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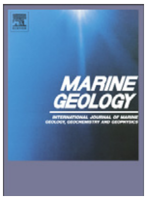

Initial characterization of cold seep faunal communities on the New Zealand Hikurangi margin

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ABSTRACT

Cold-seep communities have been known from the North Atlantic and North Pacific for more than 20 years, but are only now being explored in the Southern Hemisphere. While fisheries bycatch had suggested the presence of cold seeps on the New Zealand margin, the biodiversity and distribution of these communities remained unknown. Explorations using towed cameras and direct sampling gear revealed that cold seep sites are abundant along the New Zealand Hikurangi margin. Initial characterization of the faunal communities at 8 of these sites indicates a fauna that is associated with particular sub-habitats but which varies in abundance between sites. Community composition is typical, at higher taxonomic levels, of cold seep communities in other regions. The dominant, symbiont-bearing taxa include siboglinid (tube) worms, vesicomyid clams and bathymodiolin mussels. At the species level, much of the seep-associated fauna identified so far appears either to be new to science, or endemic to New Zealand seeps, suggesting the region may represent a new biogeographic province for cold-seep fauna. Some overlap at the species and genus level is also indicated between the sampled seep communities and the fauna of hydrothermal vents on the Kermadec Arc in the region. Further taxonomic and genetic identifications of fauna from this study will allow us to fully test the levels of species overlap with other New Zealand chemosynthetic ecosystems as well as with other cold seep sites worldwide. These apparently novel communities exhibit evidence of disturbance from a deep bottom-trawl fishery and appear to be threatened along the entire New Zealand margin. As bottom fisheries, mining, and fossil-fuel exploitation move into deeper waters, seep communities may be endangered worldwide, necessitating the initiation of conservation efforts even as new seep ecosystems are discovered and explored. Our findings highlight the unique nature of anthropogenic impacts in the deep-sea, in which reservoirs of biodiversity can be impacted long before they are even known.

1. Introduction

Cold seeps are sites where reduced geochemical compounds efflux from the seafloor at essentially ambient temperatures. These sites can occur in a wide variety of geologic settings, including both active and passive margins. In the deep sea, cold seeps harbor a characteristic suite of organisms that rely on chemosynthetic production at the base of their food chain. Seep fauna commonly include vestimentiferan tube worms in the polychaete Family Siboglinidae, vesicomyid clams, and bathymodiolin mussels (Sibuet and Olu, 1998; Sibuet and Olu-LeRoy, 2002; Kojima, 2002; Tunnicliffe et al., 2003; Levin, 2005). Other abundant taxa may include siboglinid pogonophorans, thyasirid, solemyid and lucinid bivalves, trochid and buccinid gastropods, cladorhizid and hymedesmid sponges, bresiliid shrimp, amphipods, galathaeoid crustaceans, and polynoid, dorvilleid, hesionid, and ampharetid polychaetes. Many of the taxa associated with cold seeps rely on chemosynthetic production fueled by the reduced compounds methane and hydrogen sulfide emanating from the seep sediments (Levin, 2005).

The vast majority of known cold seeps have been found in the northern hemisphere. Only recently have seeps in the southern hemisphere been explored (e.g. Sellanes et al., 2004, rest of this issue). Initial indications of cold seeps on the New Zealand margin included the collection of mollusc specimens (mostly dead) by fisheries trawls. These records included 5 species of vesicomyids, 1 species of thyasirid, a live bathymodiolin mussel (subsequently described as *Bathymodiolus tangaroa*, Von Cosel and Marshall, 2003) as well as 8 species of gastropods, including 2 species of provannid (Lewis and Marshall, 1996). All of these are taxa characteristic of seeps. Further evidence of potential seepage came from geologic surveys of the New Zealand margin (Lewis and Marshall, 1996). More recent evidence for the existence of seeps on the margin has also come from geological and

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biogeochemical studies (see papers in this issue). However, until this study, no *in situ* images of active cold seep communities had been obtained, nor had comprehensive sampling of live cold seep fauna been undertaken on the New Zealand margin.

The practical goals of our study were to explore for cold seep sites along the eastern and south margins of the North Island of New Zealand (the Hikurangi Margin) and to conduct the first in situ visual and sampling surveys of cold-seep communities in this region. This study represents the first sampling effort of the international RENEWZ project (comparison of Reducing Habitats in New Zealand) in November 2006 on the cruise TAN0616. We describe the methodologies used in our explorations, the sites sampled, and, using preliminary data, provide an initial characterization of the faunal communities. Additional sampling was undertaken under the RENEWZ project umbrella as part of the subsequent NEW VENTS voyages (SO191, Greinert et al., this issue), but the overall preliminary results of this later sampling effort are not presented here. However, use of data obtained during all RENEWZ and NEW VENTS voyages has allowed a more detailed description of two of the study sites elsewhere in this volume (Jones et al., this issue; Klaucke et al., this issue), and for presentation of initial findings concerning the trophic ecology of the fauna sampled (Thurber et al., this issue).

1.1. Methods

Sites for initial surveys for cold seeps were selected based on trawled molluscs from Lewis and Marshall (1996) (sites hereon abbreviated LM## to refer to specific location in Lewis and Marshall (1996)), previous multichannel seismic reflection surveys, multibeam bathymetry, widespread single-channel seismic data (reviewed in Barnes et al., this issue), and existing acoustic flare data (acoustic returns from bubbles plumes) from NIWA biogeochemical studies of the Wairarapa seep area (Law et al., in press). Potential seepage areas were first surveyed with multibeam (Simrad EM300) and a single beam sonar (Simrad EM60) for acoustic flares. Following flare detection, cross transects were repeated until the seabed source of the flare(s) was established. Following this, further multibeam bathymetric and backscatter mapping was carried out around the site of seepage.

With the aid of the multibeam maps, visual surveys were then conducted using the towed video and still camera system DTIS (Deep Towed Imaging System), which had a real time video link to the ship. The DTIS was towed across the flare site until evidence of chemosynthetic fauna (e.g. clam shells and worm tubes) and carbonates were recorded. Additional DTIS transects were undertaken to determine the extent of the cold seep area and its fauna. With real-time tracking of the seabed position of the camera (Simrad HPR ultra-short baseline system), we were able to pinpoint the location of cold-seep indicative fauna and carbonates. Subsequent review of the images allowed us to describe the relative abundance of seep fauna (primarily *Lamellibrachia* sp. tube worms) and the physical relief of carbonate structures (see Jones et al., this issue; Klaucke et al., this issue, for detail of this broadscale visual mapping procedure). Abundances of *Lamellibrachia* sp. are expressed relative to population densities at the site of their highest abundance and the vertical elevation of carbonate structures at the scale of the images (~2–5 m^2) is expressed as being either ‘Low’ (<1 m) or ‘High’ (>1 m). Data collected during these surveys will be used in the future to quantify the megafauna at each site and the relationship between fauna and seep habitat characteristics.

We sampled benthic fauna using an epibenthic sled, a van Veen grab, and multicorer. Table A1 provides the station locations, depths and gear types for the sampling effort at each seep site explored.

Fauna sampled by the sled and grab were immediately sorted on board with filtered seawater; large rocks and fauna were removed by hand and remaining material was sieved on 1000 and 300 μm mesh sieves. Multicore samples (9.6 cm diameter) were extruded, the top 10 cm were sieved on 300 μm, and the residue preserved in 8% formaldehyde-seawater solution or in 95% ethanol. Megafaunal specimens of each operational taxonomic unit were preserved frozen at −25 °C, −80 °C, in ethanol and in formalin to allow for future morphological identification and molecular analysis. For larger taxa such as vesicomyids, mytilids, and solemyids, a subsample of muscle or mantle and gill was saved for molecular genetic analysis, with the remainder of the specimen preserved for morphological taxonomy.

2. Results

2.1. Site surveys

We located three of the previously suspected seep sites (Lewis and Marshall, 1996) as well as six additional active seep sites at depths of 716–1166 m (Table A1, Fig. 1). Seeps were recognized by acoustic flares of methane bubbles coinciding with seafloor carbonate formations, discolored sediments, and characteristic symbiont-bearing invertebrates (Fig. 2).

Fig. 3A–G summarizes the surveyed site locations, and positions of camera tows and direct sampling relative to the bathymetry of the area. The geological underpinnings of our sample locations are discussed in Barnes et al. (this issue). The following is an outline of the initial video-based observations at the 8 of the 9 seep sites for which additional surveying and sampling were undertaken. The highest abundances of *Lamellibrachia* sp. (tube worms) were seen at North Tower with mean densities of ~20 individuals m^{-2} over ~100 m of transect and peak densities >50 individuals m^{-2} in places. At the other seep sites, abundances were generally low with mean densities <10 individuals m^{-2}, except in occasional patches at the meter scale.

2.1.1. Builder's pencil (Ritchie Ridge)

The acoustic flare at this site was detected while surveying the area of Ritchie Ridge to the south of LM1. Multibeam and single-beam sonar placed the flare source at the southern end of a weakly-defined N–S ridge at 800 m depth. Subsequent cameras and epibenthic sled tows revealed predominantly carbonate rock substrata on the ridge, with extensive areas of the seabed covered by an essentially continuous layer of *Calyptogena* spp. (clam) shells (Fig. 2). Video transects across the site indicated that clam shells cover an area of approximately 70,000 m^2 centered on 39° 32.628 S, 178° 19.908 E and extending at least 450 m along the ridge (north–south) and 300 m across it (east–west). The area covered by *Calyptogena* sp. shells at Builder's Pencil is far greater than has been seen at any other site on the Hikurangi Margin to date. However, no live clams were seen and *Lamellibrachia* sp. and bathymodiolin mussels were the only live seep fauna seen in camera transects; neither species occurring in high abundances. The east and west slopes of the ridge were composed of outcropping bedrock and boulders, and supported non-seep epifauna, including occasional cold water corals, mostly antipatharians.

2.1.2. Rock Garden knoll

An acoustic flare centered on 40° 02.388 S, 178° 08.568 E was investigated at a knoll feature at the southwest end of the bank known to fishers as the “Rock Garden”. The bank lies approximately 35 km SW of Ritchie Ridge and rises to <500 m depth. Lewis and Marshall (1996) site 3 is at the northeast end of the bank. Video transects groundtruthed with sled and grab samples showed carbonate boulders and pavements rising steeply from a muddy sediment basin at the southern end of the bank. Carbonates were eroded and fractured in appearance, with evidence of numerous small chimneys in pavements on the summit of the knoll at ~750 depth. A single live individual of *Lamellibrachia* sp. was seen in the video close to the estimated flare position but no other seep-associated fauna were recorded and no vesicomyid clam shells were seen. Epifauna were scarce generally, with occasional antipatharian, gorgonian, and stylasterid corals, and a

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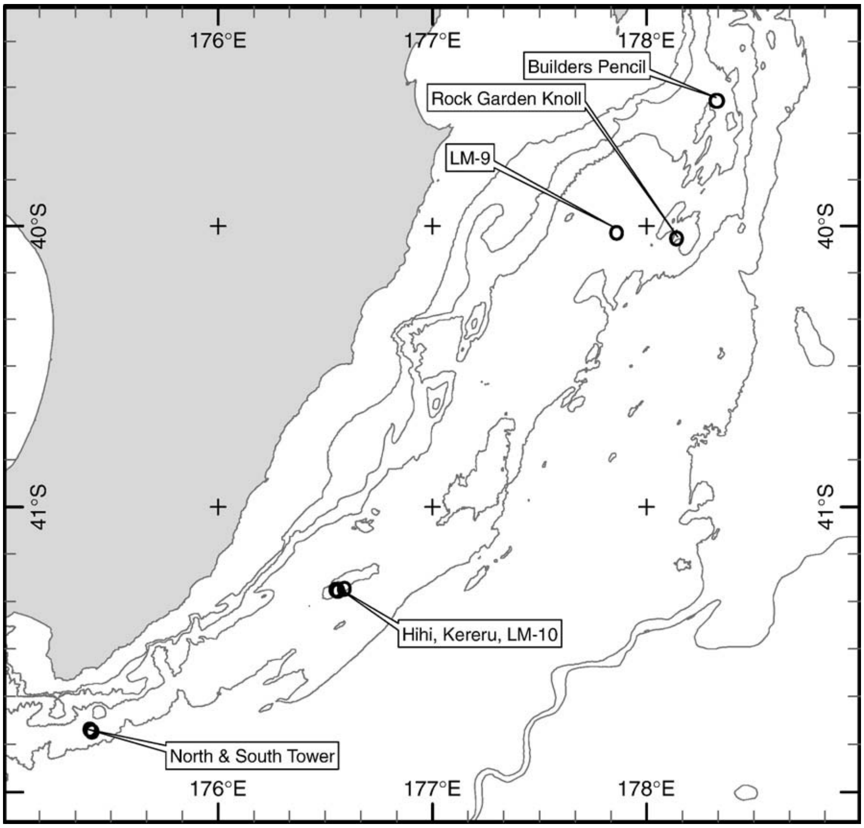

Fig. 1. Map of seep sites directly observed along the Hikurangi Margin of the North Island of New Zealand during RENEWZ I-NEW ZEEPS TAN 0616.

white demosponge being the most conspicuous taxa. Scleractinian and stylasterid coral fragments were visible in accumulated sediments on the carbonates.

2.1.3. LM10, Hihi, and Kereru (Uruti Ridge)

Three seep sites were sampled along a 4 km east-west stretch of Uruti Ridge; LM10 and two others, all at approximately 750–800 m

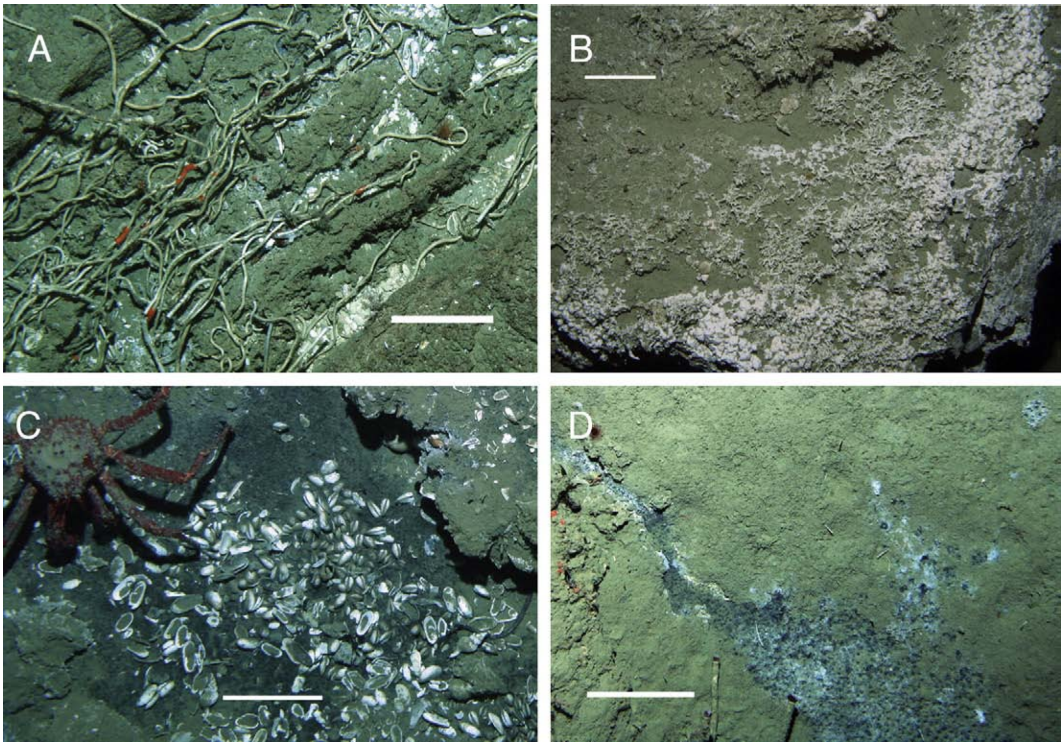

Fig. 2. Representative cold-seep associated megafauna and microhabitats found at methane seeps on the New Zealand margin. (A) *Lamellibrachia* sp. aggregation in moderate abundance on carbonate platform, Hihi; (B) Sponge mat (*Pseudosuberites* sp.) covering carbonate rock, North Tower (C) Live vesicomyid (*Calyptogena sp.*) clams and dead shells in a seepage- darkened sediment patch, North Tower; (D) Bacterial mat on suphidic sediment with pits made by ampharetid polychaetes, Hihi. See Table A1 and Fig. 1 for site locations. Scale bars show 20 cm.

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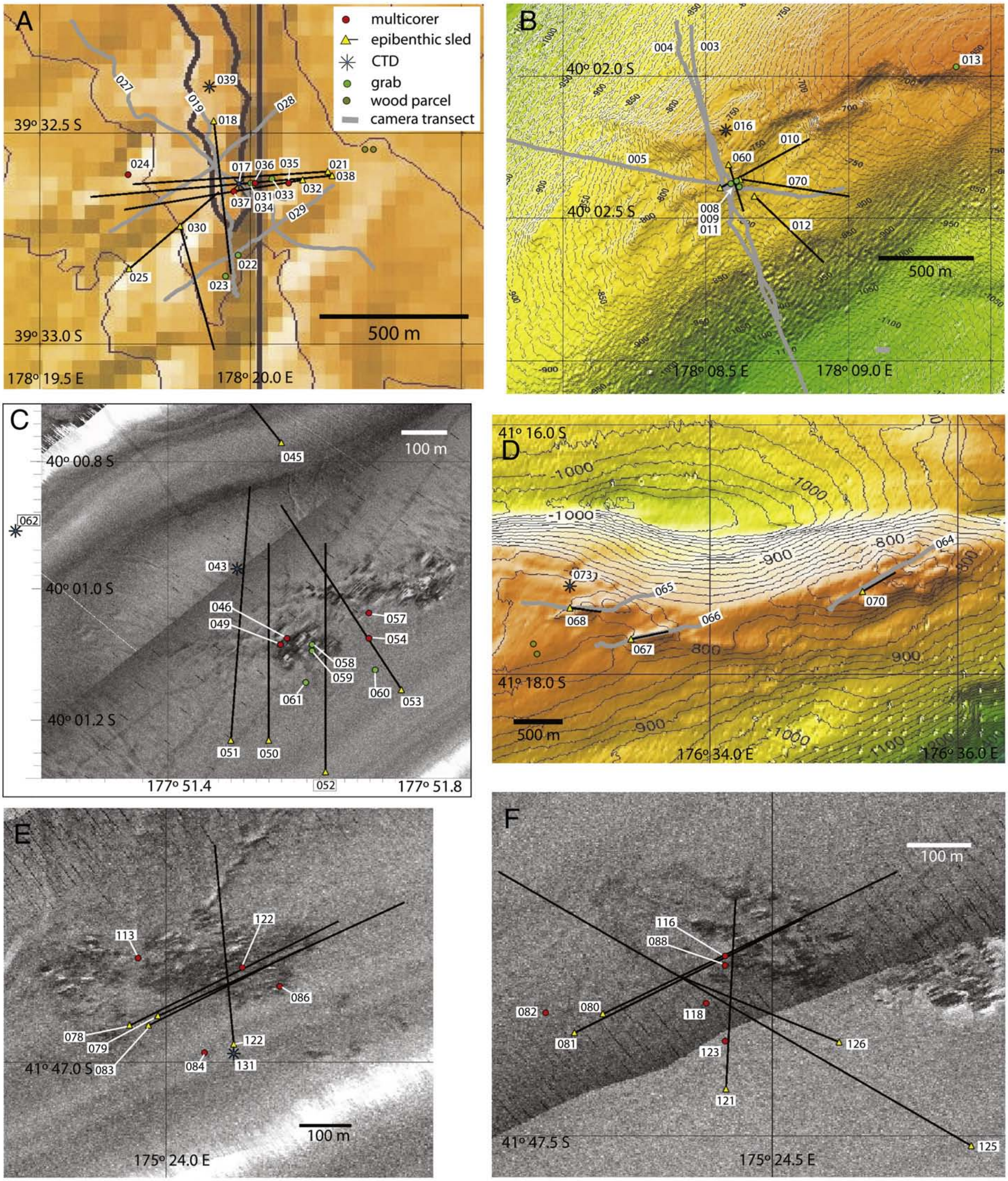

Fig. 3. Multibeam and sidescan sonar images of sites described here, with overlaid video transect and direct sampling positions: (A) Builder's Pencil, (B) Rock Garden Knoll, (C) LM9, (D) LM10, Hihi and Keruru, (E) North Tower, and (F) South Tower. Video transects at LM9, North Tower, and South Tower are shown in Jones et al. (LM9) and Klaucke et al. (North and South Towers) in this volume.

depth. Acoustic flares defined three seabed targets, each coinciding with a high knoll on the ridge. Surveys at each site included only one camera transect and one epibenthic sled sample. Thus, seep activity and fauna may be more widespread at these sites than was detected.

The three sites were similar in form. The knolls consisted of a summit area of authigenic carbonate rocks, often in the form of a relatively flat pavement, surrounded by flanks falling away to background soft-sediment habitats. *Lamellibrachia* sp. tubes occurred

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at all sites but generally in low abundance and were always growing close to the substratum within fissures and depressions in the carbonate. No other live seep-associated fauna were seen but shells of *Calyptogena* sp. clams were present within crevices and depressions in the rock.

2.1.3.1. LM10. This site was centered at 41° 17.472 S, 176° 33.012 E. The central area of carbonate rocks at LM10 extended for approximately 200 m. Shells of *Calyptogena* sp. were seen on the western flank of the knoll and in depressions across the summit, and *Lamellibrachia* sp. tubes were present at the centre of the carbonate rock habitat, again in low abundance. Occasional antipatharian corals were seen on the carbonates, and sediments on the eastern flank of the knoll were littered with fragments of scleractinian coral skeletons.

2.1.3.2. Hihi/Southern Uruti. This site was centered on 41° 17.682 S, 176° 33.534 E. The summit of the knoll was composed of authigenic carbonate structures forming a relatively flat pavement over a distance of approximately 300 m. *Lamellibrachia* sp. worms were present in low abundance throughout the carbonate area, always growing flat within rock crevices. Isolated colonies of cold-water corals, primarily antipatharians, but with occasional small thickets of the scleractinian *Madrepora oculata*, were present on the carbonates. Soft-sediment habitats on the western flank of the main carbonate knoll were covered with fragments of scleractinian coral skeletons whereas those on the eastern flank contained fragments of *Calyptogena* sp. shells. Abandoned fishing gear was seen caught on a coral thicket on carbonate rocks towards the top of the knoll (Fig. 3B).

2.1.3.3. Kereru/Western Uruti. This site was centered on 41° 17.238 S, 176° 35.358 E. Localized authigenic carbonate structures of low relief extended for approximately 200 m at the summit. *Lamellibrachia* sp. were present in low abundance and were seen only within crevices and depressions in the carbonate rock. Accumulations of *Calyptogena* sp. shells were also visible in these crevices. A single small patch of bacteria-covered rock with what appeared to be small live bathymodiolin mussels was seen towards the centre of the carbonate area. Surrounding soft sediments were littered with fragments of cold water scleractinian corals and numerous parallel marks, which were interpreted as trawl marks.

2.1.4. LM9 (Omakere Ridge)

The water column flare at Lewis and Marshall (1996)'s Site 9 (LM9) was associated with two small patches of low relief carbonate structures within a broad sediment plain. The patches were approximately 100 m north–south and 200 m east–west in size, separated by approximately 100 m, and centred on 40° 1.032 S, 177° 51.684 E at a depth of approximately 1150 m (see Jones et al., this issue). *Lamellibrachia* sp. tubes were present in moderate abundance (<20 individuals m^{-2}) among the carbonates and were also seen occasionally on open sediments. Aggregations of small pogonophoran tubes were observed in soft sediments surrounding the carbonates and spherical hexactinellid sponges were conspicuous in close association with carbonates and *Lamellibrachia* sp. tubes on the eastern edge of the southern carbonate patch. Shells of *Calyptogena* sp. were present in small patches amongst the carbonates. Trawl marks were again evident on sediments around the seep site.

2.1.5. North Tower and South Tower (Wairarapa/Opouawe Bank)

2.1.5.1. North Tower. This site formed a knoll protruding from a southeast facing escarpment at 1050 m water depth and centered at 41° 46.896 S, 175° 24.066 E. The seep consisted of high relief authigenic carbonate structures interspersed with black, sulfide-rich soft sediments over an area of approximately 40,000 m^2 and surrounded by background habitats of muddy soft sediment (see Klaucke et al., this issue). Isolated patches of dark sulfidic sediments and bacterial mats occurred in sediments immediately surrounding the carbonates and extended to the southeast in the direction of South Tower. In places, carbonate rocks were covered by a white encrusting demosponge (*Pseudosuberites* sp.) (Fig. 2B) and whelks, pagurid crabs and a large lithodid crab (*Paralomis* sp.) were seen amongst carbonates and around sulfidic sediments (Fig. 2C). *Lamellibrachia* sp. were abundant throughout the main seep area and were locally very abundant (>50 individual m^{-2}). *Calyptogena* sp. shells were present throughout, with live populations present in patches of sulfidic sediment within the main seep area. All areas of sulfidic sediments examined from seabed images and corer samples supported dense populations of previously undescribed species of ampharetid polychaetes (see Sommer et al., this issue; Thurber et al., this issue).

2.1.5.2. South Tower. This site consisted of an area of low-relief carbonates surrounded by flat soft sediments and centred on 41° 47.292 S, 175° 24.498 E, approximately 1 km to the southeast of North Tower. It was of similar size to North Tower and had a similar water column flare but was less thoroughly sampled. Camera transects showed habitats and fauna similar to those at North Tower, with abundant *Lamellibrachia* sp., populations of live *Calyptogena* sp., and numerous dark patches of sulfide-rich sediment.

2.2. Direct sampling

Table A2 provides a summary of the initial faunal collected with direct sampling at each study site. Since all direct sampling was done blindly from a surface ship, we could not determine whether multicorer and grab samples were collected directly from a seep site or from the 'background' sediments. Towed gear almost certainly integrated across habitat types. Future data analysis and sampling will reveal the extent of the association of particular species with seep or background habitat. Meanwhile Table A2 provides a qualitative record of the assemblages sampled at each site. Below we highlight those taxa that are known or presumed to be associated with seep habitats and those that have been previously recorded from vent habitats in the region.

At least 20 "seep-associated" taxa were collected. These included an undescribed species of demosponge *Pseudosuberetis* sp. (so far only positively identified from the North Tower site), at least three species of bathymodiolin mussels (*Bathymodiolus tangaroa*, *Bathymodiolus* sp. and *Gigantidas* sp.) from the Builder's Pencil site, the solemyid *Acharax clarificata* (LM9 and North Tower sites), the lucinid *Lucinoma galathea* (LM9 and Builder's Pencil), at least one species of unidentified thyasirid (LM9), and four species of vesicomyid clams (currently assigned to the genus *Calyptogena*) all recovered from the Builder's Pencil seep site. A gastropod belonging to the family Pyramidellidae also was found at the Builder's Pencil site (presumed to be an ectoparasite of *Calyptogena*). An undescribed species of thalassinid shrimp belonging to the genus *Vulcanocalliax* was sampled from the soft sediment at Rock Garden Knoll and Builder's Pencil sites. The lithodid crab *Paralomis dawsoni* from the Rock Garden Knoll site, the siboglinid polychaetes *Lamellibrachia* sp. (sampled from all sites apart from Hihi), *Sibloglinum vinculatum* (North Tower) and an unknown number of species of *Sibloglinum* were found across all seep sites. At least two undescribed species of ampharetid polychaetes (in two undescribed genera) were sampled from all sites except the Builder's Pencil seep.

A few of these seep-associated taxa have been recorded from hydrothermal vent habitats in the New Zealand region. The sponge *Pseudosuberites* sp. and the solemyid *Acharax clarificata* have been observed at the Calypso vent field in the Bay of Plenty (NIWA, unpublished data). The bathymodiolin genus *Gigantidas* and the tube worm genus *Lamellibrachia* are found at a number of vents on

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seamounts of the southern Kermadec volcanic arc (Von Cosel and Marshall, 2003; Smith et al., 2004; Miura and Kojima, 2006).

So far at least 10 'background' (non-seep endemic) species have been found at both seep and vent sites in the New Zealand region (Table A2).

Combining the results of the video observations and direct sampling, initial assessment of community composition suggests that a broadly similar suite of species are present across sites along New Zealand's Hikurangi Margin, but there are between-site differences in relative abundances of the dominant seep-associated taxa. The sites were typically composed of a number of subhabitats including carbonate rocks, sulfidic sediments and peripheral soft sediments, each harboring its own characteristic faunal assemblages (Fig. 2). Most sites had extensive cover of carbonate precipitates forming large boulders, pavements, crusts or chimneys with diverse epibiota, including bathymodiolin mussels (*Bathymodiolus* spp and *Gigantidas* sp.), aggregations of vestimentiferan worms (*Lamellibrachia* sp.) (Fig. 2A), sponge mats (*Pseudosuberites* sp.) (Fig. 2B), and/or coral thickets. Vast beds (up to 70,000 m^2 in area) of vesicomyid clam shells and smaller live aggregations of at least three *Calyptogena* species of living clams (Fig. 2C) were observed near carbonate outcrops. Commonly observed mobile megafauna included gastropods as well as pagurid, lithodid and brachyuran crabs. Soft-sediment seep habitats surrounded the carbonates and included fields of pogonophoran worms (3 species of *Siboglinum*), solemyid clams (*Acharax clarifcata*), thalassinid shrimps (*Vulcanocallix* sp.), and ampharetid polychaetes (representing 2 undescribed genera) (Fig. 2D). Core and grab samples revealed numerous additional undescribed species of peracarid crustaceans and polychaete worms. Bacterial mats were present on soft sediments primarily around the North Tower seep site.

3. Discussion

Initial indications of deep-sea cold seep communities off New Zealand came from fisheries bycatch of mollusc shells obtained through a collaborative arrangement with the New Zealand fishing industry, in which unusual specimens are donated to scientific institutions (Lewis and Marshall, 1996). However, no direct observations of seep communities had been made before our November 2006 cruise, TAN0616. Direct observation of numerous seep sites on TAN0616 and SO191, and acoustically recorded bubble flares from many more unexplored sites, indicate that cold seeps are abundant along the entire eastern margin of the North Island of New Zealand.

The initial assessment of community composition suggests that New Zealand's Hikurangi Margin hosts a broad diversity of seep microhabitats, each harboring a characteristic fauna. There is substantial faunal overlap at higher taxonomic levels between the New Zealand cold seeps and seeps from other regions around the world (reviewed in Sibuet and Olu, 1998; Kojima, 2002; Levin, 2005). Faunal overlap includes vesicomyid clams, vestimentiferan siboglinid worms, and bathymodiolin mussels, which are also characteristic of other chemosynthetic ecosystems types around the world such as hydrothermal vents and whale falls (Van Dover, 2000; Smith and Baco, 2003). Cold water corals, as observed during our study, are also common on the periphery of cold seep sites (e.g. Hovland and Risk, 2003). It is notable that the extensive area of the seabed covered by shells of *Calyptogena* sp. clams, particularly at the Builder's Pencil site, were an order of magnitude larger than any previously recorded clam bed (Olu et al., 1996, 1997). However, relatively few live individuals of this taxon were found. This contrasts with seep assemblages at Hydrate Ridge in the northeast Pacific and in the trenches of Japan and Peru, where large populations of live clams are present (Hashimoto et al., 1989; Olu et al., 1996, 1997; Kojima, 2002; Levin, 2005). Pogonophorans (frenulate siboglinid polychaetes), and solemyids are well-known from seep habitats and were common in the peripheral soft substrates of the New Zealand seeps. Some of the other dominant families of polychaetes known from other cold seep locations including Ampharetidae, Dorvilleidae, and Spionidae, also occurred in sediment cores from the New Zealand seep sites. These included a spionid polychaete belonging to a genus new to science, and two new genera of ampharetid polychaete, which formed dense aggregations (Sommer et al., this issue; Thurber et al., this issue).

Another notable difference between these sites and other cold seeps is the encrusting sponge observed at the Wairarapa sites, which appears to be a species new to science belonging to the genus *Pseudosuberites*, (Suberitidae). Stable isotope values suggest this species is trophically connected to methanotrophic microbes (Thurber et al., this volume). It also has a diverse macrofaunal epibiont community that may act as a conduit for methane-derived carbon (described in more detail in Thurber et al., this issue). Unrelated sponges in the Family Cladorhizidae, which occur at other cold seep locations (Vacelet et al., 1995) but not at the New Zealand sites, are known to harbor methanotrophic symbionts but have not been shown to harbor such diverse or abundant epifaunal communities.

Although in the early stages, morphological identifications of this seep fauna to date reveal at least six species of decapod crustaceans (Ahyong, 2008), one species of sponge, and at least three species and two genera of polychaetes which are new to science (including the seep-associated siboglinid tubeworms.). Additionally, the vesicomyid clams and bathymodiolin mussel previously recorded or described from this region (Lewis and Marshall, 1996; Von Cosel and Marshall, 2003) have not been collected from seep locations elsewhere in the world. Although biogeographic provinces have not been definitively characterized for methane seeps, our findings together with the absence of seep species from other regions, suggest that the New Zealand margin fauna represents a biogeographic province distinct from those known previously.

In fact, a number of lines of evidence suggest a new biogeographic province in the New Zealand region for all chemosynthetic ecosystems. Recent exploration of the Kermadec Arc hydrothermal vents revealed a plethora of species new to science and only a single record of a provannid gastropod, which is a dominant symbiont-bearing taxon at nearby Lau Basin vents (Rowden et al. unpublished data). Whale fall and sunken wood fauna brought up in trawls in the New Zealand region (Wolff, 1979; Marshall, 1985; Baker et al., 1986; Gibbs, 1987; Marshall, 1985 1987, 1988, 1994, 1998) also have no species overlap with other locations for these chemosynthetic ecosystem types. Thus, although species lists are limited and many of the species are not yet formally described, there is a consistent pattern of apparent endemism in the New Zealand region across chemosynthetic habitat types (although some exceptions exist, see Kojima et al., 2006). Current flow patterns around New Zealand suggest a source of deep water from the Antarctic and subantarctic (via the circumpolar current which flows eastwards across the bottom of the Indian Ocean), and a source of surface water from the Western Pacific (via eastward flowing currents of the South Pacific subtropical gyre) (Carter et al., 1998). Thus, we predict that the New Zealand chemosynthetic ecosystem fauna will be found to resemble the as yet unexplored chemosynthetic ecosystem fauna of the Antarctic region, with some similarity at higher taxonomic levels to chemosynthetic faunas of the Pacific and Indian Oceans. This hypothesis remains to be further explored and tested.

Another motivation for exploring the cold seeps of New Zealand is the opportunity to address ecological and evolutionary connectivity among chemosynthetic ecosystem types. Previous studies indicate low overlap between vent, seep, and whale-fall faunas on a global scale. For example, in the northeast Pacific seeps have been found to share 10 species with hydrothermal vents, and 20 species with sulfide-rich whale falls (Van Dover, 2000; Smith, 2006). This finding may represent a true difference between the habitat types, or it may reflect the large geographic separation between studied chemosynthetic habitat types (Van Dover, 2000). The New Zealand margin is one of the few places in the world where most chemosynthetic ecosystem types occur in close proximity, allowing us to test these alternative hypotheses. To date only

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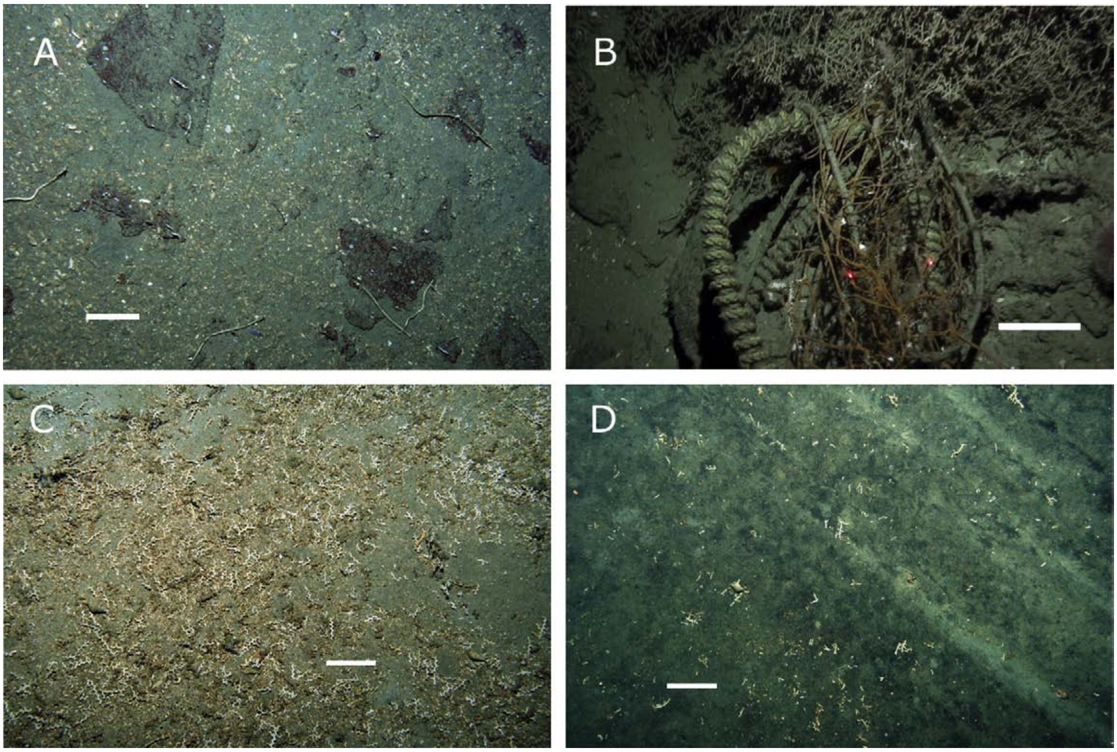

Fig. 4. Observation of trawling damage on or adjacent to seep sites. Six of the seep sites visited exhibited evidence of bottom trawling including (A) apparently recently trawled seep fauna, Builder's Pencil; (B) lost trawl gear, Hihi; (C) coral rubble, Hihi; and (D) trawl drag marks in sediments, Kereru; trawl marks and coral rubble were also observed adjacent to several additional sites (see text). Scale bars show 20 cm.

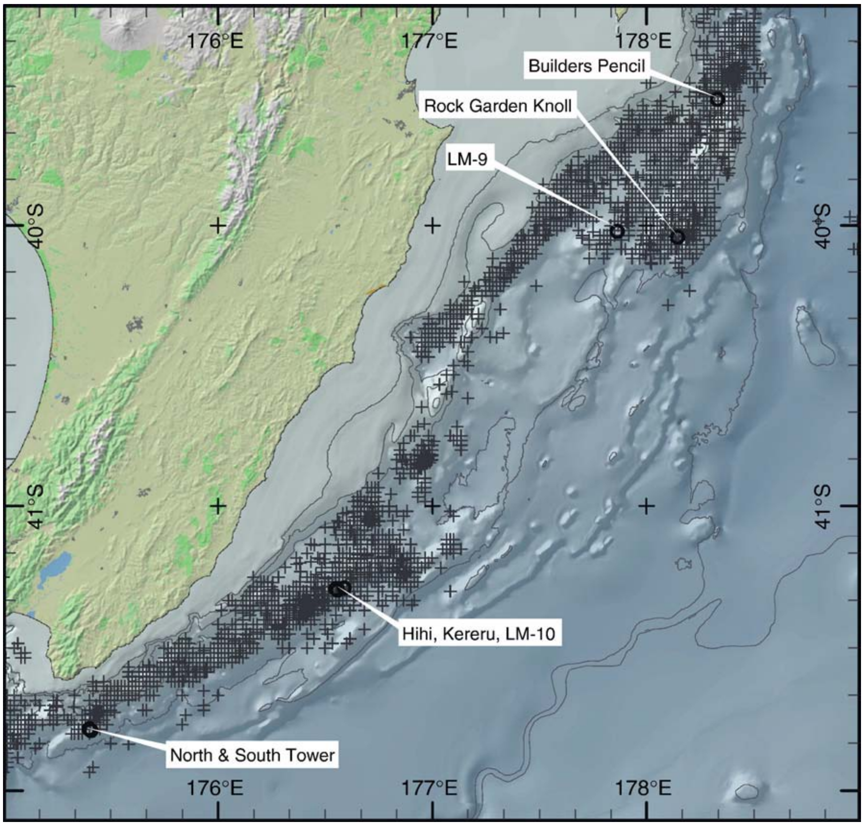

Fig. 5. Map showing seep sites directly observed during RENEWZ I-NEW ZEEPS and the distribution of bottom trawling effort for the orange roughy fishery (depth range 700–1300 m) between 1988 and 2006 (New Zealand Ministry of Fisheries). Start positions of trawls (crosses), recorded to the nearest 1 min of latitude and longitude, are plotted on the map. The number of trawl tows per seep site was calculated by summing the number of trawls that cross through the area surrounding each site (~3.4 km^2; delimitated by the 4 nearest minute data records). Number of trawl tows for each site are as follows: Rock Garden Knoll — 226; North Tower and South Tower — 100; Builder's Pencil — 10; LM10 and Kereru — 139; Hihi — 277.

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four species have been found to overlap between hydrothermal vents, whale falls or wood falls in the New Zealand region. Although this level of overlap is lower than would be expected to support the hypothesis of high species overlap between the four chemosynthetic ecosystem types in the New Zealand region, this is ~20% of the total seep-associated fauna currently identified to species level. Additionally, since all four of the habitat types are relatively undersampled in the New Zealand region, with no *in-situ* sampling of whale falls or sunken wood to date, we suggest that speculation be put off until *in situ* sampling and exploration of the four habitat types in this region is carried out to further characterize these communities. Such a cross-system comparison is part of future plans for the RENEWZ project.

An unexpected result of these surveys was the observation at several sites of seep megafauna, including tubeworms, clams and mussels, concentrated in depressions and crevices in the carbonates. Taken alone, this could be interpreted simply as indicative of the source of seeping fluids. However at a number of sites, these observations were accompanied by visible accumulations of coral or vesicomyid shell debris, lost trawl gear, or trawl marks in seep-adjacent sediments (Fig. 4). These observations suggest that trawling has disturbed the communities at most of the seep locations. Bottom trawling, targeting orange roughy and other commercial species, occurs throughout the area of seep occurrence on the New Zealand margin (Fig. 5). Trawl-effort data for the orange roughy fishery, the primary New Zealand fishery at water depths of 700–1300 m, provides strong evidence that all but one of our seep study sites has been exposed to trawling, with two of the seep sites subjected to over 200 trawling episodes in the past 18 years (Fig. 5).

While bottom trawling is known to have disturbed a broad range of shelf (Barnes and Thomas, 2005), seamount (Clark and Koslow, 2007), and deep-sea habitats (Smith et al., 2008), this is the first indication that trawling may impact chemosynthetic habitats over large spatial scales. Here, a significant reservoir of seep biodiversity is threatened within a poorly known biogeographic province. Because seep communities often coincide with the outcropping of gas hydrates, they may also be susceptible to damage from energy mining activities in the future. Thus, there is a current and growing need to instigate environmental management of the newly discovered New Zealand seep habitats, and to explore the biodiversity and evolutionary relationships of their fauna.

Methane-seep ecosystems are broadly distributed on the world's continental margins at mid-slope depths where human exploitation of living and nonliving resources is widespread and growing (Smith et al., 2008). Seep ecosystems are well known in the northern hemisphere (Sibuet and Olu, 1998; Sibuet and Olu-LeRoy, 2002; Kojima, 2002; Tunnicliffe et al., 2003; Levin, 2005) but in the southern hemisphere, e.g., the Chile and Brazil margins, they remain largely unexplored. Given the potential for major human disruption, conservation strategies for margins in New Zealand and elsewhere may need to be pro-active to avoid significant losses in unexplored reservoirs of biodiversity. Possible actions could include protection for sites that are currently unaffected by resource exploitation or for sites already exposed to heavy trawling or drilling, in order to evaluate patterns of seep faunal recovery following anthropogenic disturbance. Either or both actions are needed urgently.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.margeo.2009.06.015.

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