, negatives, digital files) were located from sampling stations within the depth range 1500 to 4999 m in New Zealand's EEZ and the Ross Sea (Figure 15) . It is of note, however, that the database records indicate that more images exist, or at least were taken, than have been located during the present project. These include 13 stations from depths greater than 5000 m (Table 8). Photographic sampling was concentrated in the shallower end of the depth range, 1500–1999 m, which encompasses almost half of the available images (Figure 13, Table 9). This is to be expected given the technical difficulties of working at greater depths and the concentration of research effort on the continental shelf and slope regions of the EEZ.

The total number of images is heavily skewed towards more recent voyages. This is because the DTIS system is capable of capturing many more images than could earlier cameras. Thus, whereas one station visualised using NIWA's earlier *Benthos* stills camera might capture fewer than 20 images, a typical DTIS station captures approximately 240 still photographs. Formal, quantitative analyses of still images was also very limited before 2006. If analysed at all, images were used for qualitative descriptions of geology (e.g., Wright et al. 2002), and, for depths below 1500 m, we have found no reports that incorporate analyses from photographs.

The only NIWA-held photographic samples from deeper than 1500 m in the Ross Dependency were those collected during the 2008 International Polar Year expedition (TAN0802) using DTIS. Nine stations deeper than 1500 m were sampled on this voyage, collecting 2244 images and nine hours of video. These are currently being analysed under MFish project IPY200701 (Table 10).

Image quality in seabed photographs can be highly variable and is dependent both on the optical resolution of the camera system and on the conditions during deployment. For silver halide film systems, the subsequent development and printing processes are also critical. It was beyond the scope of this report to analyse images in detail, particularly as many exist only as 35 mm negatives, but we made rapid visual assessments of the quality of still images from all stations in order to evaluate their potential use for further research. Images from only three stations are clearly of poor quality and most others appear to be of a quality that will allow some analysis, given funding (see Table 11).

6.2.2 Video

There are relatively few stations where video footage has been taken at depths below 1500 m in the New Zealand region. Since 2006, NIWA has been using DTIS, which produces high-definition digital video (approximately one hour per station). Almost all of the available deep-sea video footage is from DTIS deployments, and most of these are abyssal and deep continental-slope stations from the 2008 IPY expedition to the Ross Sea. Some deep-water video from the Kermadec Ridge taken from

submersibles and ROVs on visiting research vessels (e.g., RV *Ka'imikai-O-Kanaloa* voyage: Table 1) is also available on analogue VHS tapes, but most of this is from depths shallower than 1500 m. Because most video samples are recent and have been aquired to address specific research goals (e.g., Ocean Survey 20/20 habitat characterisation), the greater proportion of them that are centrally archived have been, or are in the process of being, analysed than is the case for still images.

Table 8: Camera deployment stations registered in NIWA's *Tsunami* database compared with the number of stations for which physical images (prints, negatives, digital files, video) were located during this study. (* this figure includes images from 19 stations not recorded in the database).

Depth strata (m)	Camera stations in Tsunami database	Stations for which images retrieved	Stations for which video retrieved	% of stations with images/ video retrieved
1 500–1 999	98	77	8	78%
2 000–2 999	68	53	2	77%
3 000–3 999	39	27	3	69%
4 000–4 999	33	28	0	88%
5 000–5 999	21	8	0	38%
6 000–6 999	1	0	0	0%
7 000–7 999	1	0	0	0%
Totals	261	193*	13	

Table 9: Images (prints, negatives, digital files) stored at NIWA sorted by type and depth strata. Some stations have negatives or prints only and others have negatives, contact sheets and prints. The right-hand column shows the total number of unique images per depth stratum.

Depth strata (m)	35 mm negative	Black and white print	Black and white contact sheets	Digital images	Total images (35 mm negatives + digital)
1 500–1 999	1611	931	4	2025	3636
2 000–2 999	1305	624	144	502	1807
3 000–3 999	384	129	5	751	1135
4 000–4 999	1276	20	4	0	1276
5 000–5 999	158	11	0	0	158
6 000–6 999	0	0	0	0	0
7 000–7 999	0	0	0	0	0
Totals	4734	1715	157	3278	8012

Table 10: Ross Sea camera stations deeper than 1500 m (data from *Tsunami* database). All stations were from voyage TAN0802 and used the Deep Towed Imaging System (DTIS).

Depth strata (m)	No. of camera stations	No. of images	Hours of video
1 500–1 999	5	1237	5
2 000–2 999	1	257	1
3 000–3 999	3	750	3
Totals	9	2244	9

Table 11: Image quality for recovered photographs grouped by station. Images were assessed by eye and graded per station as being one of three categories: poor = neither substrates nor biota are discernable; moderate = substrates but not biota can be determined; good = substrates and fauna clearly visible. NB. This table is an indication only of image quality. Grades are assigned on a gross basis by station and thus may not apply to all images in a station.

Depth strata (m)	Poor	Moderate	Good
1 500–1 999	3	50	24
2 000–2 999	0	33	20
3 000–3 999	0	19	8
4 000–4 999	0	12	16
5 000–5 999	0	6	2
Totals	3	122	73
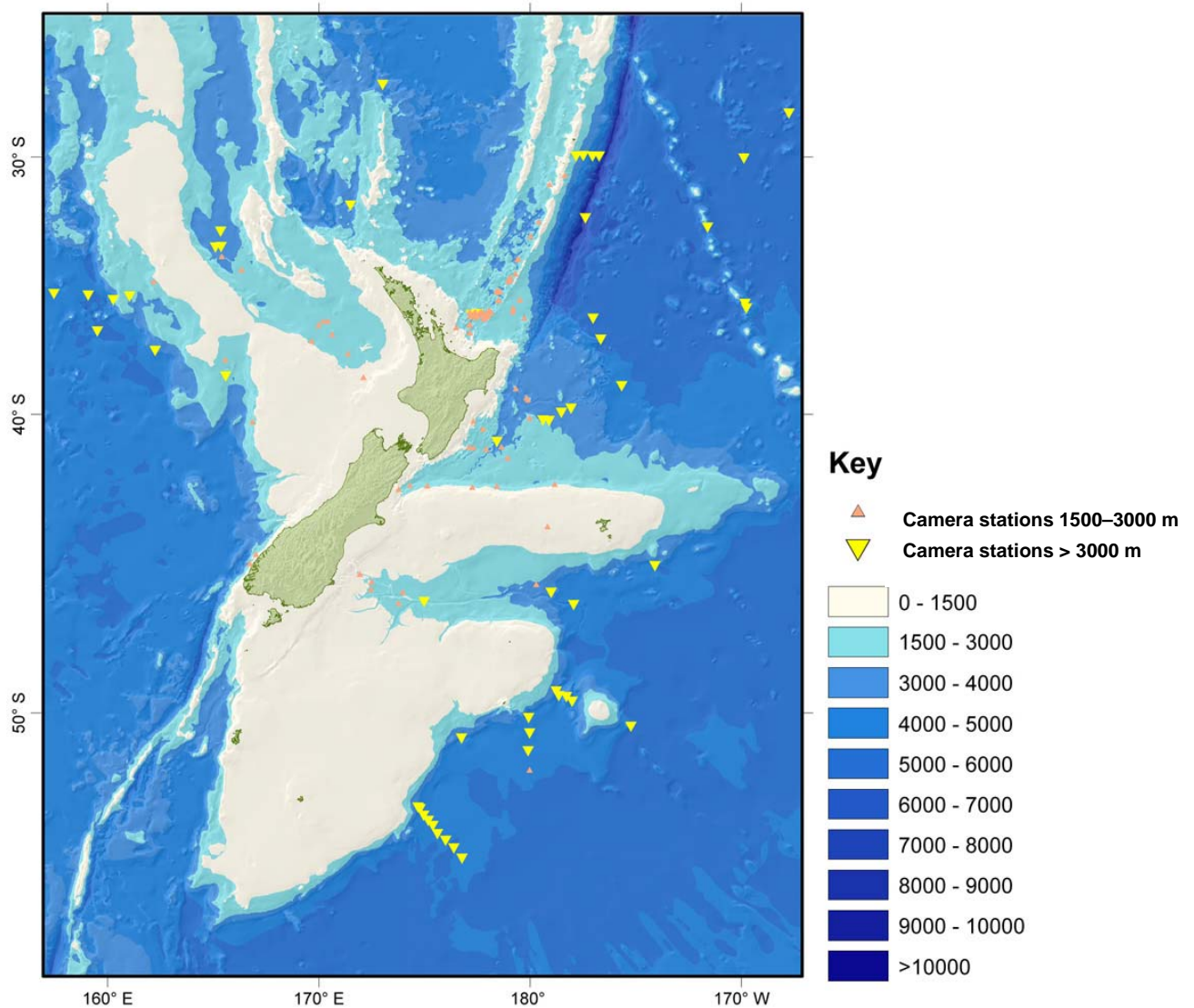
Figure 15: Camera station records in the New Zealand region below 1500 m taken from the NIWA *Tsunami* database.

6.3 Ministry of Fisheries *Trawl* database

Records below 1500 m were extracted from the Ministry of Fisheries *Trawl* database managed by NIWA (Figures 16,17), which is used to record catches of fish and invertebrate species from all trawling gear. The records in *Trawl* from samples below 1500 m date from 24 September 1989 to the present, with the earliest record from depths shallower than 1500 m in *Trawl* dating back to 23 Febuary 1960. Various mesopelagic species such as lantern fish (Myctophidae) and cephalopods, caught during trawling through the water column, have been removed so that only records of benthic fishes and invertebrates are included in the further summary of data. There will be duplication of some data between invertebrate records held in *Trawl* and *Specify* and in fish records held in Te Papa's *KE EMu* database. A larger number of records in the 1500–1700 m depth range reflect the greater trawling effort in shallower waters; this creates a biased impression that there are a diminishing number of faunal groups present with increased depth.
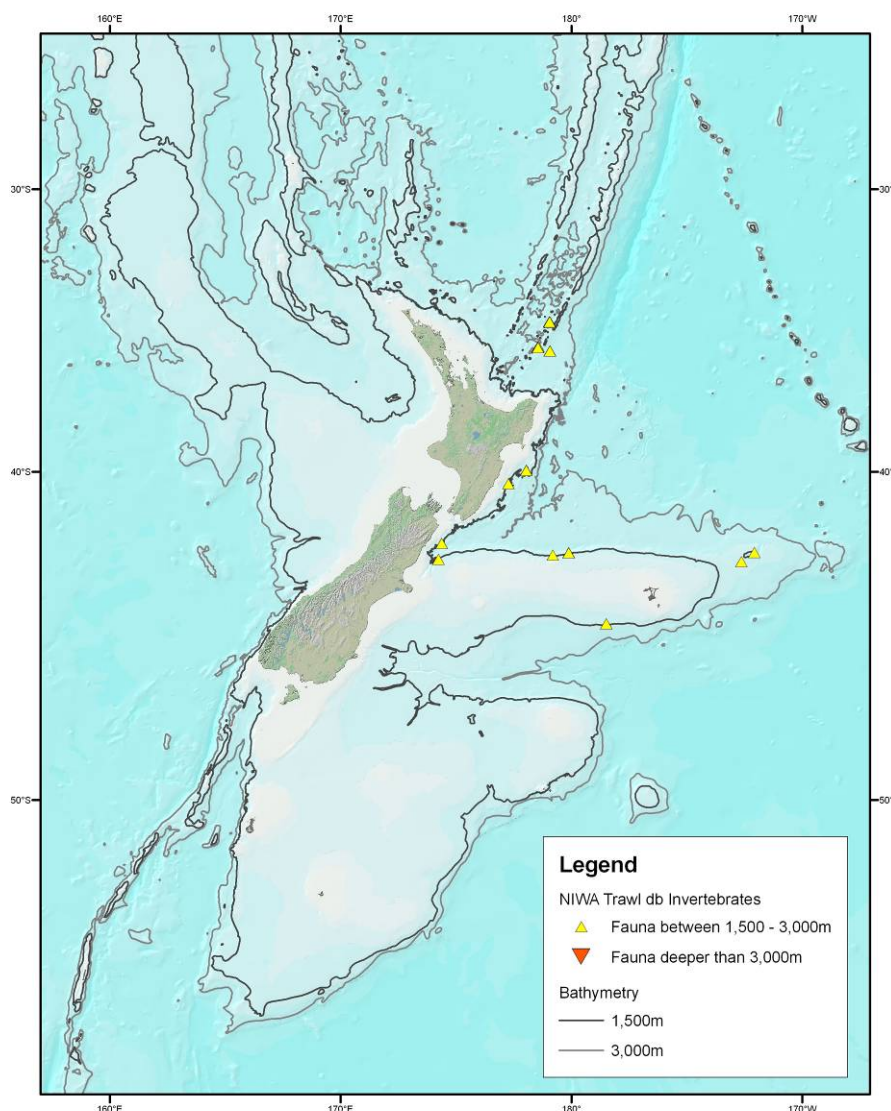
Figure 16: Benthic invertebrate samples below 1500 m from the Ministry of Fisheries *Trawl* database.
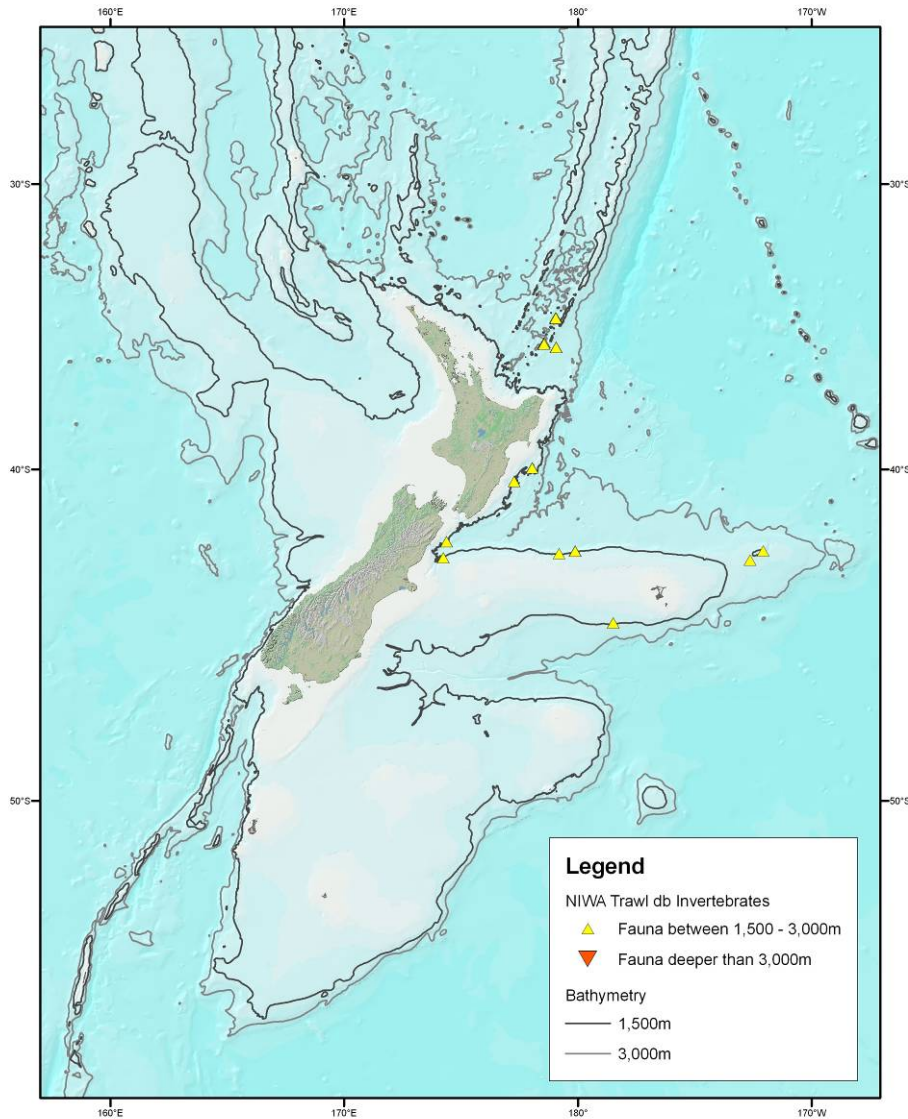
Figure 17: New Zealand fish samples below 1500 m from the Ministry of Fisheries *Trawl* database managed by NIWA.

The deepest identified fish record from the *Trawl* database for the New Zealand region is of the halosaur *Halosauropsis macrochir*, caught at 1850 m. Teleosts are the highest-represented faunal group (Table 12), which is to be expected as they are more often targeted. All groups show a reduction in numbers of records with increasing depth, with no records exceeding 1850 m for any of the three fish groups. Increased trawling effort in shallower waters may provide bias towards a larger number of records found in the shallower 1500–1700 m depth range, rather than a natural decrease in group because of depth effects (Table 12). Diverse benthic invertebrates are caught in association with the fish caught by the trawl gear and invertebrate records are more numerous than the other groups at depths greater than 2000 m (Table 12). The deepest invertebrate record in the *Trawl* database for the New Zealand region was a crinoid (sea lily) at 2120 m. These invertebrate records are likely to appear in the NIC *Specify* database.

Table 12: Number of records in the Ministry of Fisheries *Trawl* database of fish and invertebrates from abyssal depths (below 1500 m) in New Zealand waters.

Depth strata (m)	No. of records of chimaeras (Holocephali)	No. of records of elasmobranchs	No. of records of teleosts	No. of records of benthic invertebrates
1 500–1 599	10	16	117	54
1 600–1 699	1	2	24	46
1 700–1 799	1	1	9	0
1 800–1 899	0	0	1	10
1 900–1 999	0	0	0	0
2 000–2 099	0	0	0	12
2 100–2 199	0	0	0	28
Total records	12	19	151	150
Total records identified to species level	6	8	133	5

Forty-six trawl records were recovered from the Antarctic region, comprising only records from the recent IPY-CAML 2008 Biodiversity Survey in the Ross Sea. The deepest record from *Trawl*, the rat-tail *Coryphaenoides ferrieri*, was from 3490 m in the Southern Ocean. These data also appear in the Te Papa records and will be discussed further below.

Fish are mostly identified to species in the *Trawl* database, with three-letter MFish codes available for most of those caught (80% of the records). However, the number of records with species-specific codes for invertebrates is low (about 3% of records). Class- and order-level codes are most commonly used for invertebrates (e.g., ASR for Asteroidea, NAT for Natant decapod, etc.).

Trawl data feed into both NIWA's *Specify* (invertebrate) and Te Papa's *KE EMu* (fish) databases when physical specimens are returned to the collections of either institution. However, data from stations where 'known' or common species are discarded at sea, and no voucher specimen is retained for deposition in a museum collection, are not used to advance taxonomic or phylogeographic research.

## 6.4 Museum of New Zealand Te Papa Tongarewa *KE EMu* database

The data from Te Papa's *KE EMu* database include the majority of lots from deeper than 1500 m held in the museum collections (Figures 18-20). Records have been checked by Te Papa curators Bruce Marshall, Clive Roberts and Rick Webber. Most of those supplied were from NZOI or NIWA expeditions; however, duplication between the *Specify* and *KE EMu* databases is not expected as the records represent actual specimens held in the respective NIWA and Te Papa collections.

A total of 1094 invertebrate and fish records were extracted from the Te Papa *KE EMu* database from abyssal depths greater than 1500 m. The earliest records from the extracted data date back to 1883 from the S.S. *Albatross* — a mollusc and an echinoderm sampled from 2121 m. We have no information concerning what proportion of the Te Papa samples remain to be identified to species.
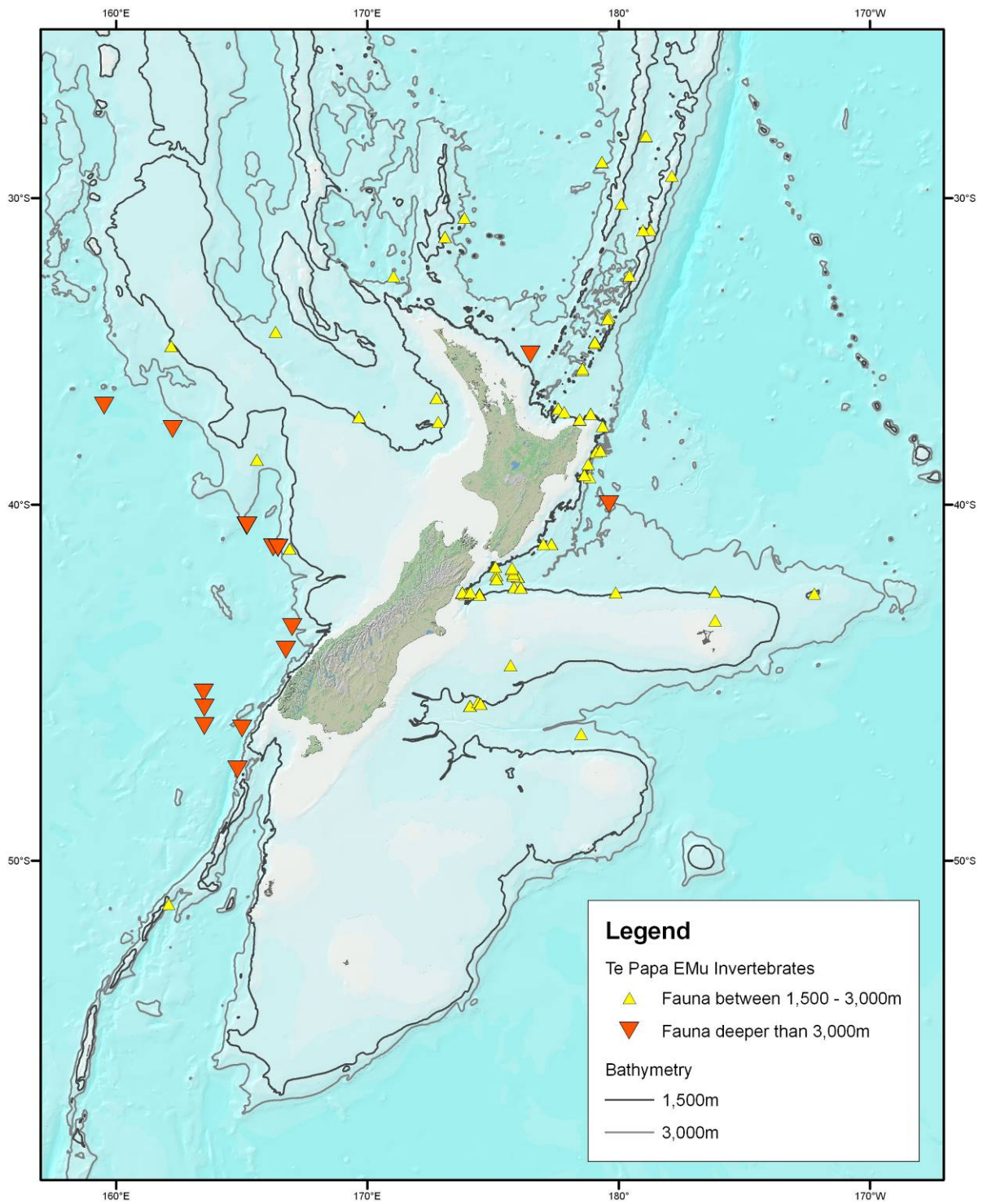
Figure 18: Benthic invertebrate samples below 1500 m recorded in the Te Papa *KE EMu* database.
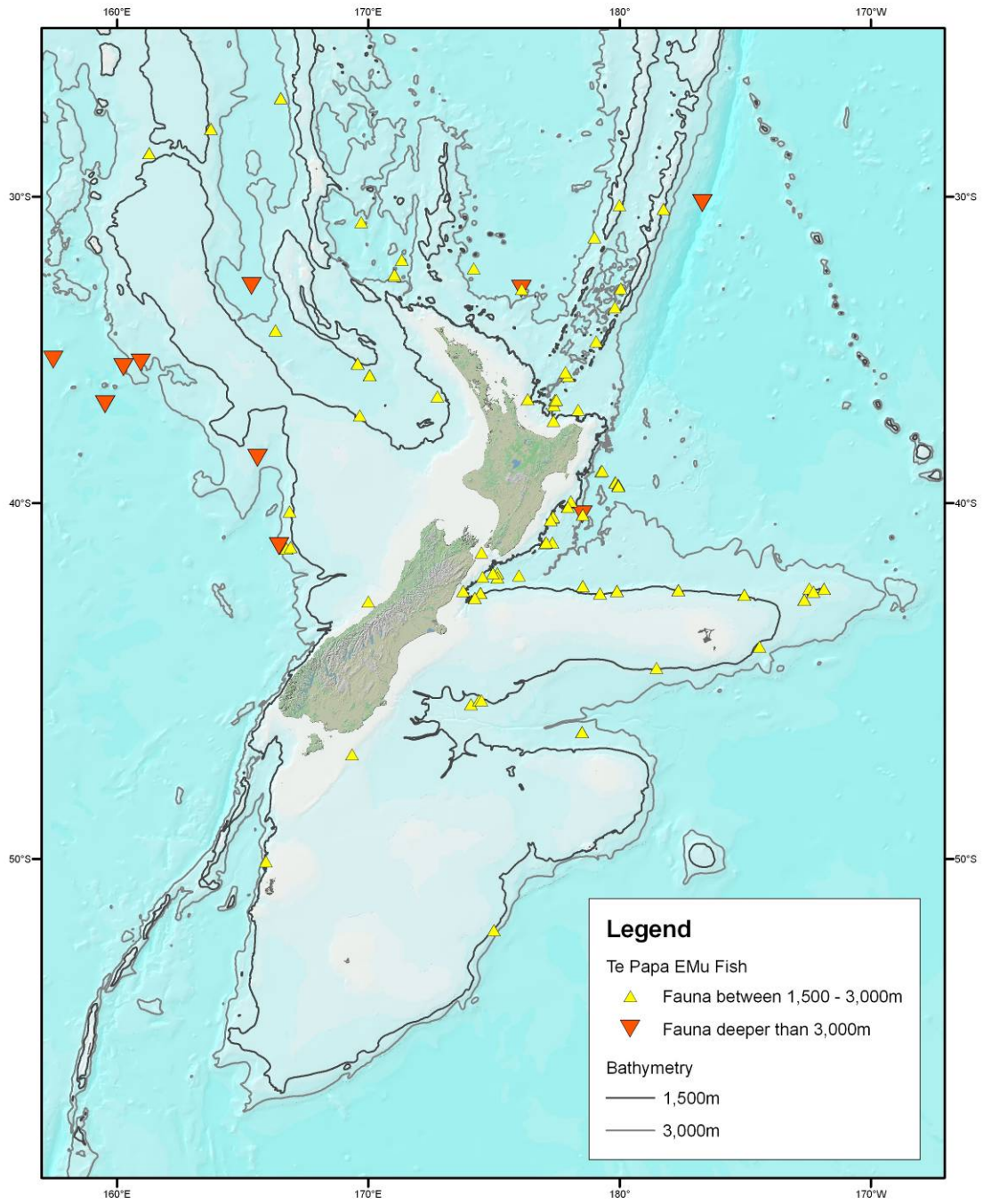
Figure 19: Demersal fish samples below 1500 m from the Te Papa *KE EMu* database.

Te Papa records include 201 from the Antarctic, including New Zealand Ministry of Fisheries scientific observer samples from commercial toothfish vessels and samples from the IPY-CAML research survey in the Ross Sea in 2008 . Fishes constitute most of the records and are significantly fewer in number below 2000 m (Table 13).
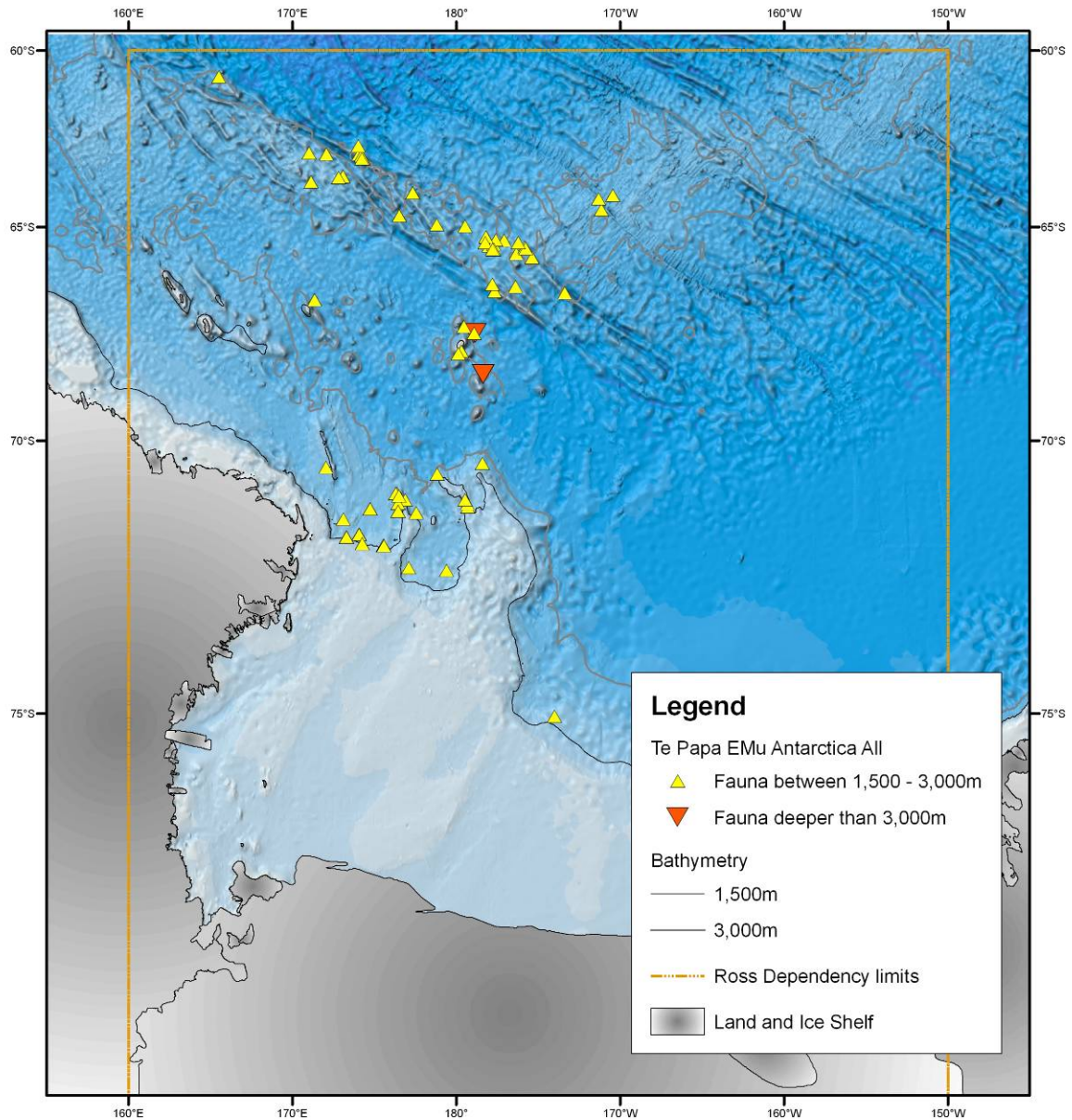
Figure 20: Antarctic (Ross Sea) fauna samples below 1500 m from the TePapa *KE EMu* database.

Table 13: Number of records in Te Papa's *KE EMu* database of fish and invertebrates in Antarctic waters below 1500 m.

Depth strata (m)	No. of fish records	No. of Arthropoda records	No. of Mollusca records
1 500–1 999	174	1	3
2 000–2 999	13	0	2
3 000–3 999	8	0	0
4 000–4 999	0	0	0
5 000–5 999	0	0	0
6 000–6 999	0	0	0
7 000–7 999	0	0	0
Totals	195	1	5

A total of 892 records are from New Zealand waters, with fish and molluscan groups comprising most records (Table 14). The deepest records are fish from 7421 m caught on a New Zealand Oceanographic Institute (NZOI) cruise to the Tasman Basin in 1982. A similar pattern for most records from depths shallower than 2000 m is seen in the *KE EMu* data (Table 14).

Table 14: Number of records in Te Papa's *KE EMu* database of fish and invertebrates in New Zealand waters below 1500 m.

Depth strata (m)	No. of fish records	No. of Cnidaria records	No. of Arthropoda records	No. of Echinodermata records	No. of Mollusca records	No. of Porifera records
1 500–1 999	237	1	59	65	213	0
2 000–2 999	90	0	16	22	89	1
3 000–3 999	45	0	1	0	24	0
4 000–4 999	6	0	1	0	19	0
5 000–5 999	0	0	0	0	0	0
6 000–6 999	0	0	0	0	0	0
7 000–7 999	3	0	0	0	0	0
Total	381	1	77	87	345	1

7.   INFORMATION/DATA GAPS

The following chapter determines information/data gaps that are used to put the known information/data into perspective and to assist in formulating recommendations for further study of New Zealand's biodiversity below 1500 m.

Less than 0.002 percent of New Zealand's deep-sea environment has been sampled — a very small fraction (Table 15).

7.1   Physical sampling gaps

A total of 1489 benthic gear deployments have been made below 1500 m by New Zealand-based sampling initiatives (see Figure 21). A total of 53 gear types have been used, and the majority were different forms of grabs and dredges. An estimate of the area sampled by static gear (n = 620) and towed gear (n = 869) was calculated using the known surface area of the static gear and the width of towed gear multiplied by the average length of the towing distance. The area sampled below 1500 m in the New Zealand region by towed gear is approximately 13.9 km^2 whilst the area sampled by static

gear below 1500 m in the region is only approximately 620 m^2. Table 15 indicates the area sampled by these two types of benthic sampling gear in different depth bands, within both the EEZ and the Extended Continental Shelf (ECS). The percentage of the seafloor of these two areas sampled below 1500 m deep is very small indeed. In the Ross Sea, five stations have been taken deeper than 3000 m, spread across eight degrees of latitude.

Very few samples relative to the total sampling effort have been taken below 1500 m water depth south of 47° S in the New Zealand region over the last 50 years (Figure 21). More samples have been collected in the deep ocean (below 3000 m) east of New Zealand rather than west, with concentrations of historical sampling along the Kermadec Ridge-Havre Trough, the Hikurangi subduction margin and the western margin of the Hikurangi Plateau off the east coast of North Island. Moderate sampling efforts are apparent in the Bounty Trough located between the Chatham Rise and Campbell Plateau and off southwestern South Island (Fiordland).

Table 15: Estimates of the area of the seafloor sampled by static and towed sampling gear below 1500 m by depth band and expressed as a percentage of the area of the New Zealand Exclusive Economic Zone (EEZ) and Extended Continental Shelf (ECS).

	Area (km^2)	Percentage
EEZ 1 500–2 000 m	368 504	0.001099449
EEZ 2 000–3 000 m	713 359	8.17413E-05
EEZ 3 000–4 000 m	559 567	8.01727E-06
EEZ 4 000–5 000 m	584 345	2.91917E-06
EEZ 5 000–6 000 m	222 612	1.54843E-06
EEZ 6 000–7 000 m	49 101	1.17105E-06
EEZ 7 000–8 000 m	22 564	0
EEZ 8 000–9 000 m	14 166	0
EEZ 9 000–10 000 m	4 104	0
Totals	253 3386	0.0012
ECS 1 500–2 000 m	46 6189	0.000871784
ECS 2 000–3 000 m	934 644	6.41054E-05
ECS 3 000–4 000 m	836 629	7.27228E-06
ECS 4 000–5 000 m	1 199 019	2.44066E-06
ECS 5 000–6 000 m	455 692	8.83052E-07
ECS 6 000–7 000 m	59 210	9.71116E-07
ECS 7 000–8 000 m	255 512	0
ECS 8 000–9 000 m	14 286	0
ECS 9 000–10 000 m	4 104	0
Totals	3 995 035	0.001
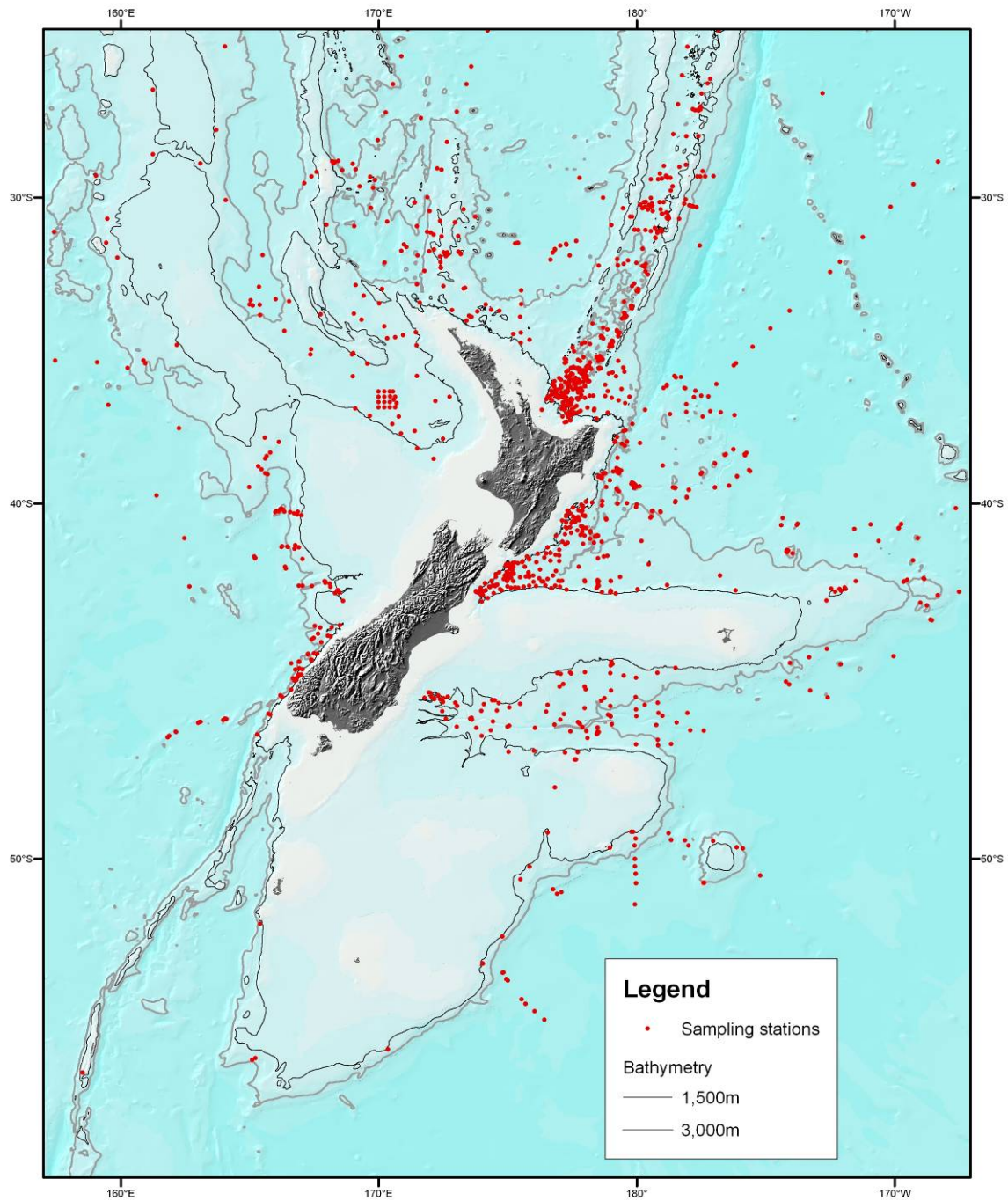
Figure 21: Bathymetric map showing the location of benthic samples from below 1500 m taken by New Zealand-based expeditions.

There has been only sporadic sampling off the Campbell Plateau, in the Emerald Basin–Solander Trough–Macquarie Ridge area, in the Tasman and Southwest Pacific basins, off the Lord Howe Rise–Challenger Plateau and in the marginal basins, ridges and troughs off northern New Zealand.

As mentioned in Section 1.3, many of the deep-ocean sampling expeditions around New Zealand have had a geological focus (see Table 1), and hence there is limited information on benthic communities arising from such datasets. For example, studies in the Kermadec Ridge–Havre Trough region have focussed on understanding geological processes associated with the active arc volcanism and back-arc rifting (e.g., Wright 1993, 1994). Similarly along the Hikurangi subduction margin most of the seafloor samples have been collected with the aim of understanding the sedimentology of deep-ocean sediment flows (e.g., Lewis 1994) and the dynamics of active subduction processes (i.e., faulting, folding) and impacts on seafloor morphological evolution (e.g., Lewis & Carter 1995; Barnes et al. 1998).

7.2   Image sampling gaps

A total of 191 camera stations have been occupied below 1500 m, from which 8012 still images have been obtained during New Zealand-based sampling initiatives. An estimate of the area of the seafloor below 1500 m that has been photographed was made by multiplying the number of 35 mm images (n = 4734) by 1.86 m^2 (*Benthos* camera field of view), and the number of digital images (n = 3278) by 2.06 m^2 (DTIS camera mean field of view). The total estimate of the area of seafloor in the New Zealand region that has been photographed below 1500 m is 0.016 km^2. This total area represents 0.000 000 632% of the EEZ that is deeper than 1500 m. Table 16 indicates the area sampled by cameras in different depth bands, within both the EEZ and the ECS.

This represents such a small sampled area of the New Zealand deep-sea domain that any future photographic sampling initiatives for biological assemblages would be justified in starting from the premise that no sampling has been conducted before. The only region that might be an exception to this is the abyssal plain to the north of the Ross Sea where 6 DTIS transects have been run.

Table 16: Estimates of the area of the seafloor below 1500 m depth sampled by cameras, by depth band and expressed as a percentage of the area of the New Zealand Exclusive Economic Zone (EEZ) and Extended Continental Shelf (ECS).

Depth strata (m)	Area of seafloor (m^2)
1 500–1 999	7 133.5
2 000–2 999	3 661.2
3 000–3 999	2 199.4
4 000–4 999	2 666.8
5 000–5 999	330.2
6 000–6 999	0
7 000–7 999	0
Total	15 991.1

7.3   Taxonomy and ecology gaps

To date, most species recorded from below 1500 m in the New Zealand region are known only from single or relatively few stations and for the most part were collected as part of major historical voyages, particularly the United Kingdom *Challenger*, Danish *Galathea* and Soviet *Vityaz* expeditions that spent only limited amounts of time in New Zealand waters, yet made significant benthic collections from New Zealand deep-sea environments. Material from these voyages is held at institutions in London, Copenhagen and Moscow, repectively, and thus is not immediately available for scientific study in New Zealand. While some benthic samples have been taken from depths below 1500 m by New Zealand-based expeditions, there has been little work on the taxonomic and or phylogenetic analysis of the fauna recovered. Because of the paucity of sampling in the deep sea around New Zealand, our present knowledge of the diversity and distributions of fauna in these habitats is at best rudimentary, while ecosystem processes in the deep-sea remain largely unstudied.

Overall, fewer than 100 name-bearing specimens (holotypes) of all taxa (protozoans, invertebrates, fishes) from New Zealand waters below 1500 m are held at New Zealand institutions. If scientists wish to study the holotype of a taxon known from the New Zealand deep sea, some of which are endemic to the region, they must request a loan or images from the overseas repository.

The few studies conducted in New Zealand waters that attempt to address process-related questions have been restricted to the Kermadec Trench and the Chatham Rise (Nodder et al. 2007; Jamieson et al. in press). The trench studies have focused on understanding of hadal ecosystems, rather than the deep-sea ecosystem in general. Research conducted on the Chatham Rise is reasonably comprehensive, as the interdisciplinary approach taken has enhanced our understanding of deep-sea ecology in New Zealand and globally. Nevertheless, the Chatham Rise studies are limited by their low taxonomic resolution, the lack of detailed descriptions of faunal assemblages and, for the purposes of this report, the lack of many stations deeper than 1500 m, with a primary focus along a single latitudinal transect (i.e., 178° 30'E; Nodder et al., 2003, 2007).

The gap in fundamental knowledge of New Zealand's deep-sea ecology contrasts with information available in other deep-sea regions of the world. Elsewhere, there are comprehensive descriptions of the deep-sea fauna (i.e., diversity patterns and trends, assemblage compositions/distributions, faunal zonation, species distributions) integrated with knowledge of important environmental factors and experimental studies. Where deep-sea mining activities have been comtemplated (e.g., manganese nodule fields near the East Pacific Rise), detailed impact assessments have also been conducted. Detailed faunal data and long-term time-series data have also enabled the quantification of key processes and interactions (e.g., pelagic-benthic coupling, trophic pathways, carbon budgets). Because of the small amount of sampling effort at depths in New Zealand below 1500 m, there is no real baseline or fundamental knowledge of the biodiversity and ecology of New Zealand's deep-sea environments, especially in areas of economic interest, such as manganese nodules. This paucity of information also hampers New Zealand research efforts in the deep sea, such that in order to gain an understanding of assemblages there, the processes that structure them and their potential vulnerability to anthropogenic disturbances (e.g., deep-sea mining, bottom trawling, climate change), New Zealand researchers generally have to utilise existing knowledge that has been generated from studies conducted elsewhere, rather than basing their conclusions on New Zealand-specific data and knowledge.

8.   CAPACITY FOR DEEP-SEA RESEARCH

The first part of the chapter eight focuses on general physical resources, including a summary of the advantages and disadvantages of each gear type as a sampling tool. The second part of the chapter focuses on New Zealand's capacity and its resources.

8.1 Physical resources

Gage and Tyler (1991) provided a summary of research vessels, frames and cranes, winches and wires, swivels and weak links, precision pingers, etc., that are needed for deep-sea research. Gage et al. (2005) described in more detail the designs of dredges, grabs and corers and related methods for sampling the benthos of the deep sea, as did Danovaro (2010) more recently. Here, we focus on the sampling equipment used in such studies. Page et al. (2000) prepared a handbook for the Maritime Safety Authority of New Zealand, 'Standard Methods for Surveying and Monitoring Deep-water Dumping Disposal Sites' and the following subchapters 8.1.1–8.1.11 are an updated modification of chapter 4 of this handbook.

8.1.1 Techniques for sampling and analysing deep-sea habitats

Techniques used to survey and monitor deep-water assemblages depend to a large extent on habitat type, logistical/financial constraints and research objectives. Table 17 summarises the advantages and disadvantages of common techniques used for studying deep-water organisms. Often, a combination of methods has to be employed to characterise deep-water communities, and decisions have to be made on equipment and optimum vessel size for a given study. The following sections outline equipment commonly used and methods for the assessment of deep-water organisms, primarily those of soft substrata (the commonest substratum type in the deep sea in the New Zealand region at depths below 1500 m). Notes are also made as to whether insitutes in New Zealand possess the particular gear types described.

8.1.2 Assemblage type

Depending on the situation, a range of techniques may need to be employed to sample different components of the benthic biota. Benthos can be divided into two groups based on where they live: organisms that live on the sediment (or other substratum) surface (known collectively as epifauna), and those that live below the surface (infauna). Macrofauna are larger organisms normally defined as those that are retained by a 0.5 mm (for continental-shelf environments) or 0.3 mm (for the deep-sea) sieve. Meiofauna are very small organisms, defined as those that pass through a 0.5 mm sieve and are retained by 0.063 mm or 0.04 mm sieves. A third size-class of fauna is also sometimes recognised, the megafauna, which includes fish as well as invertebrates. The word megafauna was used originally to describe animals that can be seen and identified in photographs of the seabed (Grassle et al. 1975), which for most camera systems are typically greater than approximately 50 mm. In the deep sea generally, most large (megafaunal) echinoderms, crustaceans and others are found on the substratum surface. However, the majority of smaller macrofaunal animals, such as polychaete worms and small crustaceans, live within the sediment. The method employed to sample any assemblage type will depend on the objectives of the study and the constraints of substratum type, sea conditions and cost and availability of survey vessels. No single method will necessarily be suitable for complete characterisation of a biological assemblage.

8.1.3 Background Information

Before designing a study, an important first step is to review existing data on habitats and assemblages. Often there may be little such information concerning seabed communities, especially in the deep-sea. Much large-scale information on the distribution of deep-sea habitats and assemblages may be inferred from sediment and bathymetric charts. The research vessel *Tangaroa* is the only New Zealand vessel with the ability to deploy a range of research equipment in waters deeper than 1500 m and accurately determine the seabed positions of sampling gear.

8.1.4   Mapping

Echo-sounders and swath-mapping systems, positioned accurately using Global Positioning Systems (GPS), can be used to identify sampling sites and to map seafloor geomorphology. Habitat type, scales of spatial variation and taxa assemblages can also be accessed from a seabed map and used to optimise survey and sampling designs. Methods used to map deep-water geomorphology and habitat type are discussed below.

8.1.5   Navigation

The quality of the site survey is highly dependent upon the accuracy of the positioning system used onboard the survey vessel. Modern GPS utilises high-altitude satellites orbiting at about 20 000 km above the surface of the earth, providing positional accuracies of ± 10 m (95% confidence interval). If used in a differential configuration (DGPS), with an onland base station at a known latitude and longitude, positional accuracy can be increased to better than ±1 m, depending on the quality of the GPS unit used. Lowreth (1997) has described the technical specifications of older radio-positioning systems (e.g., Micro-fix, Syledis) as well as the newer satellite positioning systems (GPS and DGPS).

Dynamic positioning systems that allow vessels to remain over a given station are now increasing in use on research vessels. Dynamic positioning is a computer-controlled propulsion system that automatically maintains a vessel on a chosen position by using its propellers and thrusters, countering the strong effects of water, wind, and other environmental forces. New Zealand's research vessel *Tangaroa* has been fitted with a such a system (2010).

While the position of the vessel can be precisely fixed using GPS, accurate determination of the position of deployed gear is more problematic, particulary in deep water. Depth restrictions on pingers, along with decreased precision in deep-water, lead to potential issues with accurately fixing positions on the seafloor. Repeat sampling and monitoring of sites over time require the ability to determine accurately the position of the sampling gear deployed so sites can be effectively resurveyed.

### 8.1.6   Echo-sounders and sub-bottom profilers

Bathymetric information is used to determine seafloor gradients across the site, to characterise the nature of seafloor habitats and to assist in predicting sediment movement. Such information is collected using an echo-sounder mounted in the hull or over the side of the survey vessel (see Figure 22). Single-beam echo-sounders typically operate at frequencies of 12 to 30 kHz, and produce a continuous measurement of water depth directly beneath the vessel as it transits over the sea surface. Echo-sounders emit an acoustic pulse at a known frequency that is reflected from the seafloor and back to the vessel (e.g., Lowreth 1997). Once the speed of sound in water is determined, or estimated, the depth from the sea surface to the sea floor can be calculated. At deep-sea sites, tidal amplitudes at the sea surface can be considered to be negligible, and motion compensators are often used to remove the effect of waves on the bathymetric profile. In general, minimum-accuracy and depth-resolution standards for hydrographic surveys are specified by the International Hydrographic Organisation (IHO). The use of narrow-beam echo-sounders (less than 12° total beam width) ensure that more accurate bathymetric information is collected.

The use of echo-sounders on numerous, closely spaced lines are necessary to provide sufficient data coverage across proposed study sites. Modern multi-beam (swath) and multi-transducer (sweep-bathymetric) systems can also be useful by providing 100% coverage across the seabed and minimising the number of survey tracks required to encompass the survey area. Swath mapping of the seafloor enables changes in habitat and substratum type to be identified remotely, often over relatively large areas that are approximately three times greater in width than the water depth (i.e., in 1000 m water depth a single swath width might be 2500–3000 m wide). With direct sampling, as outlined below, the features identified from swath maps can be 'ground-truthed' and relationships between

specific habitat type and benthic community structure and function elucidated, depending on the parameters measured. Typical deep-water multi-beam systems operate at frequencies of 12 or 30 kHz. Further information on the type of sediment or rock present at the seafloor can be ascertained after extensive processing of the back-scatter intensity signal also contained in the multi-beam data, and ground-truthing using seafloor sediment samples and imagery.

Sub-bottom profilers generate a stronger sound signal at lower frequencies than do echo-sounders (e.g., 3–7 kHz), therefore some of the sound reflects directly off the seafloor while the remainder penetrates beneath the seafloor and is reflected off buried layers and features. In a similar way to echo-sounders, the time it takes for the reflected sound pulse to return to the surface is a measure of a specific layer's depth and geometry. These 'time profiles' of the seafloor allow marine geologists to determine the location of active faults, submarine landslides, and sedimentary features such as sediment thickness and sandwaves and provide an indication of the composition of the seafloor sediment (i.e., acoustically transparent units are typically muddy deposits, whereas acoustically opaque units with little seismic penetration may be sands or gravels).
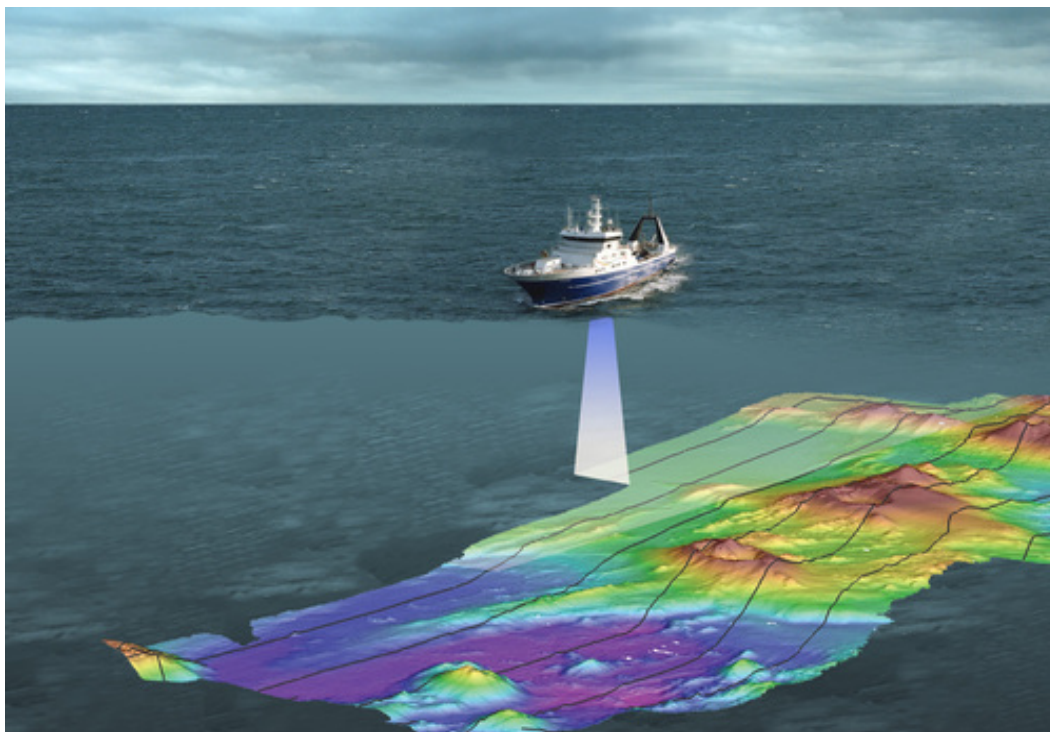
Figure 22: Multibeam echosounder is used for swath mapping, e.g., from RV *Tangaroa* down to 3500 m.

8.1.7   Benthic trawls and dredges

Trawls and dredges (Figures 22-25) are used mainly for qualitative assessment of megafauna/macrofauna, including both mobile organisms (e.g., echinoderms, crustaceans and fish) and sedentary organisms (e.g., sponges, bivalves, hydroids and corals). The organisms sampled will be mainly epifaunal, although infauna can also be sampled by trawls and dredges since some types of this gear do penetrate into the seabed. There are many kinds of trawls (e.g., beam trawl, Agassiz trawl, otter trawl) and dredges (e.g., naturalist's dredge, anchor dredge, anchor-box dredge, rock dredge, pipe dredge). The choice of trawl or dredge is dependent on the research objectives, the size of the vessel and the equipment available on the vessel (e.g., positioning system, wire length and type). Trawls are generally larger than dredges, and the latter usually have a fixed size of opening. Both types of gear collect a sample of benthic fauna in a net, the mesh size of which will vary between gear types and the

purpose of the study. For geological sampling, there are sturdy rock dredges, often with teeth, that have bags with metal rings or wire grommets. During a rock-dredging operation, pieces of rock are broken off and fall into the wire mesh body of the dredge, which is then recovered. Occasionally, tubes are connected inside the dredges to sample any soft sediment the dredge may encounter.

Otter bottom trawls are limited to about 2000 m depth, with limiting factors being the headline float-depth ratings, wire lengths and trawl-net-sensor depth ratings. New float technology and the possible use of kites to hold trawl nets open are options to overcome the trawl float-depth limitations. However depth limitations of about 2000 m for the trawl net sensors would cause problems determining the net shape and identifying potential fouling of the trawl gear on deployment. RV *Tangaroa* has trawled to 2700 m and could possibly go as deep as 3000 m, but determining the position of the net in the water column and identifying when it reached the bottom would not be possible in water deeper than approximately 2000 m (or possibly shallower if the sea conditions were rough).

Trawls towed from a single wire are more commonly used in deep-sea research. The commonest such trawls are Agassiz trawls (openings 1–3 m wide) (Figure 23) and beam trawls (openings approximately 5 m wide) (Figure 24).

Several institutions in New Zealand, including Auckland University, Otago University and NIWA, possess small trawls and dredges, but only NIWA operates the vessels, winches and cable capacity, and towing gear heavy enough to sample below 1500 m (pers. com. Drs Steve OShea, Auckland University of Technology; Mark Costello, Auckland University; Conrad Pilditch, Waikato University; Keith Probert, Otago University).

Figure 23: Agassiz trawl on deck of RV *Tangaroa*.

Figure 24: Beam trawl being brought on deck aboard RV *Tangaroa*.

Figure 25: Anchor dredge before being lowered to the seafloor and on deck of R/V *Tangaroa*.

8.1.8   Epibenthic sleds

Sleds are a useful adaptation of a dredge, used for sampling epifauna or those animals living immediately above the seabed (hyperbenthos), and for sampling uneven and soft seabed. Metal runners attached to a cage/frame in which the sample net is mounted prevent the sled (or sledge) from snagging on rocky outcrops or penetrating into the seabed.

There are many varieties of sled, but the Brenke epibenthic sledge (Brenke 2005) is typical of those sleds designed to sample the smaller animals of the deep seafloor (Figure 26). Since an opening-closing mechanism allows it to sample only when towed on the seafloor (compared to trawls which have open mouths which also potentially sample animals in the water column), the Brenke epibenthic

sledge can be regarded as a semi-quantitative sampler. NIWA owns and has successfully deployed such a sled in deep-water environments..

Figure 26: Epibenthic sledge design (Brenke 2005) — lateral and ventral views.

For sampling the epifauna of the rugged seafloor of deep sea-mounts in New Zealand waters, a robust and heavy sled was designed by the former New Zealand Oceanographic Institute (Lewis 1999b). Typically, this type of sled is configured to sample the larger macrofauna and megafauna (Figure 27). NIWA has successfully deployed such a sled to sample the larger epifauna of seamounts and also soft-sediment environments, although it is best regarded as a qualitative sampling tool.

Figure 27: Seamount sled often used in New Zealand for sampling megafauna of hard substrata.

8.1.9   Grabs

Grabs (Figure 28) generally sample quite distinct components of the benthos compared to those sampled by dredges and sleds; hence both are necessary for comprehensive evaluation of benthic communities. The grab is an efficient tool for quantitative sampling of surface sediments and associated infauna, and sedentary or slow-moving epibenthic species. Grabs are lowered from a stationary vessel by a single wire to obtain a standard sediment sample (usually 0.1–0.2 m^2) from the seafloor. The penetration depth of the grab varies with design (generally 10–15 cm), weight and coarseness of the sediment.

There is a large variety of grab designs available (e.g., Petersen grab, van Veen grab, Day grab, Smith-McIntyre grab), and each has its own advantages and disadvantages. The choice of grab is largely dependent on the objectives of the study, sediment type and capability of the vessel. Some of the large grabs, such as the Campbell and Peterson grabs, that take a large sample (approximately 0.55 m^3) with the aid of hydraulics, are heavy and can be deployed only from large vessels.

Several institutions in New Zealand have small grabs suitable for shallow-water sampling; there are also large grabs suitable for sampling below 1500 m available with NIWA. There may be issues with sample flushing during the recovery from very deep sampling sites.

Figure 28: Large grab deployed from R/V *Tangaroa* in Antarctica.

8.1.10 Corers

Corers (Figure 29) provide a means of obtaining deep, relatively undisturbed samples of sediment by forcing a box or a tube into the seafloor. Because of their weight and large size, corers are often difficult to handle, requiring a large vessel, sufficient wire and relatively calm sea conditions. The choice of coring device depends on the objectives of the sampling programme and the environmental conditions likely to be encountered (e.g., sediment type, water depth, currents). Free-fall or gravity corers penetrate the sediment under their own weight, aided by the addition of lead weights to the head of the corer (up to 1 tonne, generally 200–500 kg). The barrel of the corer may be cylindrical or square, and a cutting device is often attached to the open end of the barrel to facilitate penetration of the corer into the sediment and to assist in retaining less cohesive sediment within the barrel as the corer is removed. Depending on sediment type, cores recovered from gravity cores are generally limited to 1–2 m in length, although if sufficient weight is added to the corer (as in the large Kasten corer) or the target sediment is sufficiently fine-grained, significantly longer cores may be recovered. Corers generally have an inner plastic core-liner that can be removed and sectioned so that the exposed sediment core can be sampled at designated intervals, especially in areas where potential contamination is expected with depth. Such core samples are most commonly used in geological applications.

Gravity corers can compact sediments as they penetrate into the seafloor and distort sedimentary features in the core, especially along the contact of the sediment with the inside wall of the core barrel. Therefore, if the vertical structure of the core sample is required for sampling purposes, then a piston or vibra-corer may be preferable. These corers generally recover longer cores than gravity corers. A piston corer utilises both gravity and hydrostatic forces and outwardly resembles a gravity corer. As the cutting edge penetrates into the sediment, an internal piston remains at the level of the sediment/water interface, thereby reducing sediment compaction and internal frictional effects.

Typically, gravity and piston corers are used in conjunction with a trip weight that may either be a set of weights, another smaller coring device, or a grab sampler. An unknown amount of surficial

sediment is often lost from the upper parts of gravity and piston corers owing to flushing effects as the corer is recovered. It is therefore often beneficial and cost-effective to use a grab sampler or short pilot corer as a trip weight. This sampling set-up maximises the chances of obtaining a sediment sample, even if there are problems with core recovery because of limited penetration into the seafloor.

Figure 29: Multi-corer (left panel) and tubes (right panel).

Seafloor corers with multiple tubes attached are called multi-corers. These instruments sample sediments by creating a vacuum when caps are simultaneously emplaced over the top of the open tubes as the corer penetrates into the sediment. Bottom caps are also snapped into place to retain the intact sample in each core tube as the multi-corer is slowly pulled out of the seafloor. Such devices provide the best results for biological sampling of smaller macro-infauna, meiofauna and bacteria by ensuring minimal disturbance of surface sediments, where these small organisms are usually concentrated, as well as the overlying seawater. Non-piezophilic bacteria (i.e., bacteria that can live at normal atmospheric pressures, see Chapter 2.1) can be isolated successfully from such multi-core samples.

Figure 30: Box corer on deck of R/V *Tangaroa*.

For many biological and geochemical applications, a specialised type of large corer known as a box corer is often used (although some corers use large cylinders rather than boxes) (Figure 30). There are many different types of box corer (e.g., Reineck, Eckman, USNEL, HAJA). This type of coring device recovers a quantitative volume of sediment within a stainless steel or Teflon-lined box that can have subsampling cylinders or grids attached prior to deployment. Box corers generally take a sample with a surface area of between 0.1 and 0.25 m^2. Depth of penetration into the seafloor is limited by the dimensions of the sampling device, but is generally less than 50 cm deep. Sediment samples are often recovered in a relatively undisturbed state, except near the contact of the sediment with the inner wall of the box. Over-lying bottom water may also be recovered. In the box-corer operation, the sampling box is pushed into the sediment under the weight of the corer. Once the sampling device cannot penetrate any further into the sediment, and the corer begins to be removed from the substratum as the instrument is hauled vertically by the attached wire, a spade arm is activated to enclose the bottom of the box.

NIWA is the only institution in New Zealand possessing corers that can be deployed below 1500 m. However, NIWA presently has only one multi-corer and one box corer, with only minimal back-ups for this standard deep-sea sampling gear.

8.1.11 Baited traps

Another kind of static sampler is the baited trap. Many varieties of traps are known, differing in size, deployment time and deployment method. Traps have often been used in the deep sea and are designed to sample scavenging organisms that occur in low densities and would be less likely to be sampled by trawls, dredges, grabs or corers. Baited traps are sometimes mounted on landers to which cameras are also attached (see below).

Baited underwater cameras (BUC) (Figure 31) are an alternative, non-extractive method of sampling benthic fish abundance and biodiversity where traditional sampling methods are not practical or feasible. Variations on this method are used worldwide to sample deep-water environments, marine protected areas and sensitive habitats. In New Zealand, the method has been used extensively in shallow rocky-reef systems and marine reserves. In the Bay of Islands Ocean Survey 20/20 Coastal project, a BUC system, modified for operation to 200 m depth, was used used across all habitats and depths sampled. Different species exhibit varying behaviours in response to different sampling

methods and therefore the use of a suite of sampling tools allows a better understanding of variations in diversity and abundance across different habitats.

Te Papa, in cooperation with Massey University, is currently running a deep-water fish project using a pioneer sampling programme — Baited Remote Stereo Underwater Video Systems (BRUVS), an emerging methodology from the University of Western Australia that allows accurate length information to be collected, along with relative abundances of individual benthic fish species. Quantitative ecological analyses of the fish fauna will examine the potential interaction between depth and latitude, testing fundamental hypotheses about patterns of deep-sea biodiversity and gradients in species richness, taxonomic diversity, and community structure. The project has four central goals:

- To make fundamental biological discoveries by collecting and describing new fish species from the deep ocean.
- To illuminate the biogeographical origins of New Zealand's fish fauna by comparing and contrasting communities and individual species' distributions to reveal historical and present-day biogeographic connectivities or disjunctures.
- To explore and quantify the interaction between depth and latitude gradients in benthic and demersal fish biodiversity, especially characterising depth gradients in richness, evenness, beta diversity and community structure, primarily to answer the question: At what depth do latitudinal effects, if any, disappear?
- Produce high-quality video footage from the deep sea.

The maximum depth so far sampled with these baited video traps is 1200 m. In contrast, during the HADEEP expeditions to the Kermadec Trench, baited traps on landers were deployed beyond 7000 m.

The HADEEP expeditions [HADEEP project: University of Aberdeen, UK and University of Tokyo, Japan, supported by the Nippon Foundation (Japan) and the Natural Environmental Research Council, UK] deployed benthic landers in the Kermadec Trench in 2007 and 2009. Three landers were deployed during HADEEP 6 via RV *Kaharoa* in November 2009. The first, a free-fall Van Veen lander, was deployed once . The second, a baited video lander, was deployed twice but was lost at 7000 m. The third, a baited stills lander, was deployed to approximately 4000 m, 5000 m, 6000 m, 7000 m and 7500 m. The traps on the HADEEP video lander were 2 x 100 mm in diameter and 300 mm in length. The traps on the stills lander were 60 mm in diameter and 300 mm in length (two traps) and 90 mm x 150 mm (one trap). All funnel-entrance diameters were approximately 25–30 mm. Until now (November 2010) no analysis of the five station transects from 4000 to 7500 m across the abyssal-hadal transition of the Kermadec Trench have been published, but several publications are in preparation (A. Rowden, NIWA, pers. comm.).

Similar landers are used extensively in other parts of the world to study deep benthic processes and there is potential to develop further collaboration within Australasia that would enable the construction of more sophisticated landers with greater depth capability and a wider range of research roles. In the past and currently, NIWA has successfully collaborated with European institutions to deploy deep-sea landers in the New Zealand EEZ (e.g., Nodder et al. 2007, Jamieson et al. in press).
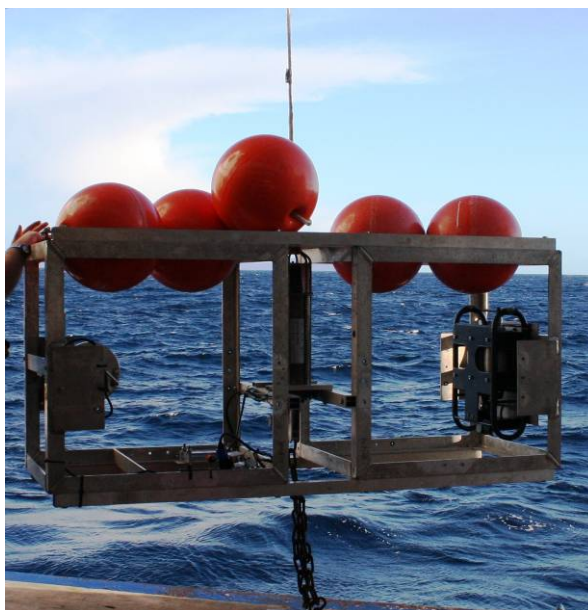
Figure 31: Example of a baited underwater camera (BUC) trap system used by NIWA.

8.1.12   Seabed imagery

In most applications, seabed images can be used to generate reliable data on only the mega- and larger macro-epibiota, and then only that which is emergent and visible in the 'upper-storey' of the assemblage (Grassle et al. 1975; Owen et al. 1967). Thus, much of the benthic macrofaunal diversity associated with, for instance, stands of live coral may not be detected in drop- or towed-camera images. Similarly, abiotic substrata in photographic images can be discriminated only on the basis of their surface appearance: bedrock overlain with a thin layer of fine sediments may be indistinguishable from fine sediment many metres deep. Photographic surveys therefore, can yield only a partial estimate of biological or habitat diversity. With remote visual imaging of the deep sea-bed, there can be considerable variability in the quality and scale of images, both within and between studies, which arises from differences in technical specification, modes of use and operational conditions. Such variability is difficult to control and affects the precision and accuracy of the data derived (Mortensen & Buhl-Mortensen 2005).

These limitations notwithstanding, visual sampling is the most effective method available for quantitative studies of mega-epifauna in the deep-sea (Rice et al. 1994), particularly on hard substrata. Despite advances in the interpretation of acoustic data, visual sampling is also the only remote method that can reliably and accurately indicate transitions between seabed areas with different biological assemblages (e.g., Fossa et al. 2005; Hewitt et al. 2004). A further advantage of visual sampling methods in contrast to traditional gear is that they are non-destructive. Thus, visual transects, particularly video, enable immediate qualitative assessment of the seabed and its associated biota with all structural and distributional relationships intact. Further, direct observation can result in a large amount of useful information being processed, if not always recorded, simply by watching the image in real time (Grassle et al. 1975; Hessler et al. 1985). Thus, without performing formal analyses, researchers are generally able to describe the main features of the transect and note where any significant regions of interest occur simply through having viewed the video footage.

Static cameras

Static cameras stand on the seabed, or are attached to a mooring, and are deployed at a single site for periods ranging from hours to months, or even years. They are used primarily for time-lapse observations and measurements of processes at small scales (e.g., Paul et al. 1978) or to study mobile

animals attracted to bait (e.g., Collins et al. 1999). Arrival times of such fauna as amphipods and fish can be used to estimate population densities (e.g., Sainte-Marie & Hargrave 1987; Priede et al. 1990; Jamieson et al. 2009a). Because static cameras image only a single patch of substratum they are of limited use for comparisons of faunal distributions in relation to physical habitat gradients.

NIWA has static cameras for use in coastal and continental-shelf depths (shallower than 250 m) but New Zealand currently has no static camera deployment systems rated to depths below 1500 m. In collaboration with European scientists, baited-trap camera and video systems are deployed in the Kermadec Trench under the HADEEP project (see Chapter 8.1.11).

Drop and towed cameras

Drop cameras are unpiloted platforms deployed on wire cables from a surface vessel. Older drop systems using only still cameras used a trigger weight to fire the camera shutter on contact with the seabed. These were simple and reliable in operation but limited in scope and have been largely superseded by more sophisticated towed camera systems. In these more recent adaptations, one or more cameras are mounted on a frame that surveys across the seabed either by being towed at slow speed or by passive drifting of the ship. Thus, these platforms have very low manoeuvrability and tend to follow relatively simple line-transect trajectories. Camera orientation and lens focal length are generally fixed.

For deep-sea operations, towed cameras fall into two categories: (1) those that are deployed on non-conducting wires and are, therefore, flown 'blind' and are constrained to record in-camera, with images being downloaded only after the camera has been retrieved, and (2) those that are deployed on co-axial or fibre-optic cables enabling near real-time/low-resolution or real-time/full-band-width data transmission to the surface, respectively. The principal disadvantage of towed camera systems is that the movement of the ship at the surface is transmitted directly to the cameras. Thus, consistent altitude above the seabed, and hence optimum image quality, is difficult to maintain in sea conditions other than calm.

From approximately 1989 to 2005, DSIR/NIWA operated a deep-sea drop camera made by Benthos Ltd, USA. This housed a single Nikon 35 mm stills camera, was rated to 10 000 m depth, and was used primarily on geological survey voyages in the EEZ. Individual images covered a seabed area of either 2 or 5 m^2 depending on set-up. The camera is no longer used, but images from these voyages are filed at NIWA, Wellington. In 2006, the Benthos camera was superseded by a new towed camera vehicle — the NIWA-designed Deep Towed Imaging System (DTIS) (Hill 2009).

At the time of this report, DTIS is the only camera system in New Zealand designed to operate to bathyal and abyssal depths (see Figure 32). The system has a designed maximum working depth of 6000 m and consists of a stainless-steel chassis carrying a Sony HD1080 high-definition video camera and a Canon 10 megapixel SLR stills camera with appropriate flood and flash lighting. It is internally powered by two Deep-sea Power and Light batteries and both video and still images are recorded at the seabed on MiniDV tape and internal flash memory, respectively. Still images are taken automatically at intervals of either 15 or 20 seconds depending on the survey requirements. Two pairs of parallel lasers, one for each camera, enable scaling of images. A unique feature of DTIS is the data-encoding-and-transmission system that enables real-time colour video to be viewed at the surface during deployment via a conventional single-conductor CTD cable (Hill, 2009). The frame-refresh rate of this feed is dependent on depth, with greater depths resulting in lower frame rates, but it has been used routinely by NIWA since 2006 to record seabed observations at depths down to 3500 m. When deployed from RV *Tangaroa*, the seabed position of DTIS is monitored by an ultra-short baseline acoustic-transponder system (Simrad HiPAP) that works to depths of approximately 4000 m. Maximum transect length is constrained by the 1 hour recording duration of MiniDV tapes. Operating at a target altitude of 2.5 m above the seabed and at a speed of 0.25–0.5 m.s^{-1}, each one-hour DTIS transect images 1800–3600 m^2 of the sea floor. From 2009 onwards, DTIS has also recorded roll, pitch and heading information, and other instruments, such as CTD, methane sensor etc., can be fitted to the chassis as required.
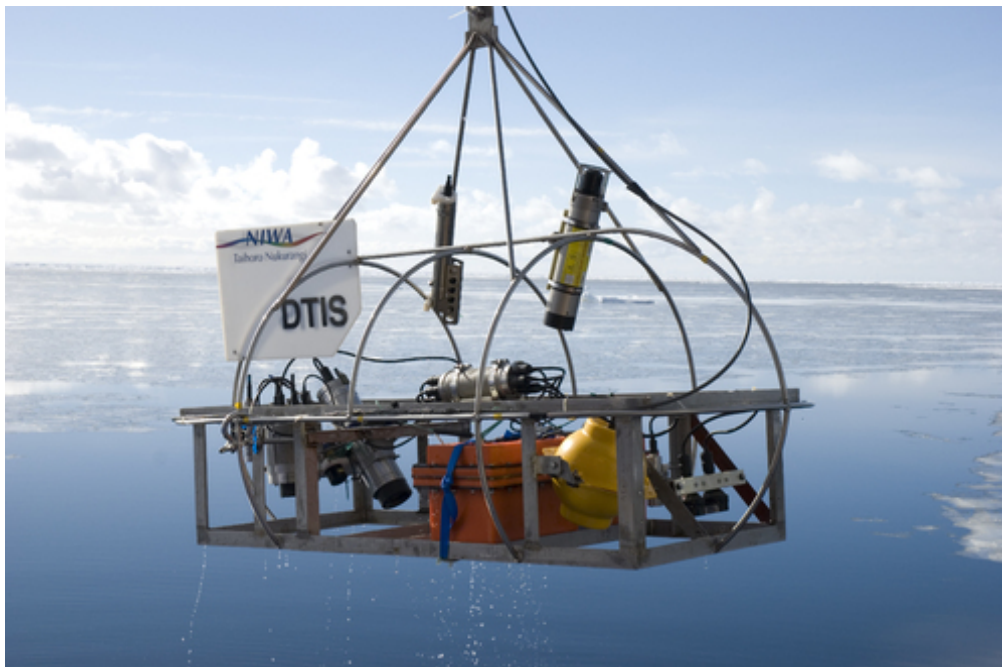
Figure 32: NIWA's Deep Towed Imaging System (DTIS). DTIS carries video and still-image cameras and is rated to 6000 m operational depth.

Remotely operated vehicles (ROVs)

ROVs are self-propelled, piloted platforms that are connected to the surface, or a 'garage' suspended at depth, via an umbilicus. The chief characteristics that distinguish ROVs from towed camera platforms are their high manoeuvrability, their ability to divert from a fixed course to investigate and remain stationary at areas of interest discovered during the dive, and the facility to continuously vary camera orientations and focal lengths. ROVs generally carry multiple cameras. Some ROVs have a limited capacity for collecting samples using manipulator arms.

ROVs demand considerably more sophisticated shipboard systems than towed camera systems. ROVs suitable for deep-sea work are deployed on armoured fibre-optic cables that enable high-resolution video to be viewed at the surface in real time for safe and accurate navigation of the vehicle. Such cables are considerably more expensive than conventional conducting wire and require purpose-designed winches and handling equipment to avoid damage. For this reason, many ROVs are operated using their own dedicated winches and cable, independent of the vessel's systems, with all control systems being containerised for transport.

No New Zealand research institute has a ROV with deep-sea capability. Research using ROVs in the deep sea around New Zealand has, to date, been conducted using vehicles from overseas institutions or via commercial-resource exploitation companies that supplied hired ROVs.

Submersibles

Submersibles are research submarines that are not tethered to the mother ship and are operated by crew working in a one-atmosphere-pressure housing. Because of their life-support systems,

submersibles are more complex than ROVs and require sophisticated shipboard facilities for handling and maintenance. Their capabilities are similar to those of ROVs but vary widely depending on actual specification. The most sophisiticated example is still the Woods Hole Oceanographic Institute's *Alvin*. The construction, maintenance, and operational costs of deep-sea submersibles are prohibitively expensive and not without risk. In consequence, more development has gone in to ROV design, particularly through the oil- and mineral-extraction industries.

There are no submersibles in New Zealand with deep-sea capability.

Autonomous underwater vehicles (AUVs)

AUVs are self-propelled and operate without any direct link to the surface but are not piloted. Rather, they can be pre-programmed to follow a specific survey pattern or to modify their survey in response to water-column or sea-bed characteristics (e.g., topography, salinity, methane concentration). AUVs can be configured to use a wide range of imaging devices, but because camera orientation and lens focal length are usually fixed, and both altitude and velocity are usually constant, visual samples captured using AUVs are more comparable with those from towed cameras than those from piloted vehicles. AUV technology is developing rapidly, in terms of both the control of the vehicle itself and of the instruments carried.

No New Zealand scientific institute currently has an AUV and those in development in Australia are not rated for deep-sea use (Singh et al. 2007).

Table 17: **Methods used for sampling deep-sea environments, modified after Page et al. (2000). Choice of method is dependent on research objectives and logistical/financial constraints. Advantages and disadvantages of each method are listed.**

	Advantages	Disadvantages
Single-beam echo-sounder	• Provides profile of seabed along a sounded line	• No information on sea bed between sounding lines • Poor results in certain habitats • Can give inaccurate results in rough sea conditions or if incorrectly calibrated
Multibeam echo-sounder (swath mapping)	• Extremely effective for broad-scale mapping (10–100 km^2 scales) of seabed topography • Backscatter signal has potential to enable discrimination between seabed habitat types	• Complex technology • For habitat confirmation, requires ground-truthing with camera, dredge, corer or grab • Relatively coarse resolution (25 x 25 m cells) when used in deep sea
Trawl/dredge	• Relatively large areas can be sampled (100 m^2 scale). • Actual specimens of fauna collected (useful for taxonomic identifications, testing for contaminants) • Provision of useful preliminary data on distribution and types of species assemblages, particularly larger surface-dwelling organisms	• Efficiency varies with substratum sampled • Not efficient on rough ground • Selective for certain groups of organisms • Long tows obscure small spatial-scale variation • Post-survey sorting may be extremely time-consuming • Can cause considerable damage to habitat and specimens
Epi- and hyperbenthic sled	• Collects semi-quantitative samples of small hyperbenthic macrofauna (> 0.5 mm) unsampled by other sled types	• Efficiency varies with substratum sampled • Current strength affects sled efficiency
Multicorer	• Collects multiple, undisturbed, quantitative, samples of surface sediment together with infauna and slow-moving or sedentary epifauna • Valuable for physical sediment characteristics, bacteria, meiofauna, and total-oxygen-consumption studies • No working-depth restriction other than available wire length	• Penetration depth varies with sediment type • Small sample size (total 0.06 m^2 per deployment), therefore many replicates may need to be taken • Does not sample larger mobile surface-dwelling species effectively • Does not allow for the isolation of piezophilic bacteria
Baited trap	• Collects mobile scavenging and predatory animals • Arrival times can be used to estimate population densities (of e.g., Amphipoda)	• Selective for certain groups of organisms

	Advantages	Disadvantages
Video photography	• Records a permanent visual record of the undisturbed sea bed, retaining spatial realtionships, biogenic structure, and habitat or species associations • Accurate and precise estimates of abundance can be obtained for epifauna • Can be reanalysed at a later date to answer new questions • Samples relatively large areas (100–1000 s m^2) • Size measurements of organisms and geological features can be made • Non-destructive	• A need to use other techniques to collect reference organisms • Difficult to identify organisms from footage if reference specimens are not available • Can be difficult to calibrate for varying distance from the seabed, and in three dimensions when calculating percentage cover • Lengthy viewing times and analyses escalate cost • Sea-state and current conditions may compromise data quality
Still photography	• As for video (above) but generally with higher optical resolution, enabling more accurate measurements, particularly of smaller taxa	• As for video (above) but smaller spatial coverage

8.2   New Zealand's deep-sea sampling capacity and resources

Sampling in the deep ocean requires a specialised research platform capable of working in offshore waters with winch/wire combinations to enable sampling gear to be deployed to abyssal depths. Presently, the only vessel that operates specifically in the NZ EEZ with such a specialised capability to sample abyssal depths is New Zealand's RV *Tangaroa*. NIWA has undertaken a major upgrading of the RV *Tangaroa*, with the commissioning of a dynamic positioning system (DPS). A new deep-ocean winch capable of holding 10 000 m of 16 mm wire has been available since October 2009. This capability allows static gear, such as grabs and corers, to sample to water depths in the vicinity of 6000–6500 m, based on a wire-to-depth ratio of 1.5 (see below). As of October 2009, the vessel has approximately 6000 m of 16 mm coring wire that can be used for deep-sea coring and dredging operations, allowing sampling to water depths of 3000–3500 m.

The difference in wire length and the sea-floor depth that can be sampled arises because of the relatively low drag arising from the deployed gear and the high weight involved in large pay-outs of wire. For example, from a depth of 3000 m and deeper, the ratio of wire length to depth (scope ratio) is only 1.5, contrasting with a ratio of about 2 at 1000 m depth (see Gage & Tyler 1991).

While New Zealand has all the gear commonly used in deep-sea research, such as epibenthic sleds, beam trawls, small Agassiz trawls (1 m opening) and box and multi-corers, the depth limitation of the biological sampling gear is set by the length of wire available. While several New Zealand institutions, including Otago University, Auckland University's Leigh Laboratory and Victoria University of Wellington, have gear to sample shallow benthic habitats (e.g., small grabs), it is generally too light to sample effectively below 500 m. NIWA also has deep-sea sampling gear available (see Table 18) (pers. comms Steve O'Shea, AUT; Mark Costello, Auckland University; Conrad Pilditch, Waikato University; Keith Probert, Otago University).

Currently, there is no sampling equipment, such as high-pressure, low-temperature incubation facilities, for isolating and maintaining piezophilic bacteria from New Zealand waters.

Table 18: Summary of deep-sea sampling gear available at New Zealand institutions.

	Gear Type	NZ Institution
Single-beam echo-sounder	Bathymetry only (e.g., 12 kHz) Sub-bottom (e.g., 3.5 kHz)	NIWA (hull-mounted, RV *Tangaroa*) NIWA (hull-mounted, RV *Tangaroa*)
Multibeam echo-sounder (swath mapping)	EM300 (Kogsberg, 30 kHz, 135 beams, 1 "ping" every 6 seconds, 150° angular coverage, accuracy ~ 0.2% of water depth, ~ 5 m horizontal (DGPS), depth coverage 100–3500 m); upgraded to EM302 in 2010	NIWA (hull-mounted, RV *Tangaroa*)
Trawl/dredge	Beam trawl (4.2 m width, 0.4 m high, 30 mm mesh opening) Beam trawl Agassiz trawl (1 m width, 0.5 m high, 30 mm mesh) Rock dredges	NIWA Otago University NIWA NIWA
Epi- and Hyperbenthic sled	Epi-benthic sled ('Seamount', 1 m width, 30 mm mesh opening) Brenke hyperbenthic sled (1.3 m width, 0.36 m high, 50 mm mesh)	NIWA NIWA

	Gear Type	NZ Institution
Corers	Ocean Instruments MC-800 Multicorer (10 cm diameter, 90 cm-long cores, maximum 8 cores per deployment)	NIWA
	Oktopus box corer (50 x 50 x 50 cm box with vegematic subsampling grid)	NIWA
	NZOI box corer (old) (50 x 50 x 50 cm box)	NIWA
Cameras	Deep-Towed Imaging System (DTIS: still and video photography, maximum depth rating 6000 m, but currently operational to approximately 3000 m)	NIWA
	Baited Underwater Video (BUV)	NIWA

8.2.1 Marine scientists

Accurate taxonomic treatment of the deep-sea fauna requires expert taxonomists. This is particularly relevant to abyssal species because a large proportion of the fauna that is encountered is new to science. Globally, the numbers of taxonomic experts are diminishing, so accurate knowledge of marine organisms, especially of taxonomically novel deep-sea species, is increasingly difficult to acquire. Fortunately, taxonomic experts for several taxa that dominate the deep-sea fauna are based in New Zealand institutions. For example:

Dr Kareen Schnabel	Crustacea	NIWA
Dr Anne-Nina Lörz	Crustacea	NIWA
Dr Dennis Gordon	Bryozoa	NIWA
Dr Michelle Kelly	Porifera	NIWA
Dr Geoff Read	Polychaeta	NIWA
Dr Daniel Leduc	Nematoda	NIWA
Peter McMillan	Fishes	NIWA
Dr Malcolm Francis	Fishes	NIWA
Dr Andrew Stewart	Fishes	Te Papa
Dr Clive Roberts	Fishes	Te Papa
Dr Bruce Marshall	Mollusca	Te Papa

There is currently a lack of taxonomic expertise within New Zealand for various taxa that are often encountered in deep-sea habitats, such as: Isopoda, Cumacea, Tanaidacea and corals.

8.2.2 Taxonomic Collection resources

In the face of changing technology and concepts, it is often the specimens of particular species that can provide the basic foundation for testing various scientific hypotheses. Specimens supply the fundamental, raw biological data but rely on the availability of authoritatively identified material and/or identification capability. Registered type specimens provide a reference point for the determination of species and for resolving identifications and synonymies in the case of previously named species.

Samples collected during deep-sea voyages have to be housed, curated and databased in a safe, formally managed facility, and data made accessible to experts in the wider scientific and taxonomic community. Two New Zealand natural history collections have historically processed the majority of deep-sea samples, the Museum of New Zealand Te Papa Tongarewa and the NIWA Invertebrate Collection (NIC) (formerly the New Zealand Oceanographic Institute, now NIWA). While Te Papa has recently expanded to house the most significant marine fish and seabird collection in the New Zealand region, plus some historic invertebrate samples, the NIC now houses the largest New Zealand

collection of many groups of marine invertebrates and operates with funding as a "Nationally Significant Collection and Database" provided by core funding (formerly part of the Foundation for Research, Science and Technology (FRST), now the Ministry of Research and Innovation (MSI). The MSI-funded Outcome Based Investment (OBI), entitled 'Effective management of marine biodiversity and biosecurity' is a multi-year research partnership managed by NIWA that supports research on marine biosystematics as well as the maintenance and support of the NIC.

Both collections operate under current national standards of best practice and collections are managed according to international Natural History Collections standards (Rose et al. 2009), with full-time staff dedicated to the safe housing and databasing of materials received. Other institutions in New Zealand, such as Auckland and Canterbury Museums, also have smaller collections of deep-sea biological material.

Sediment and rock samples collected using a variety of corers, grabs and dredges throughout the New Zealand EEZ since 1955 are housed at NIWA in the Geology Sample Collection. This comprises more than 6500 surface-sediment samples, 1525 rock samples and approximately 1600 sediment cores. Although not comprehensively inventoried, most of the surface-sediment samples from the New Zealand region have been analysed for grain-size and calcium carbonate content, as reflected in the use of these data in sediment-chart compilations (e.g., Mitchell et al. 1989). Approximately 240 rock-sample locations are from deeper than 1500 m, including many of the volcanic Kermadec Ridge–Havre Trough samples (e.g., Wright 1993, 1994) and manganese nodules from the Campbell Plateau and Tasman Basin (e.g., Glasby & Wright 1990; Graham & Wright 2006). These have been analysed for their chemical composition (major and trace elements). The deepest rock sample is from the Kermadec Trench (5355 m). Many sediment cores have also been analysed for a variety of parameters, including down-core grain size, calcium carbonate and stable isotopes (C and O).

In addition, NIWA holds all paper and digital records of bathymetric and sub-bottom profiler data collected in the New Zealand region by NZOI/NIWA, although some historical data are also held by GNS science. Much of the archived data, however, are kept only as paper records, as is information on sediments from archived sediment and core samples. The NIWA datasets are in the process of being captured electronically. Digital bathymetric data are collected and maintained by NIWA and to some extent by GNS Science. NIWA archives and manages New Zealand-wide digital bathymetric data under contract to Land Information New Zealand as part of the "Digital Data Repository".

9. CONCLUSIONS

1) The objective of this review has been addressed through the provision of a physical and geographic description of the known deep-sea habitats, organisms and historical sampling effort in the New Zealand region. We have determined that a total of 1489 benthic gear deployments below 1500 m have been conducted by New Zealand-based scientific sampling initiatives since 1955. Most of these expeditions, however, were focussed on obtaining geological samples, primarily sediments or rocks, not organisms. A review of benthos sampling and photography achieved by New Zealand-based expeditions (i.e., not originating overseas), indicates that fewer than 20 benthic samples have been taken from New Zealand's abyssal waters below 3000 m by New Zealand expeditions over the past 20 years.

2) Taxonomy-based studies of benthic taxa reported in New Zealand waters below 1500 m have been reviewed. Only species considered to be benthic (i.e., living on or in the seafloor) or demersal (i.e., swimming near and associated with the seafloor) were included in the review. Bacteria (8 species) are discussed separately from the kingdoms Protozoa (293 species) and Animalia (785 invertebrate species, 56 fish species). An extensive checklist of all reported taxa of Protozoa and Animalia is provided, giving the name (genus and/or species), authority, endemism status and known depth range. To date, most deep-sea species in the New Zealand region are known from only one or a few stations, many of which were collected by historical

expeditions, such as the *Challenger* and *Galathea*. Consequently, many of these specimens are held in overseas institutions and are not immediately available for scientific study in New Zealand.

3) All ecological studies that include assemblage descriptions (meio-, macro-, and megafaunal including demersal fish) from New Zealand waters have been reviewed, including studies in which data from below 1500 m depth are incorporated with information from shallower depths. A more restricted review of international literature resulted in a review of key studies to place the current state of New Zealand knowledge of deep-sea biological processes in a global context. The review documents a profound lack of information about deep-sea invertebrate and fish assemblages in New Zealand waters across all types of deep-sea habitats, with the most complete data limited to soft-sediment benthos from the Chatham Rise and to abyssal and hadal fauna (macroinvertebrates and demersal fish) from the Kermadec and Tonga trenches. This deficiency is particularly evident in comparison with other geographical regions in the world, for which detailed assemblage descriptions and data from process-orientated studies of deep-sea ecosystems are often available.

4) All process-orientated benthic studies from New Zealand and selected key studies from the international literature have been reviewed. In New Zealand waters, process-orientated studies to date have been limited to short-term (i.e., one-off) examinations of pelagic-benthic coupling and ocean productivity on the Chatham Rise slope and of trophic interactions in the Kermadec and Tonga trenches. In contrast, ecosystem studies in other regions (i.e., the northern Atlantic and Pacific Oceans), provide comprehensive and long-term datasets of pelagic-benthic processes, trophic interactions, food webs, benthic productivity, disturbance and (re)colonisation.

5) Geological studies that provide records of benthic fauna found below 1500 m depth include results from two surveys in the Campbell Plateau area. Separate assessments of the distribution of polymetallic nodules and of sediment dynamics include seafloor images of echinoderms at the sediment surface, documenting the presence of deep-sea ophiuroids and holothurians in this under-studied area.

6) Availability of data so far unanalysed: We provide an evaluation and summary of the metadata collated from the NIC/Te Papa collections and databases, NIWA's image holdings and the potential use(s) of such data. An exhaustive search of multiple data sources has been carried out. Information has been collated on data from the NIWA Invertebrate Collection's *Specify* database, NIWA's image and video archives, the Ministry of Fisheries *Trawl* database and the Museum of New Zealand Te Papa Tongarewa's *KE EMu* database. The potential uses of such data have been identified.

7) Information/data gaps have been determined. The seafloor area of the New Zealand Exclusive Economic Zone (EEZ) deeper than 1500 m has been calculated (over 65% of EEZ), as well as the area sampled scientifically by towed (approximately 13.9 km^2) and static gear (approximately 0.000 620 km^2). The numbers are calculated from the stations in the 'CruisesDB' database. This database comprises all NIWA stations including those in the MFishresearch *Trawl* database and 'biods' biodiversity database, as well as stations from *Specify*.

These estimates translate to less than 0.001 % of the seafloor area of the EEZ below 1500 m having been sampled scientifically. More than 8000 images (including prints, negatives and digitised images) have been taken of the seafloor below 1500 m before the HADEEP initiatives. The total area represented by these images equates to 0.016 km^2. Information on the understudied fauna and the unanalysed photographic images has been summarised. In view of the dearth of ecological studies, there is a distinct lack of knowledge of New Zealand deep-sea assemblages, including benthic fauna and demersal fish. There are no detailed descriptions of faunal assemblages from representative deep-sea habitats, and the lack of baseline data prevents understanding of fundamental ecosystem processes.

8) Capacity for deep-sea research: A brief assessment of the types of sampling equipment and resources required to undertake deep-sea research in the New Zealand region, and whether New Zealand institutes have and/or are likely to possess such capacity is provided, along with photographs of the main gear types and a table summarising the advantages and disadvantages of the types of gear used for sampling of deep-sea benthos. While New Zealand currently lacks the capacity to sample towed gear deeper than 3000 m, most of the standard sampling gear for deep-sea research is available in New Zealand.

10. RECOMMENDATIONS FOR FUTURE ACTIVITIES AND RESEARCH

The recommendations below for potential future activities and research in the deep sea are drawn from the above review and have been developed by a recommendations team with scientists at NIWA, Te Papa and the University of Otago. The recommendations are set in the following contexts:

1. The gear required to sample the deep sea
2. Future analysis of existing data and samples
3. Research questions to develop our knowledge of New Zealand's deep-sea habitats
4. Identification of geographic regions/habitats/locations for future sampling
5. The need for an integrated deep-sea research programme in New Zealand.

10.1 Gear requirements

10.1.1 Recommendations for future purchases

- 7000 m of 20–22 mm wire for deep-sea trawling and sled deployments
- 8000 m of 10 mm conducting cable for sampling water-column physical and biological environments (CTD/MOCNESS) and seafloor assemblages (DTIS)
- tapered wire or special warp to reduce weight and winch space
- high-density-foam trawl-floats with 6000 m rating
- back-up seabed-sampling equipment, such as is used in coring (e.g., multi-corer, box corer)
- development of Australasian benthic lander, ROV and/or AUV capabilities and/or fostering of international collaborations

10.1.2 Rationale

The only New Zealand vessel capable of sampling the seafloor below 1500 m is RV *Tangaroa*, managed by NIWA Vessel Management Ltd. The capacity and capability of standard deep-sea gear deployed by RV *Tangaroa* is summarised in Table 19.

A major 2010 refit has significantly increased *Tangaroa's* deep-sea capability, but there are still aspects of deep-sea sampling that will require further attention. As part of the refit, a larger deep-sea winch has been fitted that holds 10 000 m of 16 mm coring wire, enabling vertical deployment of gear to depths greater than 6000 m. This wire is suitable for deployment of corers and other single-wire mechanical samplers (e.g., grabs) that sample directly below the vessel. However, there is as yet no wire facility for the routine use of towed gear, such as trawls and sleds, to depths below approximately 2000 m. Larger trawl gear types must be deployed over the stern using the trawl winches, which currently each hold 4000 m of 28 mm wire, and therefore sampling by towed gear is limited to shallower than 3000 m depth.

In order to sample routinely at depths below approximately 2000 m, it will be necessary to upgrade some systems aboard *Tangaroa* in line with the new winch capability. For instance, the underwater

electronics (net monitors, bottom contact sensors) currently used on the vessel are, for the most part, rated to a maximum depth of 2000 m; the depth to which the vessel can presently trawl.

The DTIS camera system is rated to 6000 m, but the acoustic tracking system presently in use (Simrad HPR 410) has a maximum range of approximately 2000 m. The new HiPAP system that will replace the HPR in 2010 has a maximum range from ship to transponder of approximately 4000 m, which is the best that can be achieved with current technology.

Table 19: Types of benthic gear with maximum sampling depth capacity from RV *Tangaroa* October 2009.

	Capacity and capability	Equipment deployed
Deep-sea winch	• Maximum capacity 10 000 m of 16 mm wire • Current wire on winch 5 600 m • Potential sampling depths below 6 000 m for vertical deployments (corers, grabs)	• Gravity corers • Multicorer • Grabs • Box corers
Camera winch	• Maximum capacity 10 000 m of 10.5 mm conducting cable • Current wire on winch 2 000 m • Possible to get to 6 500 m bottom depth	• DTIS camera system • Other video and still camera systems
CTD winch	• 6 000 m of 10.5 mm conducting cable • Possible to get to about 4 000 m	• DTIS camera system • Other video and still camera systems
Trawl winches	• 4 000 m 28 mm wire on each winch • Trawls known to get to 2 700 m, possibly to 3 000 m • Current wire on winch 4 000 m per side	• Beam trawl • Epibenthic sleds • Brenke sleds • Demersal trawls

NIWA is the only New Zealand research institution with deep-sea sampling capability at present, including sleds, corers, grabs and cameras. However, while there are backup units for sleds and DTIS, this is not the case for the multicorer and box corer. Benthic landers provide the ability to measure and observe benthic processes and communities in situ, but such capability is not available readily at New Zealand institutions, requiring collaborations, partnerships and use of borrowed gear as mentioned above (see Chapter 8.1.11) in the case of the Te Papa/Massey University Marsden project and the HADEEP expeditions to the Kermadec Trench. The latter, conducted with partners from Aberdeen and Tokyo Universities, involved NIWA scientists in 2007 and 2009 and future voyages are planned for 2011 and 2012. Such scientific relationships may continue in the future, but typically reqire a long lead-in time and funding to allow the use of expensive overseas gear in New Zealand-based research programmes. ROVs and AUVs are, in many respects, the optimum tools for exploration of the deep-sea, as demonstrated by their use by major marine research institutions and commercial operations worldwide (e.g., Rex, 2010). However, purchase and operational costs are very high. The *Tangaroa* refit, particularly the installation of a dynamic positioning system to enable the ship to hold station and manoever precisely, can through collaboration allow for the deployment of ROVs or AUVs in the future.

10.2   Future analyses of existing data and samples

The review has revealed that there are many existing samples and data that can be analysed to improve our knowledge of deep-sea biodiversity abundance and distribution. There are three sets of recommendations, pertaining to images, specimen database information and unidentified specimens.

10.2.1 Recommendations concerning image data

- Digitise and store images in ATLAS database (complete with metadata)
- Analyse images taken below 1500 m

10.2.2 Rationale concerning image data

The large collection of nearly 5000 negatives and 2000 half-tone prints that exist in the NIWA image collection should be digitised as soon as possible because this is a valuable historical resource that is deteriorating over time and without digital backup is vulnerable to loss through accident. Digitising these images will enable quantitative analysis to be undertaken that is not possible with analogue versions and will make the archive available to a broader spectrum of research initiatives. For example, the digital images produced by this process would be immediately available for uploading into the NIWA image database (ATLAS) once they have been tagged with the correct metadata. The images could then be analysed to identify major types of deep-sea organisms, their distributional patterns and major habitat type (substratum type), e.g., the biota of manganese-nodule fields on the Subantarctic Slope.

10.2.3 Recommendations concerning specimen database information

- Complete registration of all deep-sea invertebrate specimen lots held at NIC, in the nationally significant database held by NIWA
- Reconcile invertebrate specimen data in NIWA's *Specify* and Te Papa's *KE EMu* databases
- Complete recording of metadata from all New Zealand deep-sea benthic databases
- Develop an electronic means to access all marine invertebrate specimen records and images (across multiple New Zealand databases) to enable robust future analyses
- Analyse available deep-sea fish records

10.2.4   Rationale concerning specimen database information

A large quantity of invertebrate material collected in New Zealand waters below 1500 m remains unregistered in the NIC. The sample lots are derived from known collections made in the past and registration of this material will greatly enhance our knowledge of deep-sea biodiversity. Ultimately, the entire specimen collection information held at New Zealand and international institutions should be made accessible electronically, which will require reconciliation of station and taxonomic information across institutions. Once this reconciliation is achieved, the specimen-based data will provide a powerful resource for many research questions. For example, analysis of species abundance and diversity could be mapped across deep-sea habitats and such information could then feed into management and conservation strategies if required, for example, as part of appraising deep-water mining consents (Wright, 2010). However, not all specimens are linked to relevant metadata, such as geographic position. The fish data provided by the Ministry of Fisheries *Trawl* database and the Te Papa *KE EMu* database are of high taxonomic resolution and already reconciled. Therefore analysis of these datasets could proceed immediately.

10.2.5   Recommendations concerning unidentified specimens

- Identify specimens to lowest possible taxonomic unit (ideally species-level)
- Formally describe species new to science

10.2.6   Rationale concerning unidentified specimens

The complete registration of specimen lots from known cruises and stations below 1500 m (e.g., Kaikoura Benthic expedition 1982 led by K. Swanson on (the former) R/V *Tangaroa*) into the NIC *Specify* database is guaranteed to uncover species new to science. In addition, a large proportion (50–100% depending on the phylum) of specimens already registered from below 1500 m are not identified to species level. In many cases, this reduces our ability to make meaningful comparisons of biodiversity between regions and habitats within New Zealand and between New Zealand and other regions. It is clearly important for unidentified material to be processed. However, the ability to identify all material in New Zealand is limited by the availability of taxonomists with an expertise in the faunal groups that are common in the deep-sea (Table 20).

Table 20:   **Invertebrate samples held in the NIWA Invertebrate Collection (NIC), level of identification, taxonomic expertise in New Zealand, available literature and general diversity for the taxa groups in deep-sea waters. Taxonomic expertise indicates whether active research taxonomists are present in New Zealand: * parataxonomic expertise is available at NIWA, e.g., all Echinodermata and some coral and anemone groups; (*) expertise in some crustacean groups is absent or at an elementary level in New Zealand, e.g., Isopoda and Cumacea; (#) under active study by international experts; (@) some expertise exists for shallow-water forms but not deep-water species. Recent taxonomic literature — indicates whether or not the New Zealand fauna has been dealt with in the past two decades. General diversity gives an overall indication of the level of species diversity.**

Phylum	No. of records in Specify	No. of records identified to species	Taxonomic expertise in NZ	Recent taxonomic literature available	General diversity
Annelida	49	9	Present	Present	High
Arthropoda	610	142	Present (*)	Partial	High
Brachiopoda	3	1	Present	Partial	Moderate
Chaetognatha	3	0	Absent	Present	Low
Cnidaria	166	23	Absent* (#)	Present	Moderate to high
Bryozoa	42	22	Present	Present	High
Echinodermata	529	112	Absent* (#)	Present	Moderate
Hemichordata	1	1	Absent	Absent	Low
Kinorhyncha	4	1	Absent	Absent	Low
Mollusca	103	37	Present	Present	High
Nematoda	1	0	Absent (@)	Absent	High
Nemertea	1	0	Absent	Present	Low
Platyhelminthes	2	0	Absent	Absent	Low
Porifera	79	14	Present	Present	Moderate to high
Priapulida	1	0	Absent	Absent	Low
Protozoa	22	8	Present	Present	Moderate to high
Sipuncula	9	0	Absent	Present	Low
Tunicata	6	1	Absent	Absent	Low

Foraminifera are well documented from New Zealand waters below 1500 m (see Chapter 2.2); unfortunately it is not possible to know whether the specimens were alive or dead when sampled. For future collections of samples, we therefore recommend the use of standard colouring procedures (e.g., Rose Bengal) when sampling Foraminifera. This will allow for the selection of live specimens during sorting and meaningful biological analysis.

10.3   Research questions

10.3.1 Recommendations concerning research questions
- Develop through discussion with the wider science community agreement on management goals and resulting questions that can direct future research of New Zealand's deep-sea biodiversity.

10.3.2 Rationale concerning research questions

The present review demonstrates that the most basic questions regarding biological diversity and ecosystem function in New Zealand waters below 1500 m cannot be fully answered yet. Further research could focus on addressing questions such as:

- What benthic species are present in New Zealand's deep sea and what is the nature of their distribution and abundance?

Specific research questions would pertain to species-assemblage definition, diversity documentation, taxonomic and phylogenic relationships, and the evolution of the deep-sea fauna and biogeography. Addressing these questions would clearly be set in both global scientific and policy contexts. The latter includes the New Zealand Biodiversity Strategy, which in turn is linked to the Convention on Biological Diversity and the newly emerging Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), so that decisions concerning the deep sea are made on the basis of the best available scientific information on conservation and sustainable use of biodiversity and ecosystem services.

- What are the historical and ecological drivers of biodiversity in different habitats of the deep sea and how comparable are these drivers between the different environments?

This would extend aspects of the new MSI (ex FRST) programme 'Vulnerable Communities of Deep-Sea Environments' (MSI-funded 2009–2015) into deeper water. The current programme is limited to water depths shallower than 1500 m.

- What are the functional aspects of deep-sea ecosystems?

For example, carbon processing, nutrient cycling, 'keystone' species, trophic structure, benthic-pelagic coupling and biogeochemical roles. Aspects of similar work are currently being studied in the MSI (ex FRST)-funded programme 'Consequences of Earth-Ocean Change' and the 'Coasts & Oceans' OBI.

- What is the effect of human and other influences on biodiversity?

For example, climate change and ocean acidification, changes in benthic-pelagic coupling/foodweb dynamics; mining — physical removal of nodules, cobalt-rich ferromanganese crusts, seafloor massive sulphides, hydrates, oil and gas; 'deep' fisheries — species and habitat disturbance; toxic-waste disposal — direct CO_2 sequestration in sediments and dumping.

- If there are impacts, what are the best ways to manage/conserve deep-sea biodiversity?

For example, accounting for species assemblage differences and population connectivity, informing MPA design and managing economic interests.

10.4   Future sampling

10.4.1 Recommendations concerning future sampling

- Sample representative habitats deeper than 1500 m, in particular the abyssal plains
- Sample the deep-sea along environmental gradients
- Sample the deep-sea in areas where resource exploitation may take place in the future
- Establish long-term monitoring stations in the deep-sea.

10.4.2 Rationale concerning future sampling

The present review has revealed that very few biological samples exist from New Zealand waters below 1500 m, especially deeper than 3000 m. Most of these samples were collected during geological surveys and contain little biological information. Deep-water soft-substratum organisms are under-represented in New Zealand collections.

In terms of major habitat types, only a handful of samples have been recovered from abyssal plains — the habitat with the largest area in the EEZ below 3000 m. Few samples have also been taken from prominent deep-sea habitats, such as troughs, channels, trenches, slopes (such as the Subantarctic Slope), deep rises, seamounts and ridges (particularly the Colville Ridge). Geographically, fewer samples have been taken from the southern part of the EEZ.

If we are to begin to define the deep-water fauna of the New Zealand region, there is a need to establish representative sampling of the deep sea throughout the EEZ. Any new sampling effort should also take account of environmental gradients and locations that may be sites of future resource use that will potentially impact upon deep-sea biodiversity. for example, fishing for toothfish below 1500 m on the Macquarie Ridge and in the Ross Sea, seafloor sulphide mining on the Kermadec Ridge and Colville Ridge seamounts, and manganese-nodule mining on the Subantarctic Slope. Knowledge of these areas will be required for effective and sustainable resource management and biodiversity conservation. Sampling in all the aforementioned habitats and areas could lead to the establishment of long-term monitoring stations that would allow for the detection of change (including ocean acidification and other climate-change-related phenomena such as reductions in food supply to deep-sea benthos). Monitoring efforts could make use of currently established sites to the south and north of the Chatham Rise or the establishment of seafloor observation sites (e.g., off Cook Strait in the vicinity of the Australian-Pacific plate-boundary transition, characterised by the occurrence of deep-sea gas hydrates and cold seeps).

10.5   Establishing an integrated research programme in the New Zealand deep sea

10.5.1 Recommendations concerning a deep-sea research programme

- A programme of environmental research in the EEZ deeper than 1500 m should be formulated, early in the proposed UN 2011–2020 Decade of Biodiversity
- This should involve New Zealand and international partners

10.5.2 Rationale concerning a deep-sea research programme

One of the six areas of of priority action for New Zealand's Biodiversity Strategy is to 'Manage the marine environment so that biodiversity is sustained'. Habitats below 1500 m are in the scope of the New Zealand Biodiversity Strategy as 'offshore areas within New Zealand's jurisdiction (the Exclusive Economic Zone)'. The Ministry of Fisheries Benthic Protection Areas (BPA) are designed to protect seabed biodiversity in 30% of the EEZ, and a significant proportion of BPAs is in water depths below 1500 m. The implicit assumptions are that biodiversity per se is protected sufficiently by BPAs and that impacts from fishing are mitigated by their presence. Whether or not this is true is presently hard to assess given the dearth of knowledge of deep-sea biodiversity. Further, no habitat below 1500 m is in a potentially fished/anthropogenically exploited area.

The diversity of some New Zealand shelf taxa (e.g., Porifera, Octocorallia, Bryozoa, Brachiopoda, Kinorhyncha) is among the richest in temperate parts of the globe, matching that in the area included in the European Register of Marine Species, which is 5.5 times larger than the New Zealand EEZ, with high levels of endemism on the New Zealand shelf (Gordon et al. 2010). It remains to be seen whether the pattern of shelf diversity extends to deeper water and what this would mean scientifically and for management. Biogeography is closely linked to biodiversity (Brandt et al. 2004). Biogeography deals with the geographic distribution of species and taxa and it can help to identify the origin of species on the basis of their phylogenetic relationships. New Zealand's unique geological, geographic and hydrographic settings provide the opportunity to: A) investigate specific deep-sea structures such as continental margins, abyssal plains, canyons and trenches, B) test general large-scale deep-sea hypotheses and C) investigate evolutionary questions, all within the EEZ. Below, we discuss several hypotheses in these contexts and propose a list of those that may be fruitfully explored in our region [see end of section].

A) Biodiversity, large-scale hypotheses. Ramirez-Llodra et al. (2010) summarised global knowledge of deep-sea ecosystems and claimed that deep-sea biodiversity is among the highest on the planet, mainly composed of macro- and meiofauna, with high evenness. This is true for most continental margins and abyssal plains, with hotspots of diversity found on some seamounts or in cold-water coral habitats. Contrasting these patterns are hydrothermal vents, where biodiversity is low, but abundance and biomass are high and the communities are dominated by a few species. Consequently, two large-scale hypotheses have been proposed for consideration in the deep sea:

(1) There exists a unimodal relationship between diversity and depth. This is often observed, with a peak at intermediate depths (2000–3000 m) although this spatial trend is not universal because it is apparent that particular abiotic processes can modify the relationship. Although diversity-depth trends are not completely understood, it seems likely that they are shaped by complex interacting factors that operate at different temporal and spatial scales (Levin et al. 2001; Stuart et al. 2003).

(2) There is a poleward trend of decreasing diversity. This gradient is supposed to be particularly pronounced in the Northern Hemisphere (North Atlantic and Norwegian Sea), but studies on taxonomic groups other than the gastropods, bivalves and isopods tested by Rex (1993) do not support this notion (e.g., Lambshead et al. 2002), and there appears to be no benthic latitudinal diversity gradient in the Southern Hemisphere (Gray 2002; Gage et al. 2004).

New Zealand has the ideal setting to test both of these hypotheses since the EEZ covers deep-sea areas from the shelf to hadal depths, and in particular the abyssal plains around the New Zealand landmass have an average depth of 4500 m. Recent investigations of Antarctic deep-sea biodiversity have shown a very high abundance and diversity of benthic fauna (Brandt et al. 2007a, b). If the subantarctic abyssal benthos off New Zealand is similarly high, a latitudinal gradient of the New Zealand deep-sea benthos might occur in the opposite direction than suggested by Rex (1993), with higher diversity

towards the pole. Adapting the standard sampling equipment and procedures established during the Census of Marine Life would set New Zealand's deep sea biota in a global context.

B) Evolutionary questions. The source-sink hypothesis for macrofauna, formulated by Rex et al. (2005) states that abyssal populations in many species of molluscs are regulated by a balance between extinction arising from vulnerabilities to Allee effects (i.e., reproduction and survival of individuals decrease for smaller populations) and immigration from bathyal sources, with some non-reproductive populations occurring at abyssal depths. In other words, abyssal assemblages are supposed to depend on immigration from bathyal populations. However, the source-sink model remains to be tested for taxa other than molluscs in the North Atlantic, and for all taxa in the largest abyssal basins in the Pacific Ocean (Smith et al. 2008; Ramirez-Llodra et al. 2010). It does not seem to apply to a number of highly successful and species-rich taxa in the abyss, including isopods, polychaetes, holothurians and asteroids (Ramirez-Llodra et al. 2010; Young 2003 and references therein; Smith et al. 2008 and references therein). Our third hypothesis is that the source sink theory does not apply to the deep-sea environment of New Zealand.

The taxonomic composition, size, diversity patterns and functioning of deep-sea communities are a product of evolutionary legacy and ecological processes (Ramirez-Llodra et al. 2010). New Zealand's geological history, temporal and geographical isolation, and physiographical complexity have helped shape the character of its marine biodiversity (Gordon et al. 2010 and references therein). Following the previous 80 million years or more of evolution of the marine biota, the Pleistocene glaciations, covering the past 2.6 million years, have been considered important in determining the character of much of New Zealand's present-day shelf biota. Hypotheses to consider include: New Zealand's deep-sea has been colonised by the shelf fauna. The fauna from the deep-sea basins is linked to the shelf fauna. [Hypothesis 4]

C) New Zealand's unique hydrographic and geological settings. The uniqueness of the hydrography in the New Zealand region has the potential to deliver several testable hypotheses regarding the connections of benthic fauna to the overlying water masses. Smith et al. (2008) showed that ecosystem structure and function in the abyss are modulated strongly by the quantity and quality of detrital food material sinking from the surface ocean. While the Kermadec Trench and neighbouring parts of the abyssal plain are overlain by subtropical surface waters (i.e., warm, nutrient-poor, low oxygen), bottom-water layers are typified by the Deep Western Boundary Current (see Figure 2) that transports Antarctic Bottom Water (cold, high oxygen, salty) into the New Zealand region. The intervening water masses are also important as it is thought that these will be the locus of observations of human-induced ocean warming and acidification, with flow-on effects on benthic organisms at water depths of 800–1500 m. Subtropical surface waters show an annual spring bloom significantly increasing the detrital food supply to deep-sea communities. In contrast, south of the Subtropical Front, subantarctic surface waters are relatively cold and nutrient-rich, and no spring blooms take place, although organic carbon flux at this time can be important (Nodder et al. 2005). One might hypothesise, therefore, that 1) particulate-organic-carbon flux from the euphotic zone controls patterns of biomass and abundance in New Zealand's deep-sea benthos down to 10 000 m, and 2) a significant difference in biomass and abundance of deep-sea benthos north and south of the Subtropical Front will be observed. [Hypotheses 5a, 5b]

A focus of New Zealand's deep-sea research should be the Kermadec Trench. It has a globally unique hydrographic feature — in the top 600 m, warm subtropical water of the Tasman Inflow trends northwards above the 3500–10 000 m Deep Antarctic Bottom Water, which also flows northwards, via the Deep Western Boundary current. It is likely that Antarctic-derived taxa occur in the Kermadec Trench and have spread shelfwards from there (e.g. the bryozoan *Amastigia antarctica subtropicalis*). [Hypothesis 6]

Initial studies of the Kermadec trench fauna via baited camera and trap landers (Jamieson et al. in press) suggest an ecotone between abyssal and hadal environments based on the different scavenging-amphipod assemblages collected between 6007 and 6890 m. Based on the bathymetric distribution of

amphipod species, Kamenskaya (1981) has suggested an ecotone between abyssal and hadal environment for Pacific trenches generally. [Hypothesis 7]

The most geologically diverse components of the deep-ocean floor are continental margins, with high habitat heterogeneity (Levin & Dayton 2009; Menot et al. 2010; Levin et al. 2010). Passive margins occur where an ocean rift has split a continent in two, generating an ocean basin in between. Along active margins, the variability of habitats for life is even more striking (see Ramirez-Llodra et al. 2010). Active margins are found where the ocean floor has cooled so extensively that it sinks back into the Earth's interior, forming deep ocean trenches along subduction zones. Subduction zones extend along almost the entire length of the New Zealand EEZ.

Another very heterogenous deep-sea habitat is represented by canyons and channels. The EEZ has several such systems (see Chapter 1.3). Canyon heads and walls can present rocky outcrops suitable for sessile suspension feeders such as cnidarians and sponges, while the axis of the canyon can accumulate soft sediment and have a fauna dominated by deposit feeders, scavengers, and predators such as echinoderms, crustaceans and fish (Ramirez-Llodra et al. 2010). Over the past 10 000 years, uplift of the Southern Alps has continued at an average of 10 mm or more a year. It is offset by erosion, which results in huge quantities of sediment being transported to both coasts, onto the shelf and into the deep sea via canyons and channels. Because of their higher habitat heterogeneity and accumulation of organic matter, canyons and channels are predicted to support a higher diversity and biomass than the adjacent slope or plains. [Hypothesis 8]

10.5.3 Some testable hypotheses for the New Zealand deep sea

- Hypothesis 1. New Zealand's deep-sea diversity will belong to the highest levels of diversity known from abyssal depth worldwide.
- Hypothesis 2. A latitudinal diversity gradient is expressed by New Zealand's deep-sea fauna, with an increase from subtropic to subantarctic waters.
- Hypothesis 3. The abyssal assemblages are independent from the bathyal populations, this will apply to benthic taxa having larvae as well as brooders.
- Hypothesis 4. The currently known high endemism of New Zealand's shelf fauna is matched by an equally high degree of endemism in the deep sea.
- Hypothesis 5a. Particulate-organic-carbon flux from the euphotic zone controls patterns of biomass and abundance in New Zealand's deep-sea benthos down to 10 000m; 5b: A significant difference in biomass and abundance of deep-sea benthos north and south of the Subtropical Front will be observed.
- Hypothesis 6. That Antarctic Fauna has settled in the Kermadec Trench and expands from there towards the NZ abyssal plains and shelf (known as emergence).
- Hypothesis 7: The existence of an ecotone in the Kermadec trench between the abyssal and the hadal habitat remains to be tested with other faunal elements and more samples.
- Hypothesis 8: The high habitat heterogeneity of the active continental margins, canyons and channels will be matched by high biodiversity.

10.5.4 Anthropogenic impacts

One key question is whether human influences are noticeable in deeper water. Three areas of interest are discussed briefly below.

Fishing. Since the 1990s, the most dramatic human impact on deep-water communities is associated with fishing (Ramirez-Llodra et al. 2010). In the past 30 years, the catch per tow of the main deep-water fish species has declined by up to 99% (Devine et al. 2006). Although fishing activity occurs down to only 1500 m (Clark et al. 2006), Bailey et al. (2009) have shown that its impact is found in excess of 3000 m depth. Deep-sea fish species are typically long-lived and reach reproductive maturity at advanced ages, resulting in the slow re-establishment of exploited populations. Deep-water fishing

has major impacts on the sea bed, especially in areas of habitat-building corals or very old, large solitary gorgonians. There is the impact of 'ghost fishing' via abandoned or lost gear.

Restriction of fishing on the high seas is difficult; some nations do not abide by the rules and there are regions where regulations are non-existent (Gianni, 2007). But the decline in biomass of certain species and the destruction of habitats such as cold-water corals has led to the enforcement of protection rules in some regions, such as the protection of coral ecosystems on the Darwin Mounds in the northeastern Atlantic (De Santo & Jones 2007) and the legal ban of drift-net fishing and benthic trawling below 1000 m depth for the whole Mediterranean Sea (Gianni, 2004). The latter initiative has led to the deep Mediterranean benthic realm becoming the largest protected area in the world. Adjacent to some established BPAs, New Zealand's deep-sea fishing continues unhindered, with deep-sea benthos protection deriving only from gear limitations such as wire length.

Global warming and ocean acidification are expected to affect calcification in all marine organisms that have calcium carbonate skeletons, including larval and adult and free-living and sessile animals and shelled protozoans. For benthic organisms that use carbonate, the depths of the calcite saturation horizon (CSH) and aragonite saturation horizon (ASH) are critical (see Section 1.4). Assuming that global warming is potentially linked to high fertilisation input on land related to agriculture shifts, there may be increased surface algal blooms that will result in increased particulate organic carbon transfer to deeper water. There will be both direct and indirect effects that are felt in the deep sea. Land erosion rates, intensified by extensive removal of native-forest cover, are also the cause of significant carbon transfers (approximately 4 million metric tons per year) to the ocean (Zeldis et al. 2009). Since we do not know the baseline status of deep-sea assemblages below 1500 m, we will not be able to say how much taxonomic composition, abundance or biomass have changed over time from these perturbations.

Mineral resources. Deep-water phosphorite and polymetallic manganese nodules occur in some abundance in EEZ, but extraction may be economically unfeasible (Glasby & Wright 1990; Gordon et al. 2010). On the other hand, metalliferous sulphides associated with hydrothermal venting in the Kermadec arc have attracted enough interest for prospecting applications to be lodged with Crown Minerals and some have been granted (Wright 2009). There is some concern about the likely impact of mining on bacterial and metazoan biodiversity insofar as many vent-associated species have very restricted distributions.

One of the major limitations to developing robust conservation and management options is the relatively small amount of information available on deep-sea habitat distribution, faunal composition, biodiversity and ecosystem functioning (Clark et al. 2006). A revision of past, present and future anthropogenic impacts on the deep sea and analysis of the effects in the habitats and fauna was prepared by Ramirez-Llodra et al., in press.

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