



Earth Sciences
New Zealand

Benthic data summary for Gigablue's area of interest with respect to marine carbon dioxide removal

Prepared for Gigablue

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Contents

Executive summary	7
1 Background	9
1.1 Project scope.....	9
2 Study area	10
3 Task 1. Data discovery	11
3.1 Extent of macrofauna, stills photos and Deep Towed Imaging System DTIS) video datasets.....	11
3.2 Extent of multibeam bathymetry coverage from legacy voyages.	23
3.3 Extent of habitat maps, heterogeneity modelling and benthic habitats.	26
3.4 Dissolved oxygen data from historic CTD casts.	38
3.5 Interstitial measurement of pore-waters.	40
3.6 Xenophyophore still image analysis	42
3.7 Occurrence of any sensitive environment communities or protected species.....	43
3.8 Occurrence of organisms known or likely to be particularly vulnerable to variability in oxygen or particulate smothering.....	84
3.9 Review of seasonality (or lack thereof) and any long-term trends, where available	88
3.10 Identify any proxy data that might support assumptions in the absence of some data types.....	90
3.11 Identify any local data gaps directly relevant to Gigablue's AOI	90
4 Task 5: Predictive benthic species distribution modelling	91
4.1 Model extent and resolution	91
4.2 Environmental data	92
4.3 Faunal data.....	93
4.4 Model details	94
4.5 Results	95
5 Summary.....	111
5.1 Data discovery	111
5.2 Species distribution modelling	112
5.3 Gaps in knowledge.....	112

6	Acknowledgements	113
7	Glossary of abbreviations and terms	114
8	References	116

Tables

Table 3-1:	Benthic invertebrate location records: data sources used.	11
Table 3-2:	Summary of invertebrate species location records from within the benthic AOI.	12
Table 3-3:	Summary of FNZ catch effort data of non-QMS species by phylum within the benthic AOI.	16
Table 3-4:	Summary of FNZ Observer catch data of non-QMS species by phylum within the benthic AOI.	17
Table 3-5:	MBES bathymetric coverage across each of the regions of interest as shown in Figure 3-6.	23
Table 3-6:	Xenophyophore densities from 2023 survey.	43
Table 3-7:	Summary of known sensitive environments within the benthic AOI.	70
Table 3-8:	Summary of protected cnidarian groups.	82
Table 3-9:	At Risk - Naturally Uncommon.	83
Table 3-10:	At Risk - Declining.	84
Table 4-1:	Taxa selected for species distribution modelling.	94
Table 4-2:	Environmental variables used for species distribution modelling, reduced from a larger set by eliminating those with greatest overall correlation.	96
Table 4-3:	Binomial model variable selection.	97
Table 4-4:	Regression model variable selection.	98
Table 4-5:	Performance metrics for the regression and binomial model components of the hurdle models for eight modelled taxa.	99

Figures

Figure 2-1:	Spatial extent of the study area.	10
Figure 3-1:	Available benthic invertebrate records within the benthic AOI.	13
Figure 3-2:	Spatial location of the FNZ catch effort data of non-QMS species within the benthic AOI.	15
Figure 3-3:	Spatial distribution of FNZ Observer catch data of non-QMS species within the benthic AOI.	18
Figure 3-4:	Available imagery data within the benthic AOI.	20
Figure 3-5:	Earth Sciences NZ's Deep Towed Imaging System (DTIS).	21
Figure 3-6:	Overview of available bathymetry data within the benthic AOI.	25
Figure 3-7:	Habitat types identified during the 2019 baseline survey for OMV New Zealand Ltd.	27
Figure 3-8:	Known habitats within, and in the vicinity of, the benthic AOI.	28
Figure 3-9:	Summary of sampling during the Ocean Census survey of the Bounty Trough.	29

Figure 3-10:	Example of a DTIS transect on the broad slope basin from the 2019 baseline survey.	30
Figure 3-11:	Example images from the broad slope basin habitat from the 2019 baseline survey.	31
Figure 3-12:	Example of a DTIS transect at a channel site in the 2019 baseline survey.	32
Figure 3-13:	Example images from channel sites from the 2019 baseline survey.	33
Figure 3-14:	Example of a DTIS transect at a seamount site from the 2019 baseline survey.	34
Figure 3-15:	Example images from seamount sites from the 2019 baseline survey.	35
Figure 3-16:	Macroinvertebrates such as <i>Ophiocoma/Ophiopteris</i> spp. using bryozoan colonies.	36
Figure 3-17:	Example images of biogenic habitats.	37
Figure 3-18:	CTD casts within the benthic AOI.	39
Figure 3-19:	Dissolved oxygen profiles from CTD casts.	40
Figure 3-20:	Sediment community oxygen consumption (SCOC) data locations (Stratmann et al. 2019) in the Aotearoa New Zealand region.	41
Figure 3-21:	Sediment oxygen profiles from retrieved cores taken at Butterknife sites, Chatham Rise.	42
Figure 3-22:	DTIS image showing branching stony coral at a seamount site within the benthic AOI.	45
Figure 3-23:	DTIS image showing intact, but dead, branching stony coral (with yellow primnoid sea fans (gorgonians)) at a seamount site within the benthic AOI.	45
Figure 3-24:	Distribution of records of live branching stony corals within the benthic AOI.	46
Figure 3-25:	KEA species distribution models: branching stony corals.	47
Figure 3-26:	DTIS images showing xenophyophore beds observed within the benthic AOI.	49
Figure 3-27:	Species location records of xenophyophores within the benthic AOI.	50
Figure 3-28:	Known sensitive environments for xenophyophore beds within the benthic AOI.	51
Figure 3-29:	Specimen location records of Bryozoa within the benthic AOI.	53
Figure 3-30:	KEA species distribution modelling: habitat-forming Bryozoa.	54
Figure 3-31:	Spatial location of Chaetopteridae records within the benthic AOI.	56
Figure 3-32:	Spatial distribution of sea pen records within the AOI.	58
Figure 3-33:	KEA species distribution models: sea pen.	59
Figure 3-34:	Spatial distribution of Porifera (sponge) records within the benthic AOI.	61
Figure 3-35:	KEA species distribution modelling: sponges.	62
Figure 3-36:	Spatial distribution of habitat-forming bivalve records within the benthic AOI.	64
Figure 3-37:	KEA species distribution modelling: bivalves.	65
Figure 3-38:	DTIS image showing a brachiopod bed amongst barnacle plates at a seamount within the benthic AOI.	66
Figure 3-39:	Spatial distribution of Brachiopoda within the benthic AOI.	67
Figure 3-40:	KEA species distribution modelling: brachiopods.	68

Figure 3-41:	Location of known sensitive environments present within the benthic AOI.	71
Figure 3-42:	Spatial distribution of Antipatharia records within the benthic AOI.	73
Figure 3-43:	KEA species distribution modelling: black coral.	74
Figure 3-44:	Spatial distribution of "Gorgonacea" (gorgonian corals) records within the benthic AOI.	76
Figure 3-45:	KEA species distribution modelling: gorgonians.	77
Figure 3-46:	Spatial distribution of Scleractinia records within the benthic AOI.	78
Figure 3-47:	KEA species distribution modelling: scleractinian cup corals.	79
Figure 3-48:	Spatial distribution of Stylasteridae (hydrocoral) records within the benthic AOI.	81
Figure 3-49:	KEA species distribution modelling: Stylasteridae.	82
Figure 3-50:	Macroinfaunal abundance of vulnerable taxa recorded within the benthic AOI.	86
Figure 3-51:	Macroinfaunal abundance of vulnerable taxa recorded within the benthic AOI.	87
Figure 3-52:	Terebellid worm with gathered salp faecal pellets in its tentacles.	89
Figure 3-53:	Temporal variation of ophiuroids in repeat surveys in the benthic AOI.	90
Figure 4-1:	Study area showing the location of video transect sites used to train species distribution models.	92
Figure 4-2:	Stylasterid hydrocorals – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data.	102
Figure 4-3:	Bryozoans – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data.	103
Figure 4-4:	Cup corals – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data.	104
Figure 4-5:	Gorgonian corals – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data.	105
Figure 4-6:	Porifera (sponges) – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data.	106
Figure 4-7:	Pennatulioidea (sea pens) – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data.	107
Figure 4-8:	Reef-forming Scleractinia (stony corals) – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data.	108
Figure 4-9:	Xenophyophores – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data.	109

Executive summary

Gigablue is developing a technology for capturing carbon dioxide through growth of phytoplankton on particles released into the marine environment. Gigablue propose to release 9(2)(b)(i), 9(2)(b)(ii) into iron-poor subantarctic waters to the east of the southern part of Aotearoa New Zealand's Te Waipounamu South Island. Particles are expected to remain at or near the sea surface for up to approximately 21 days during which time it is envisaged that phytoplankton will grow on and within the particles. The particles will then sink into deep water and settle on seafloor sediments, and benthic communities, resulting in the sequestration of carbon into deep-sea sediments with an expected deposition of up to ~25 g of organic matter m⁻² (Gigablue figures).

Gigablue's area of interest (AOI) for examination of the effects of particle deposition on benthic communities covers a large area (approximately 106,996 km²) off the southeast coast of Te Waipounamu South Island, and includes seabed features such as shelf slope, broad slope basin, channel systems and seamounts. Available data have been summarised to highlight the known and predicted distribution of key faunal groups and habitats as well as to identify key knowledge gaps.

A total of 13,741 species location records were identified from within the benthic AOI. These records were most densely located along the north and west boundary of the benthic AOI and otherwise were sparsely distributed throughout the rest of the area. The exception to this was a cluster of records generated from a spatially focussed 2019 benthic survey in the area.

Schedule 6 of the EEZ and Continental Shelf (Environmental Effects - Permitted Activities) Regulations 2013 defines sensitive environments for various taxonomic groups within the Aotearoa New Zealand marine benthic environment. Sensitive environments for stony coral thickets or reefs, xenophyophore beds, and brachiopod beds are present within the benthic AOI. In addition, sensitive environments for bryozoan thickets and Chaetopteridae worm fields are also likely to be present either within, or in close proximity to, the benthic AOI. It is also possible that sea pen fields, sponge gardens, and beds of large bivalve molluscs are present within the benthic AOI.

With respect to marine species protected under the Wildlife Act (1953), Antipatharia (black corals), gorgonian corals (sea whips and sea fans), Scleractinia (stony corals) and stylasterid hydrocorals are all known to be present within the benthic AOI. Many of the sensitive environment and protected species taxa were particularly associated with the shelf slope, channel and seamount habitats within the benthic AOI. However, it is notable that xenophyophores (sensitive environment) and scleractinian cup corals (protected species) were present in high densities on the muddy sediments of the broad slope basin.

All of the identified taxa deemed from the available literature to be vulnerable to variability in dissolved oxygen and particulate smothering (see Ingels 2025) were found to be present within the benthic AOI.

An extensive dataset of seabed imagery from within the benthic AOI and surrounding seas enabled the application of species distribution modelling to predict species abundance across all unsampled space within the area, with a focus on the presence and abundance of sensitive, protected, and vulnerable marine environment species within the benthic AOI.

High abundances of some taxa, especially stylasterid hydrocorals and bryozoans, were predicted for some isolated locations, particularly around the channels in the north of the benthic AOI.

There are large areas within the benthic AOI for which there are no empirical faunal data (either imagery or specimen data) and/or no detailed multibeam bathymetry data to accurately represent seabed geography. Benthic species distribution modelling goes some way to overcome some of these gaps, however, this relies on spatial representations of predictor variables which themselves are based on sparse data, and ground truthing of modelled predictions would be needed to reduce uncertainty on predictions.

No interstitial pore-water data were available from within the benthic AOI that may have provided information on natural dissolved oxygen levels in the sediments of the AOI. Available data from historic Conductivity, Temperature, Depth (CTD) casts showed dissolved oxygen measurements in the 1,000–1,500 m depth range were between 150 and 200 $\mu\text{mol/kg}$ (or approximately 4 ml/l), which is consistent with the oxygen minimum layer in Upper Circumpolar Deep Water and North Pacific Deep Water intermediate depths (~1,200–1,500 m) south of the Chatham Rise.

This report covers three of six specified contracted tasks in this project (benthic data discovery, predictive benthic species distribution modelling and xenophyophore still image analysis, respectively). Remaining tasks are provided in separate reports/data packages.

1 Background

Gigablue is developing a technology that aims to capture carbon dioxide through growth of phytoplankton on particles released into the marine environment. 9(2)(b)(i), 9(2)(b)(ii)

Gigablue propose to release these particles into the marine environment, in iron-poor subantarctic waters to the east of the southern part of Te Waipounamu South Island. Particles are expected to remain at or near the sea surface for up to approximately 21 days during which time it is envisaged that phytoplankton will grow on and within the particles. The particles will then sink into deep water and settle on seafloor sediments, and benthic communities, in order to sequester carbon into deep-sea sediments with an expected deposition of up to ~25 g of organic matter m⁻² (Gigablue pers. comm.).

Given the relatively small size and weight of each individual particle, one metric tonne would contain between approximately 33 and 200 million particles. Deployment of particles would take place from a suitable vessel, and the deployment location, and subsequent dispersal of particles, would be within Aotearoa New Zealand's Exclusive Economic Zone (EEZ). For commercial-scale deployments of particles to proceed, Gigablue must obtain the necessary consents, for which they need to investigate the potential impacts of the deployment on the marine environment. This report covers the known information on habitats and benthic species present within the Area of Interest provided by Gigablue.

1.1 Project scope

NIWA (now Earth Sciences New Zealand (NZ)) was asked to provide a desktop review of available and relevant benthic data and identify benthic species thresholds (e.g., to depleted dissolved oxygen or sedimentation/deposition of particulates), where they can be established, for Gigablue's area of interest (AOI) in the Bounty Trough.

There are six tasks related to this project:

1. Benthic data discovery
2. Review of international literature
3. Addressing specific questions
4. Preparation of data products
5. Predictive benthic species distribution modelling
6. Xenophyophore still image analysis

Tasks 1, 5, and 6 are addressed within this report as detailed below. Tasks 2 and 3 are presented in a separate report (Ingels 2025). Task 4 is being provided as a separate GIS package.

2 Study area

Gigablue's benthic AOI is a large area off the southeast coast of Aotearoa New Zealand's Te Waipounamu South Island (Figure 2-1) encompassing polygon areas provided by Gigablue and providing a "buffer zone". This benthic AOI is approximately 470 km long (NNE-SSW) and 240 km wide (WNW – ESE) with an area of approximately 106,996 km². The western edge roughly follows the shelf edge. The green polygon indicated in the plot shows the spatial extent of a comprehensive benthic baseline survey conducted for OMV New Zealand Ltd., hereafter referred to as the 2019 baseline survey.

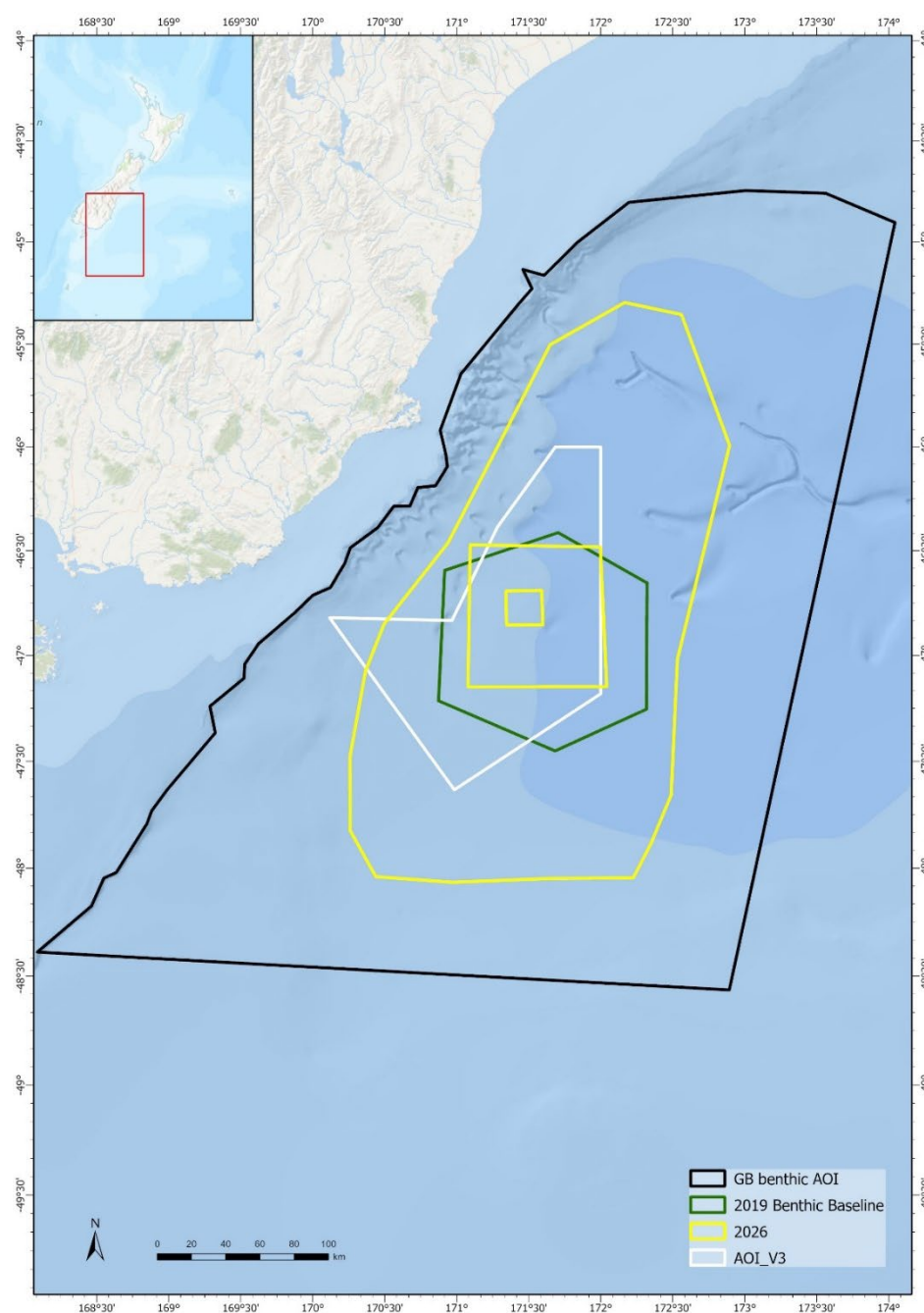


Figure 2-1: Spatial extent of the study area. Black line indicates benthic AOI, which provides a "buffer" zone around the areas of interest provided by Gigablue. Yellow lines indicate areas of interest (2026), the white line indicates Gigablue's area of interest (AOI_v3) and the green line indicates the extent of a 2019 benthic baseline survey conducted for OMV New Zealand Ltd. Inset map indicates spatial extent of main map.

3 Task 1. Data discovery

3.1 Extent of macrofauna, stills photos and Deep Towed Imaging System (DTIS) video datasets.

This section describes the extent of available macrofaunal and imagery data within the benthic AOI.

3.1.1 Macrofauna: physical samples – benthic invertebrate location records

Records of all benthic invertebrates collected from the area were sourced from the Earth Sciences NZ Invertebrate Collection database (NIWAinvert/SPECIFY), the southwestern Pacific node of the Ocean Biogeographic Information System (OBIS), and museum records from Te Papa Tongarewa (Te Papa) and Auckland museums (Table 3-2).

Table 3-1: Benthic invertebrate location records: data sources used.

Source: Datasets	Description
Ocean Biogeographic Information System, Southwestern Pacific Node (OBIS)	This is an online database that provides species occurrences for a wide range of taxa within Aotearoa New Zealand's EEZ and the wider South Pacific and has the highest number of invertebrate records for Aotearoa New Zealand waters of any database. Most biogenic habitats and their key habitat-forming species are represented to some level in this database. OBIS records for all marine invertebrates within the benthic AOI were extracted in June 2025.
Earth Sciences NZ Invertebrate Collection (NIWAinvert/SPECIFY)	This specimen collection (NIWAinvert) is located at the Earth Sciences NZ's Greta Point campus in Wellington and is Earth Sciences NZ's repository for marine invertebrates from almost all phyla found in the Aotearoa New Zealand region, including the wider Southwest Pacific and the Ross Sea. It houses an estimated 300,000 collection lots that have been collected over half a century of biological research (Schnabel et al. 2014). Collection records for benthic marine invertebrate species in the region were extracted in March 2025 using the database management software SPECIFY.
Museum of New Zealand Te Papa Tongarewa Natural Environment collection (Te Papa)	The Te Papa natural history collections contain the national collection of plant and animal specimens housing more than 1 million collection lots. It is the largest, most comprehensive collection of Aotearoa New Zealand fauna and flora, with most major taxonomic groups of plants and animals represented. The database management software KEmu was queried to extract all marine invertebrates in the region. Data provided by Kerry Walton at Te Papa, June 2025.
Auckland War Memorial Museum Tāmaki Paenga Hira (Auckland Museum).	The Auckland Museum and collections are located in the Auckland Domain. The Natural Sciences collections cover terrestrial and aquatic botany, entomology, land vertebrates, marine fauna, geology and palaeontology specimens from across the regional Pacific. The marine collection numbers an estimated 200,000 specimens and includes fish and invertebrates. The focus of the herbarium collection is on wild plants (native and naturalised) in all plant groups principally from northern Aotearoa New Zealand and its offshore islands. It is principally a research collection and provides evidence of Aotearoa New Zealand's changing flora. Some of the earliest specimens date from James Cook's voyages. The dataset was provided by Auckland Museum in August 2019.

Datasets from each of these sources were filtered to exclude any records from outside the benthic AOI, then compiled following a sequence of assessments and formatting for consistency. This is in addition to previous quality checks and assessments that have included substantial grooming. Duplicate records were deleted where identified (e.g., NIWAinvert records deleted from OBIS). Species location records were most densely populated along the north and west boundary of the benthic AOI and otherwise were sparsely distributed throughout the rest of the benthic AOI with the exception of a cluster within the 2019 benthic baseline survey area (Figure 3-1). In total, 13,741 species location records were available (Table 3-2). Phylum Mollusca had the greatest number of records, followed by Arthropoda, Echinodermata and Cnidaria.

Table 3-2: Summary of invertebrate species location records from within the benthic AOI. Listed by phylum, in descending order of the number of available records.

Phylum	SPECIFY	OBIS	Te Papa	Auckland Museum	Total
Mollusca	509	1,511	5,211	1	7,232
Arthropoda	1,395	438	274	3	2,110
Echinodermata	706	697	146	2	1,551
Cnidaria	430	564	14		1,008
Porifera	365	1,480	16		1,861
Bryozoa	288	8	45		341
Annelida	225	12	6		243
Chordata (tunicate)	64	138	11		213
Brachiopoda	31	7	17		55
Foraminifera	38				38
Kinorhyncha	15	1			16
Nematoda	11				11
Nemertea	11				11
Invertebrata	8				8
Chaetognatha	5	1			6
Sipuncula			5		5
Cercozoa	2				2
Hemichordata	2				2
Platyhelminthes	2				2
Priapulida	2				2
Entoprocta	1				1
Grand Total	4,110	3,880	5,745	6	13,741

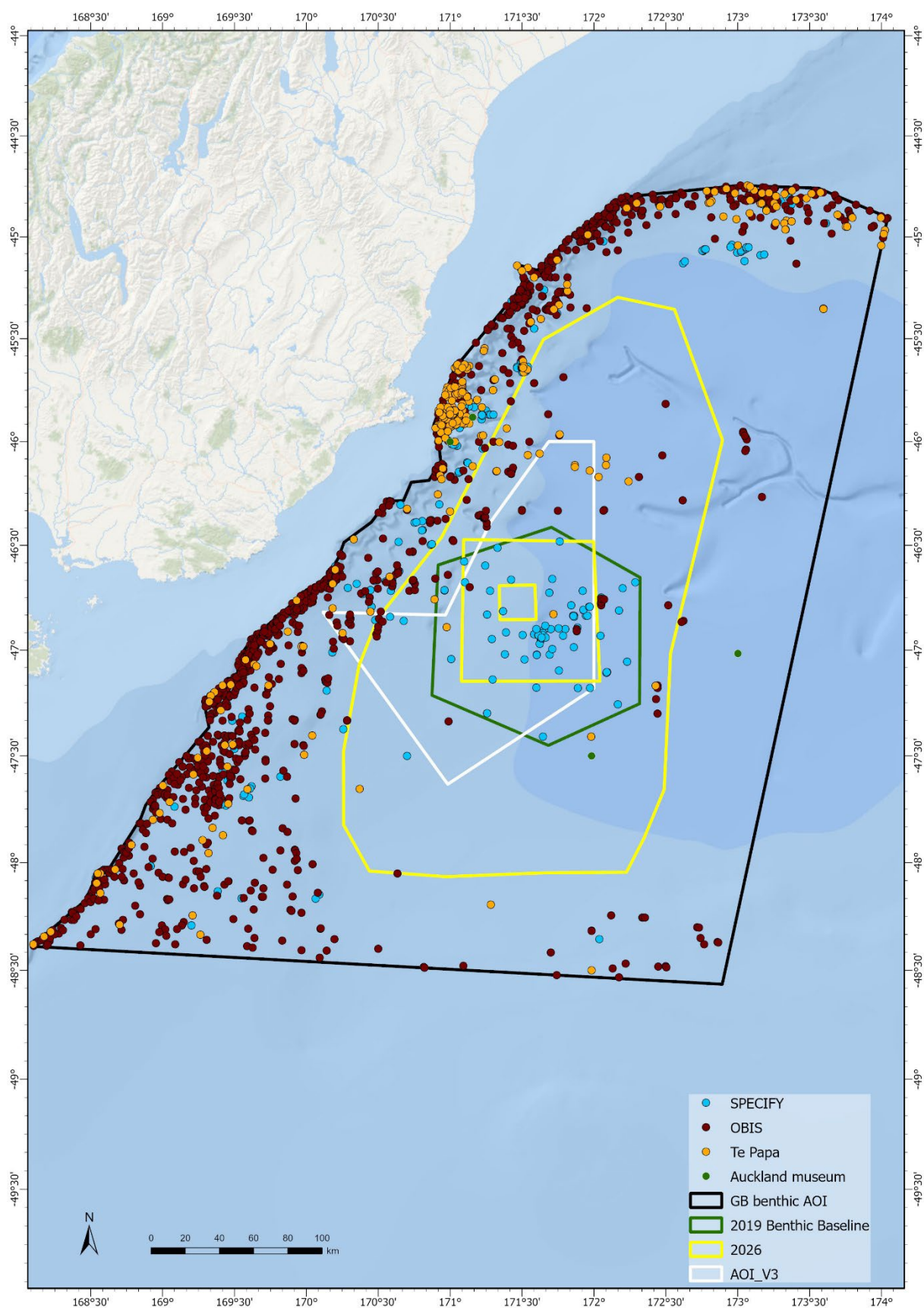


Figure 3-1: Available benthic invertebrate records within the benthic AOI. Includes records from Earth Science’s NZ (SPECIFY), OBIS, Te Papa, and Auckland Museum.

3.1.2 Macrofauna: reported catches –Fisheries New Zealand bycatch data

Details of reported catches of all non-Quota Management System (QMS) species within the benthic AOI were extracted from the Fisheries New Zealand (FNZ) catch effort database in June 2025. These records represent captures of invertebrate species that, in the vast majority of cases, were not retained and not identified by experts and therefore may be considered less reliable than other data sources. These records (Figure 3-2, Table 3-3) were examined and the distribution and abundance of sensitive environment and protected species plotted. These records have a similar distribution to that of the physical samples, with most coming from the western and northern boundaries of the benthic AOI (especially in the south) along with a few scattered records from deeper waters further offshore. Note that as this report is focussed on the benthic environment, records from midwater trawl, squid jig and surface/midwater longline fishing methods were excluded.

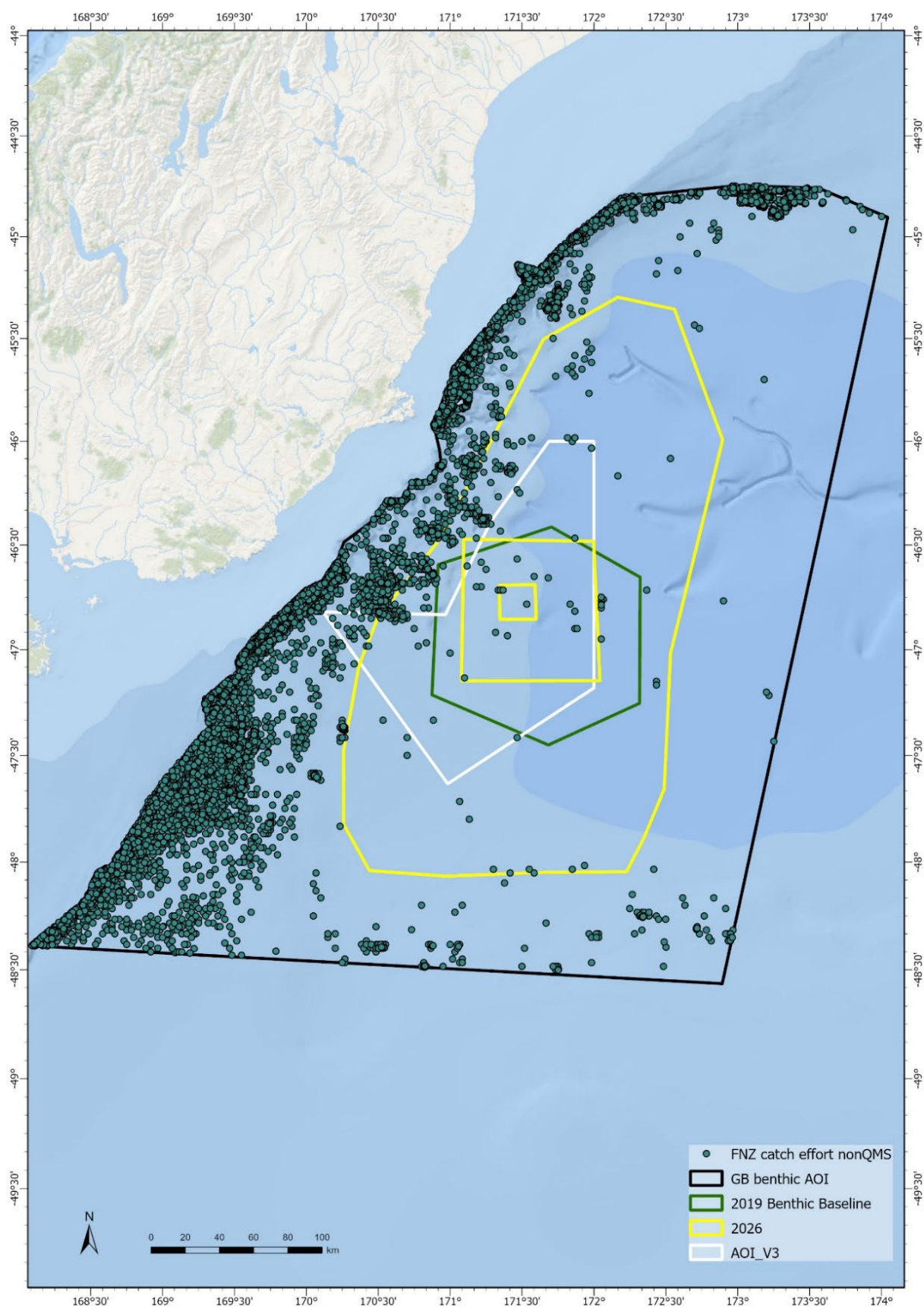


Figure 3-2: Spatial location of the FNZ catch effort data of non-QMS species within the benthic AOI. Excludes records from midwater trawl, squid jig and surface/midwater longline fishing methods.

Table 3-3: Summary of FNZ catch effort data of non-QMS species by phylum within the benthic AOI. Excludes records from midwater trawl, squid jig and surface/midwater longline fishing methods.

Row Labels	Count of Phyla
Arthropoda	95
Cnidaria	61
Echinodermata	355
Salp/Jellyfish	187
Mollusca	3,336
Unknown	187
Chordata (vertebrate)	33,145
Grand Total	37,366

3.1.3 Macrofauna: FNZ observer catch data

This dataset comprises an extract from COD, the Centralised Observer Database, with details of all invertebrate species catches from bottom and midwater trawling plus some squid jig fishing, for all available fishing years (since about 1990), within the benthic AOI. As for the reported catch data in the previous section most specimens were not retained, however the government fisheries observers recording these data are highly trained in the identification of benthic invertebrates – therefore these data are more reliable. Data (Figure 3-3, Table 3-4) were extracted in June 2025.

Table 3-4: Summary of FNZ Observer catch data of non-QMS species by phylum within the benthic AOI. Data excluded from table: shell and bone fragments and substrata (sand, gravel, wood).

Phyla	Count
Annelida	44
Arthropoda	2,855
Brachiopoda	4
Bryozoa	52
Chordata (Ascidian)	13
Cnidaria	1,570
Coral rubble	9
Coral rubble - dead	16
Egg case	15
Fish eggs	1
Invertebrate, unknown	3
Jellyfish/salp/pyrosoma (pelagic)	1,218
Mollusca	3,717
Platyhelminthes	1
Porifera	1,480
Sipuncula	13
Unknown	24
Chordata (Vertebrate)	3,119
Total	14,154

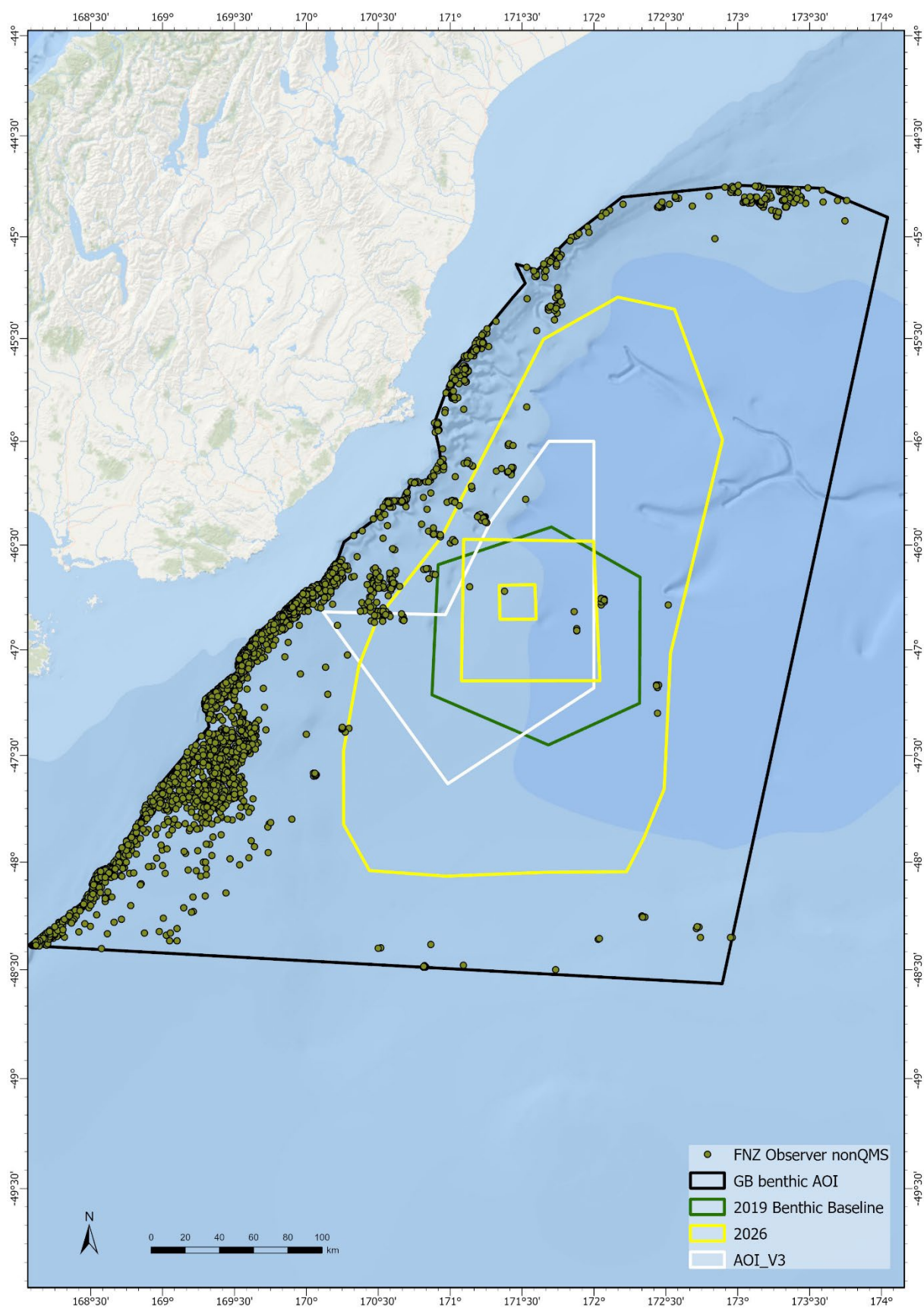


Figure 3-3: Spatial distribution of FNZ Observer catch data of non-QMS species within the benthic AOI.

3.1.4 Imagery data

The distribution of available imagery-derived data within the benthic AOI is shown in Figure 3-4. These data were all derived from surveys of benthic epifauna and habitat types using Earth Sciences NZ's Deep Towed Imaging System (DTIS, Hill 2009). DTIS (Figure 3-5) is a towed camera platform that records continuous high-definition video (1080 p) and simultaneously takes high-resolution still images (24 MP) at 15 second intervals. DTIS was typically towed at 2–3 m altitude above the seafloor at a speed of 0.6 knot for a distance of approximately 1 km at each survey site. A USBL (ultra-short baseline acoustic positioning system, Kongsberg HiPAP) enabled accurate tracking of DTIS, and all positional and seabed observation data were recorded continuously in real time using Ocean Floor Observation Protocol software (OFOP¹) linked to RV *Tangaroa*'s data acquisition system (DAS).

Full high definition resolution video files were analysed using OFOP. Each video was synchronised with its corresponding navigation data file and replayed to enable geo-referenced observations of seabed habitat (i.e., substratum type and geomorphology) and biological observations to be recorded. For each observation recorded, OFOP automatically captures time, global positioning system location information, and other metadata captured from the ship's DAS. Substratum type was recorded continuously throughout each transect as coarse categories (i.e., bedrock, boulders, cobbles, pebbles, gravel, shell-hash, coral rubble, sand, mud – as defined in Greene et al. (1999). Epibenthic megafauna (organisms visible to the eye, greater than ca. 4 cm) and lebensspuren (signs of life, such as trails, burrows and mounds) were recorded as observations of individual specimens or occurrences. Biota were identified to broad taxonomic levels (e.g., asteroid, gorgonian, gastropod), or finer where possible (e.g., family or genus, occasionally species), and the corresponding higher-resolution still images were referred to for confirmation of identifications.

Faunal data were summarised as total counts per transect, standardised to the number of individuals per 1,000 m² (inds. 1,000 m⁻²).

Of the available imagery data for the benthic AOI, only those collected during the 2019 baseline survey have been previously assessed specifically for the presence of sensitive environments according to the definitions specified in Schedule 6 of the EEZ and Continental Shelf (Environmental Effects - Permitted Activities) Regulations 2013 (See section 3.6 below).

¹ www.ofop-by-sams.eu

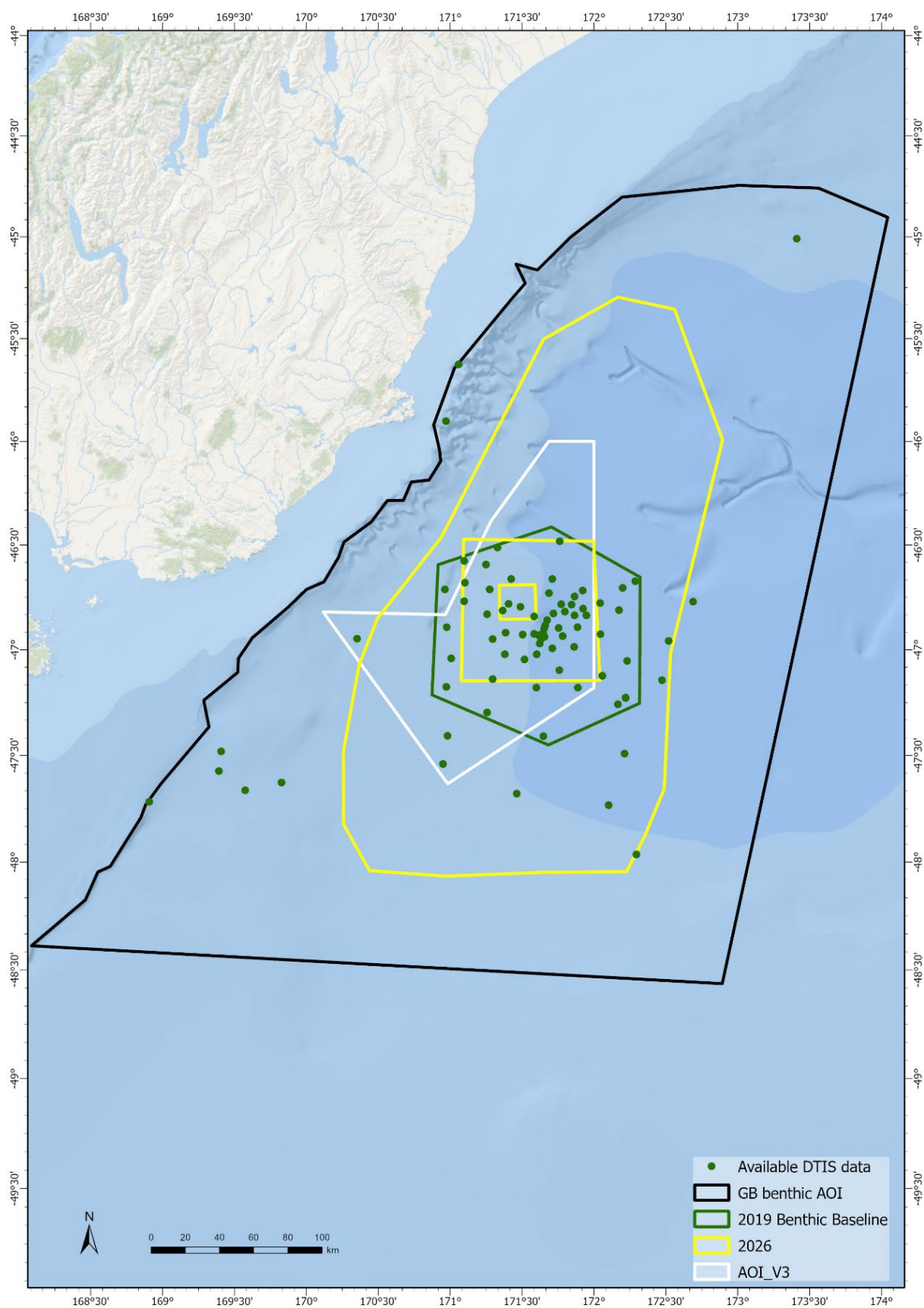


Figure 3-4: Available imagery data within the benthic AOI. Green dots show the spatial distribution of available imagery data

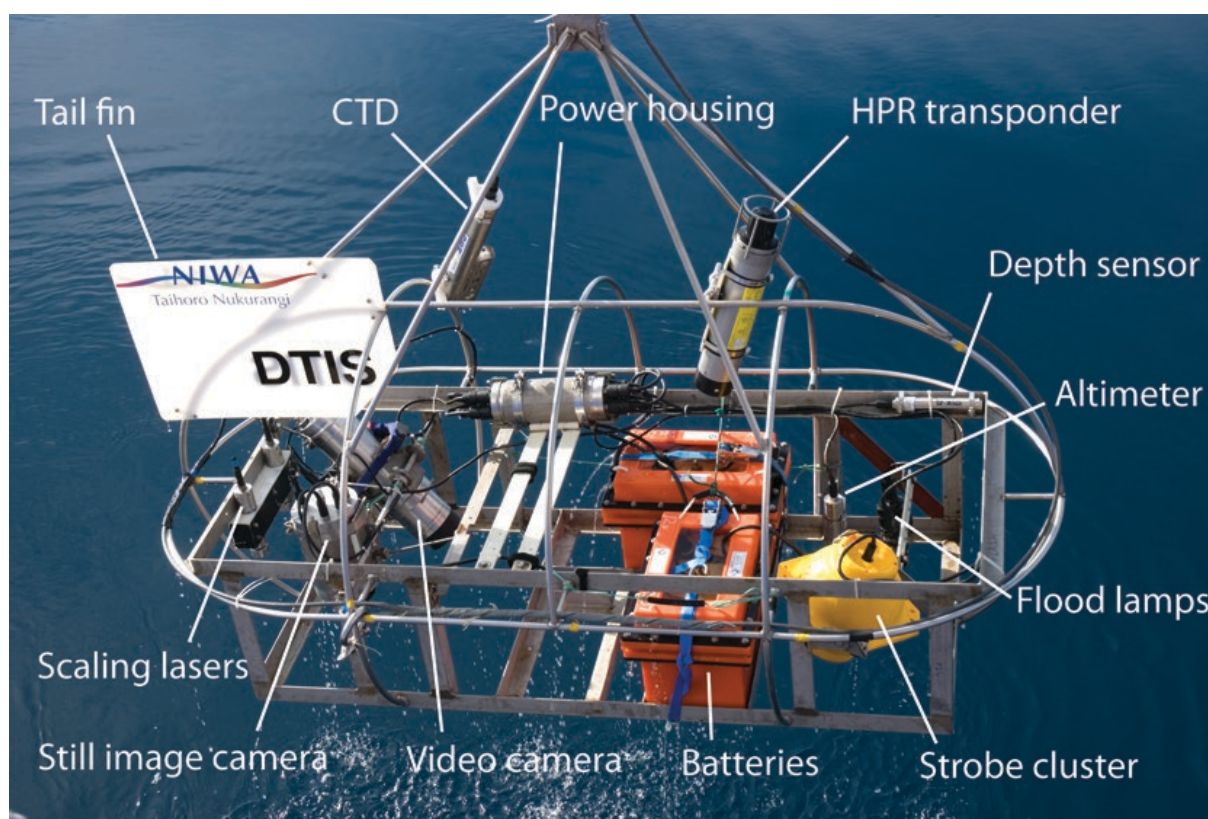


Figure 3-5: Earth Sciences NZ's Deep Towed Imaging System (DTIS). Note this image shows an earlier configuration of the system. Updated video and still image camera systems were used in the 2019 baseline survey but the only conspicuous outward change from the image above is in the strobe housing, the yellow strobe cluster housing being replaced by two individual strobe units, each in a titanium pressure housing. The DTIS has since been further updated to include a forward-facing video camera.

Sensitive environments: 2019 baseline survey

Imagery data collected during the 2019 baseline survey were assessed for the presence of sensitive environments according to the definitions specified in Schedule 6 of the EEZ and Continental Shelf (Environmental Effects - Permitted Activities) Regulations 2013 (See section 3.6 below). Note that detailed analyses of sensitive environment thresholds have not been carried out for imagery data from other surveys carried out in the benthic AOI (e.g., TAN1108, TAN1701, TAN2004).

In order to determine densities of key taxa (e.g., those listed as indicative of sensitive environments in Schedule 6), the patchiness of taxa across DTIS transects was assessed using a geographic information system (GIS). Where abundances were patchy across a transect, high-density locations were identified and counts or percentage cover of the fauna calculated to determine maximum densities, as individuals or coverage per unit area. For taxa where densities within Schedule 6 were specified at the 1 m² scale (e.g., sea pens) still images captured by DTIS were analysed for densities at this smaller scale using the image analysis software *ImageJ*.

Within Schedule 6, the indication of a sensitive environment is defined by percent cover over a minimum area for some taxa (e.g., the threshold for branching stony corals is an average of 15% percent cover over 100 m² or more). Percent cover was measured in DTIS still images, using

ImageJ software. Calculation of seabed area framed in each still image, combined with the navigational data for the transect to assess the total swept area of the transect for a given number of images, enabled estimation of percent cover at spatial scales specified in Schedule 6 (e.g., 100 m² for stony corals).

Due to the small and obscure nature of xenophyophores, only the largest and most obvious individuals were able to be recorded from video analysis, which may result in an under-estimate of abundances and associated density estimates. A more robust estimate of xenophyophore densities can be derived through still image analysis. However, due to time constraints for the 2019 survey analyses, xenophyophores were counted on DTIS still images from a single site and a scaling factor from the ratio of the video counts to the still image counts from this site was used to scale-up the estimate of xenophyophore densities at all sites. For sites with heterogeneous habitats (such as at or near channel and seamount features), estimates of density were made only for those sections of the transect with habitat suitable for xenophyophores.

Xenophyophore analysis: 2023 survey for OMV

Available images from a 2023 follow-up survey of the 2019 baseline survey were analysed for this report in order to quantify and validate the abundances of xenophyophores observed, and further compare against sensitive habitat thresholds for this taxon. This work is described in detail in Section 3.6 (Task 6).

3.1.5 Key Ecological Area species distribution models

The Department of Conservation contracted NIWA (now Earth Sciences NZ) to explore criteria that could assist with mapping ecologically important areas to be considered as part of future marine protected area processes, for identifying gaps in the existing marine protected area network, and potentially to inform other resource management planning in the coastal and marine environment. The nine Key Ecological Area (KEA) criteria proposed for further investigation, based on the Convention on Biological Diversity's criteria for Ecologically and Biologically Significant Areas, were: 1) Vulnerability, fragility, sensitivity, or slow recovery; 2) Uniqueness/rarity/endemism; 3) Special importance for life history stages; 4) Importance for threatened / declining species and habitats; 5) Biological productivity; 6) Biological diversity; 7) Naturalness; 8) Ecological function; and 9) Ecosystem services.

Twenty seven datasets were collated and ensemble predictions combining outputs from boosted regression tree and random forest models used to predict species occurrence and distribution maps for a range of taxa (Lundquist et al. 2020). The spatial extent of the benthic invertebrate models produced was Aotearoa New Zealand's EEZ and for macroalgae the model extent was limited to reef habitat within the Territorial Sea (TS) and offshore islands.

These KEA models predicted the occurrence of 207 benthic invertebrate taxa for which there were greater than 50 records within the raw data, on a 1 km x 1 km Albers equal area grid. The 207 taxa comprised 2 genera of Chordata, 5 genera of Brachiopoda, 9 genera of Annelida, 11 genera of Bryozoa, 12 genera of Porifera, 32 genera of Mollusca, 33 genera of Cnidaria, 42 genera of Arthropoda, and 61 genera of Echinodermata.

Distribution layers produced from that study are used here to show the predicted probability of occurrence of key taxa such as genera containing protected or sensitive environment species.

The data layers are freely available within an atlas of seabed biodiversity for Aotearoa New Zealand (Stephenson et al. 2023) via an open-access database, together with estimates of uncertainty.

Note that this work was conducted in 2019 and, therefore, much of the recent data collected within the benthic AOI was not available to the models (e.g., the 2019 baseline survey for OMV NZ Ltd.) which were based mostly on sample data from outside of the benthic AOI. Updated species habitat modelling of key faunal groups, using the latest available data spatially relevant to Gigablue’s benthic AOI, is presented in Section 4 (Task 5) below.

3.2 Extent of multibeam bathymetry coverage from legacy voyages.

Earth Science NZ hosts a data archive of seafloor bathymetric data acquired by multibeam echosounder systems (MBES) across Aotearoa New Zealand, the South Pacific, and Antarctica. There have been several significant seafloor mapping campaigns undertaken by NIWA/Earth Sciences NZ over the areas of interest identified across the Otago shelf canyons and western Bounty Trough regions (black polygon - Figure 3-6).

Since 1990, NIWA has mapped more than 50,000 km² of seafloor in the benthic AOI (purple polygon – Figure 3-6). Additional MBES datasets sourced from hydrographic surveys, commissioned by Land Information New Zealand, and transit legs from international research vessels comprise an additional ~33,000 km² of available seafloor bathymetry data (green and blue polygons, respectively – Figure 3-6).

Overall, the wider Otago shelf canyons and western Bounty Trough region have been well-mapped with respect to the global average of seafloor mapping coverage. In total, 55% of the seafloor within the benthic AOI has been mapped by MBES (Table 3-5). In contrast, the 2025 compilation of publicly available bathymetry data through the Nippon Foundation-General Bathymetric Chart of the Oceans (GEBCO) funded Seabed 2030 project represents only 27.3% total coverage of the world’s oceans with various survey systems (21 June 2025²). Within the benthic AOI, only one of the areas of interest has been completely mapped by MBES (region E – Table 3-5), however all other areas have been relatively well-mapped, particularly across their northern extents (Figure 3-6).

Table 3-5: MBES bathymetric coverage across each of the regions of interest as shown in Figure 3-6.

Region of Interest		Area (km ²)	MBES Coverage (km ²)	Percent Region MBES Coverage	Nominal Grid Resolution (m)
A	2026	41,444	27,874	67%	25 – 150 m
B	AOI_V3	12,894	10,895	84%	25 m
C	2019 benthic baseline	9,952	7,522	76%	25 m
D	Max plume area	5,311	4,774	89%	25 m
E	Max top 5% conc.	347	347	100%	25 m
Buffered zone		106,995	58,636	55%	25 – 150 m

² <https://seabed2030.org/>

Due to the variable purposes/parameters constraining how the MBES data have been acquired, the quality of the MBES data across the region is highly variable. The most common MBES data within the region represents dedicated scientific seafloor surveying, which commonly meets (or exceeds) International Hydrographic Organisation (IHO) S-44 Order 1a acquisition parameters (IHO 2022). Other data across the region are largely derived from vessel transits where MBES data was recorded on an opportunity basis. This is evident in bathymetry coverage maps as single swath corridors across the seafloor (Figure 3-6) and has variable adherence to IHO acquisition parameters.

3.2.1 Regional bathymetry

In regions where MBES data are unavailable, the publicly released New Zealand Regional Bathymetry model developed by NIWA/Earth Sciences NZ is available for analysis (Mitchell et al. 2012). This bathymetric model, last updated in 2016, integrates MBES data with available single-beam depth track data, backed by the GEBCO_08 bathymetry grid (version 20120927), to generate a seamless elevation model at 1:5,000,000 scale (~250 m spatial resolution).

The other regional compilation of bathymetric data across the region includes the GEBCO global terrain model compilation (spatial resolution of 15 arc seconds), produced annually on behalf of GEBCO by the Seabed 2030 Project (GEBCO Compilation Group 2024).

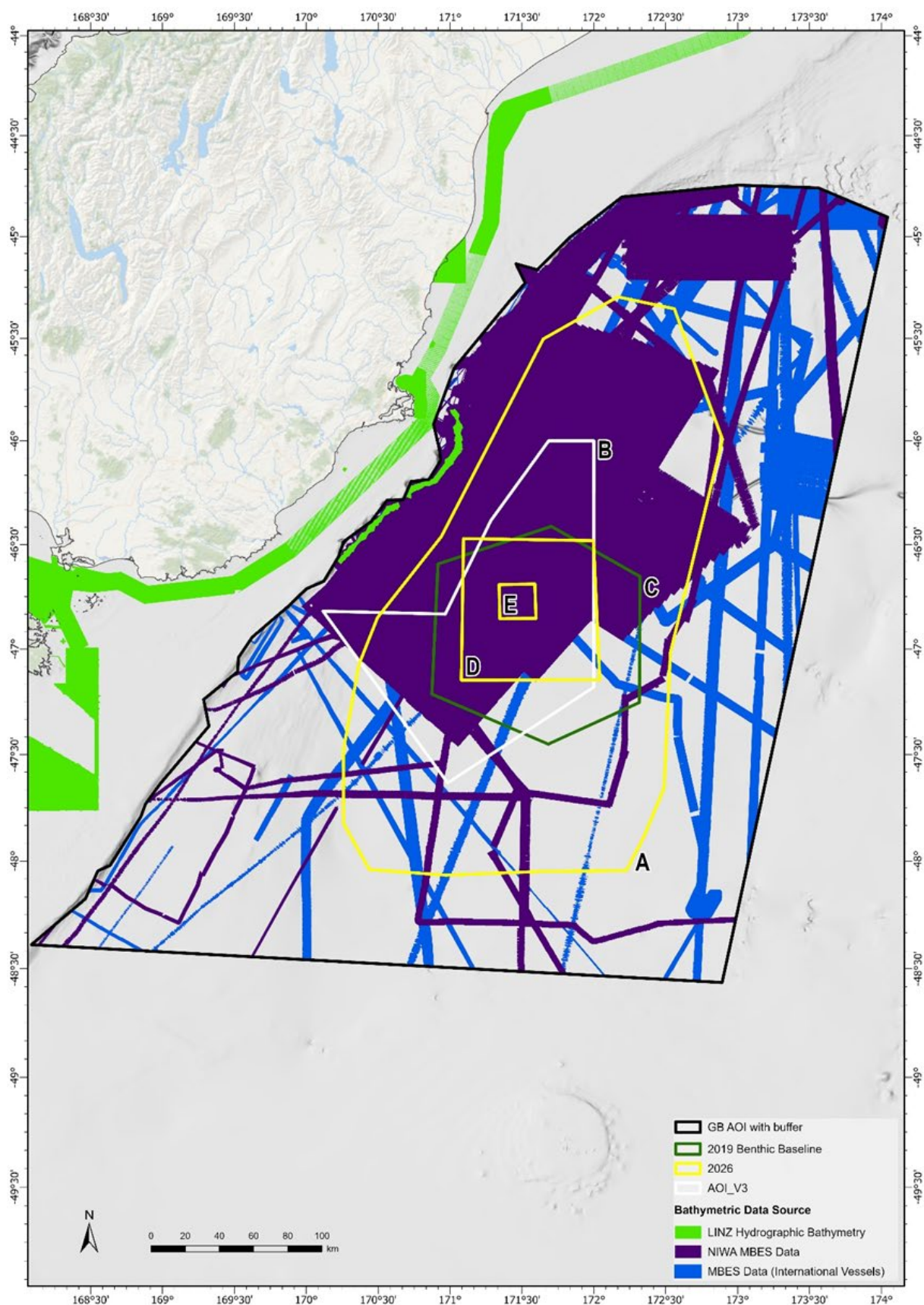


Figure 3-6: Overview of available bathymetry data within the benthic AOI. Text labels refer to regions of interest highlighted in Table 3-5.

3.3 Extent of habitat maps, heterogeneity modelling and benthic habitats.

The 2019 baseline survey consisted of 73 sites across three broad habitat types within the benthic AOI: broad slope basin, channel system (South Channel and its tributaries), and seamount features (Figure 3-7). Muddy sediment was the dominant substrate across survey sites, though harder substrates dominated the seamount and some channel sites.

Separately to the NIWA/Earth Sciences NZ surveys, biogenic habitats have also been reported from other studies in or near the benthic AOI. For example, the epibenthos on the Otago shelf, from 70 m water depth to the shelf break, includes an abundant community of large, heavily calcified bryozoans (Wood and Probert 2013). These bryozoan thickets dominate an area of about 110 km² on the midshelf, providing habitat at a range of scales (Figure 3-8). These bryozoan thickets on the Otago shelf are mostly outside of the benthic AOI, but there is overlap on the western boundary on the shelf edge.

A study of biogenic habitats on New Zealand's continental shelf by Jones et al. (2018) also included the Otago Shelf region. The definition used for a biogenic habitat in that study was "*a) those living species that form emergent three-dimensional structure, that separate areas in which it occurs from surrounding lower vertical dimension seafloor habitats and b) non-living structure generated by living organisms, such as infaunal tubes and burrows*"

Jones et al. (2018) interviewed local fishers with detailed knowledge of their fishing grounds to capture local ecological knowledge (LEK) on the presence of biogenic habitats which were memorable for the distinctive habitats/species that were caught as bycatch, sometimes in sufficient amounts to damage gear or make cleaning the net difficult. This LEK (Figure 3-8) was translated into digitised maps of fisher-described habitats. Biogenic habitat categories made up 66% of the areas drawn on charts, with the most commonly mentioned biogenic habitats being corals (likely to include bryozoans), sponges, kelp, horse mussels and bryozoans.

An Ocean Census³ voyage in 2024 (RV *Tangaroa* voyage TAN2402) to the Bounty Trough collected specimens from a variety of habitat types within the benthic AOI including seamounts, channel sites, pockmarks, and the broad slope basin (Figure 3-9). Imagery collected on this voyage has not yet been analysed, but specimens collected are included within the SPECIFY dataset described in section 3.1.1 above.

An even more recent voyage (Schnabel et al. 2025; Freiwald et al. in press) mapped and studied an area of volcanic features in the southwest extent of the benthic AOI. Research activities of the RV *Sonne* expedition SO309 provided the first detailed maps (Figure 3-8) and *in-situ* observations of these features. Most notable were two large, flattened guyots, and several smaller conical and flat-topped features nearby. Biological communities observed included dense patches of purple branching stony coral *Enallopsammia rostrata* as well as a diverse community of suspension and filter feeders including solitary hard corals, gorgonians and soft corals, sponges and other mobile invertebrates. Video footage from this survey is also yet to be analysed, but specimens collected are included in the SPECIFY dataset described above.

Lewis and Marshall (1996) recorded numerous *Maorithyas* sp. valves in a dredge sample collected in 555-604 m water depth in the head of the Papanui Canyon, off the Otago Peninsula, which they suggested were associated with vent sites. Orpin (1997) described this same site as an upper-slope seep chimney site, but with no evidence of currently active seeps.

³ <https://oceanensus.org/>

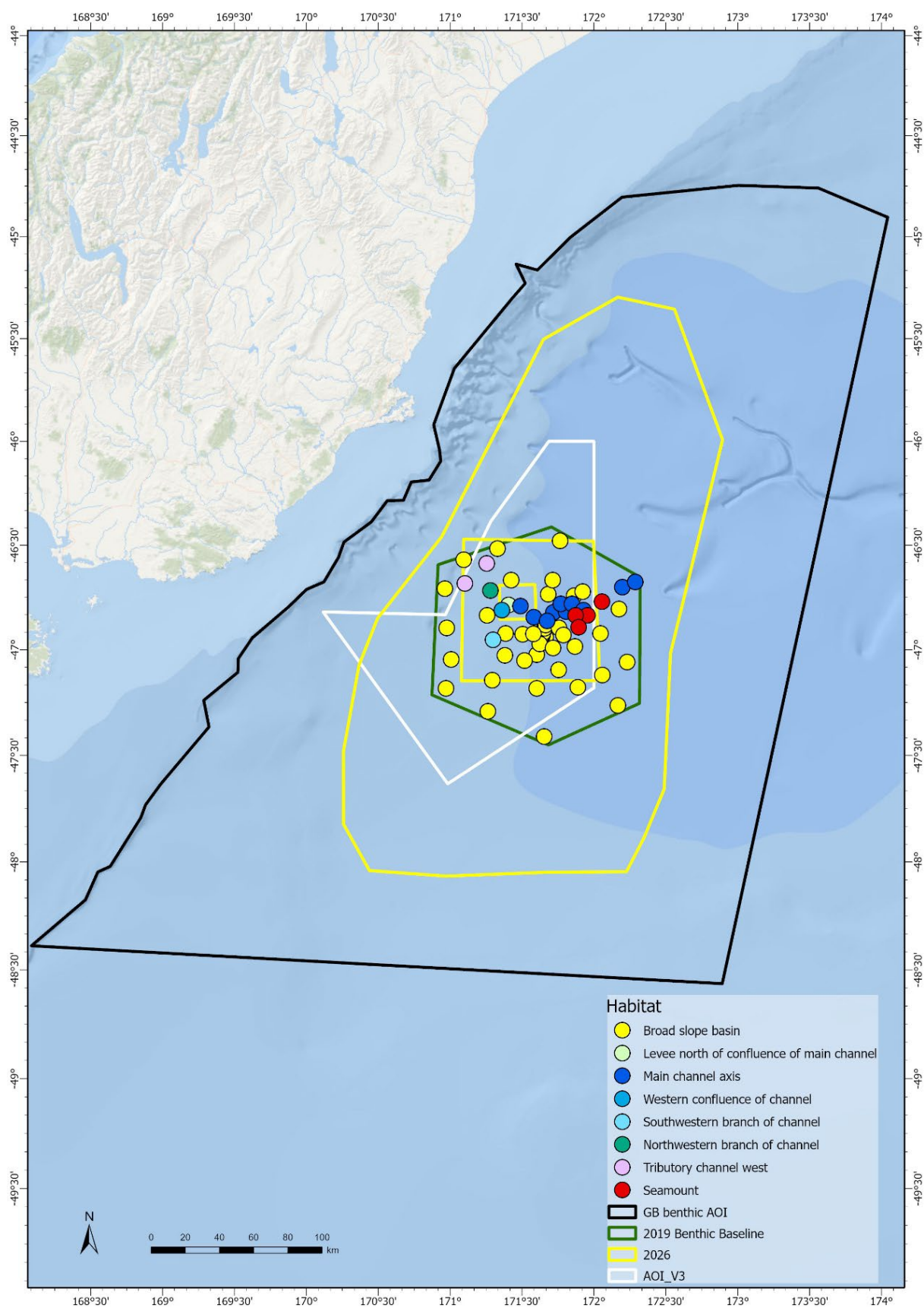


Figure 3-7: Habitat types identified during the 2019 baseline survey for OMV New Zealand Ltd.

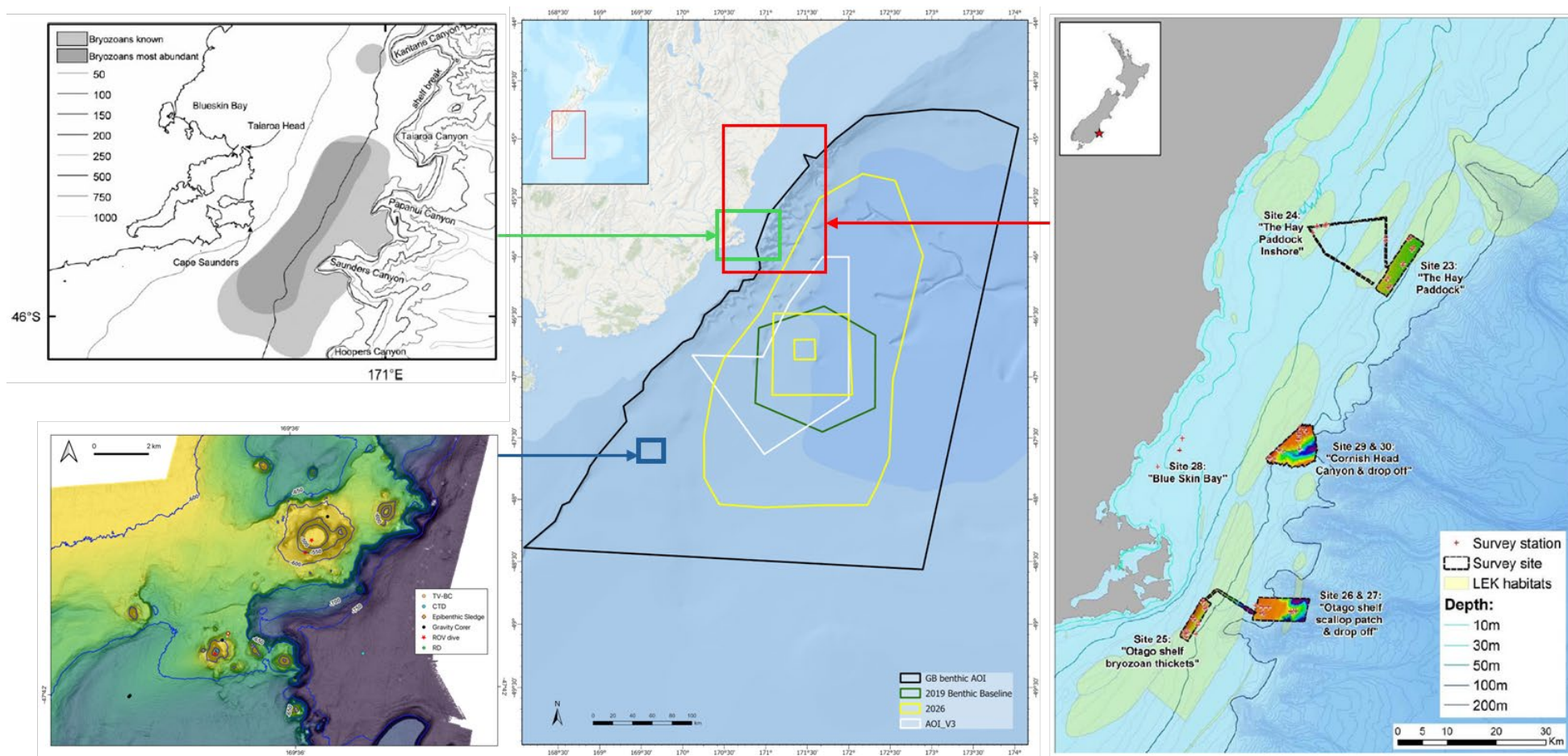


Figure 3-8: Known habitats within, and in the vicinity of, the benthic AOI. Green box: spatial distribution of habitat-forming bryozoa (WoodProbert 2013); red box: local ecological knowledge map (Jones et al 2018); blue box: volcanic features (Freiwald et al. in press).

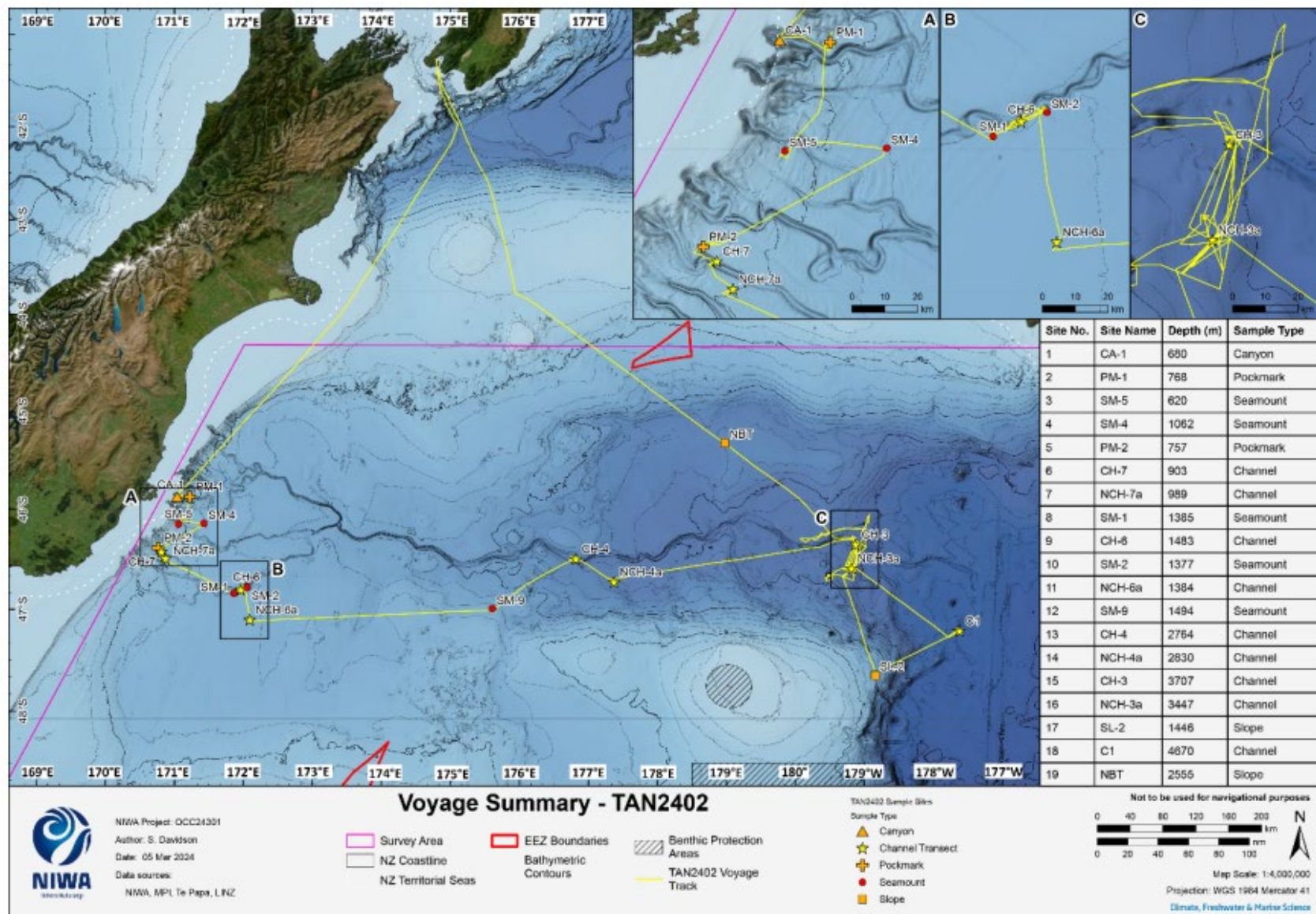


Figure 3-9: Summary of sampling during the Ocean Census survey of the Bounty Trough. Figure copied from Mills et al. (2024). Specimen data collected/identified during this voyage have been included in the Earth Science NZ SPECIFY data extract presented in section 3.1.1 above.

3.3.1 Range of benthic habitats within AOI.

The main habitat types within the benthic AOI, for which there is detailed information, are described below.

Broad slope basin

The broad slope basin is characterised by soft, muddy sediments on a gentle slope (Figure 3-10). Faunal observations included ophiuroids (brittle stars), porifera (sponges), Actiniaria (anemones), scleractinian cup corals, tunicates (ascidians), echinoids (sea urchins), gastropods, holothurians (sea cucumbers), fish, terebellid worms, xenophyophores, Bryozoa and scaphopods (tusk shells) (Figure 3-11).

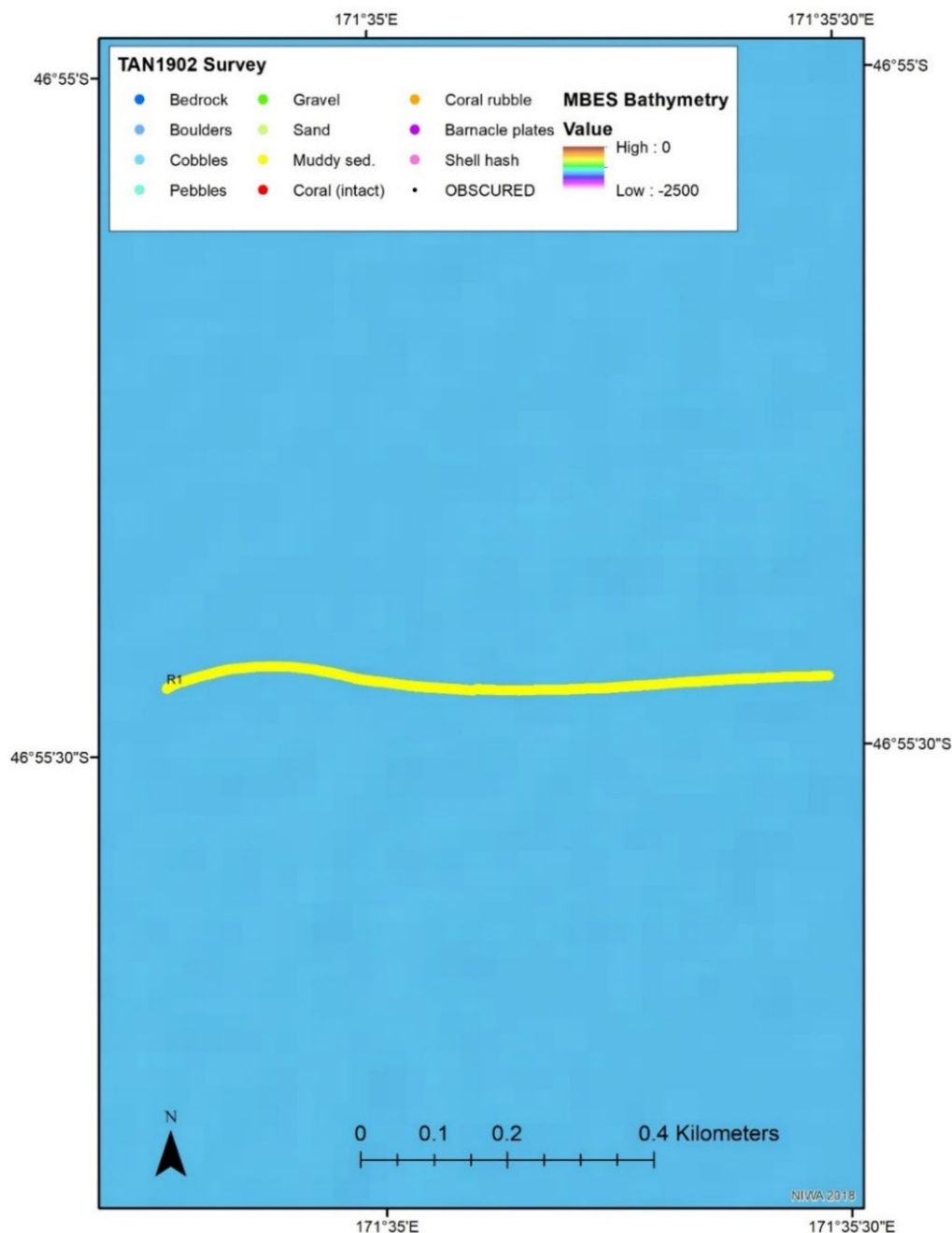


Figure 3-10: Example of a DTIS transect on the broad slope basin from the 2019 baseline survey.

Sites on the broad slope basin consisted of soft, muddy sediments on a gentle slope. Figure created for OMV NZ Ltd.

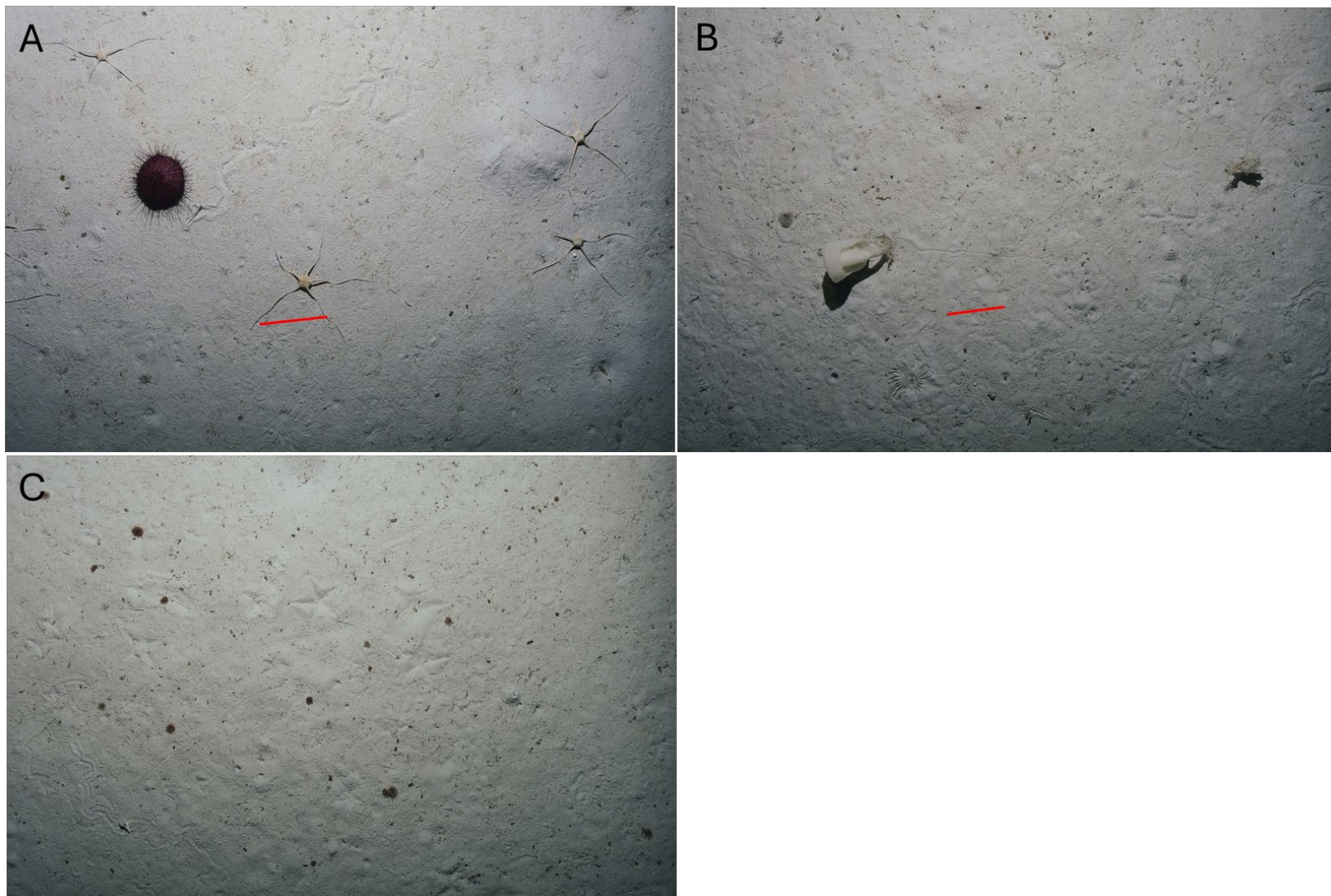


Figure 3-11: Example images from the broad slope basin habitat from the 2019 baseline survey. Muddy sediments with A) ophiuroids (*Ophiomusium lymani*), a scaphopod mollusc and associated track, and a large echinothurioid echinoid (Tam O'Shanter urchin). B) sponges (*Sericolophus reflexus* centre left), unidentified ophiuroids, a spatangid (heart urchin), scaphopod molluscs and associated tracks, anemones, and large agglutinated foraminifera. C) small dark-red solitary cup corals, star-shaped imprints from asteroids, and a gastropod. The red scale bar is drawn between laser beams, where available, which are 20 cm apart.

Channel sites

Sites associated with channels were characterised by muddy/sandy sediments on the channel levee or nearby basin flank, and steep channel sides with many ledges and boulders. Channel floors were dominated by soft, muddy or sandy sediments (e.g., Figure 3-12). The example images in Figure 3-13 show fauna in channel systems to include sponges, urchins, gorgonians, barnacles, soft corals, ascidians, squat lobsters, crinoids, and hydroids.

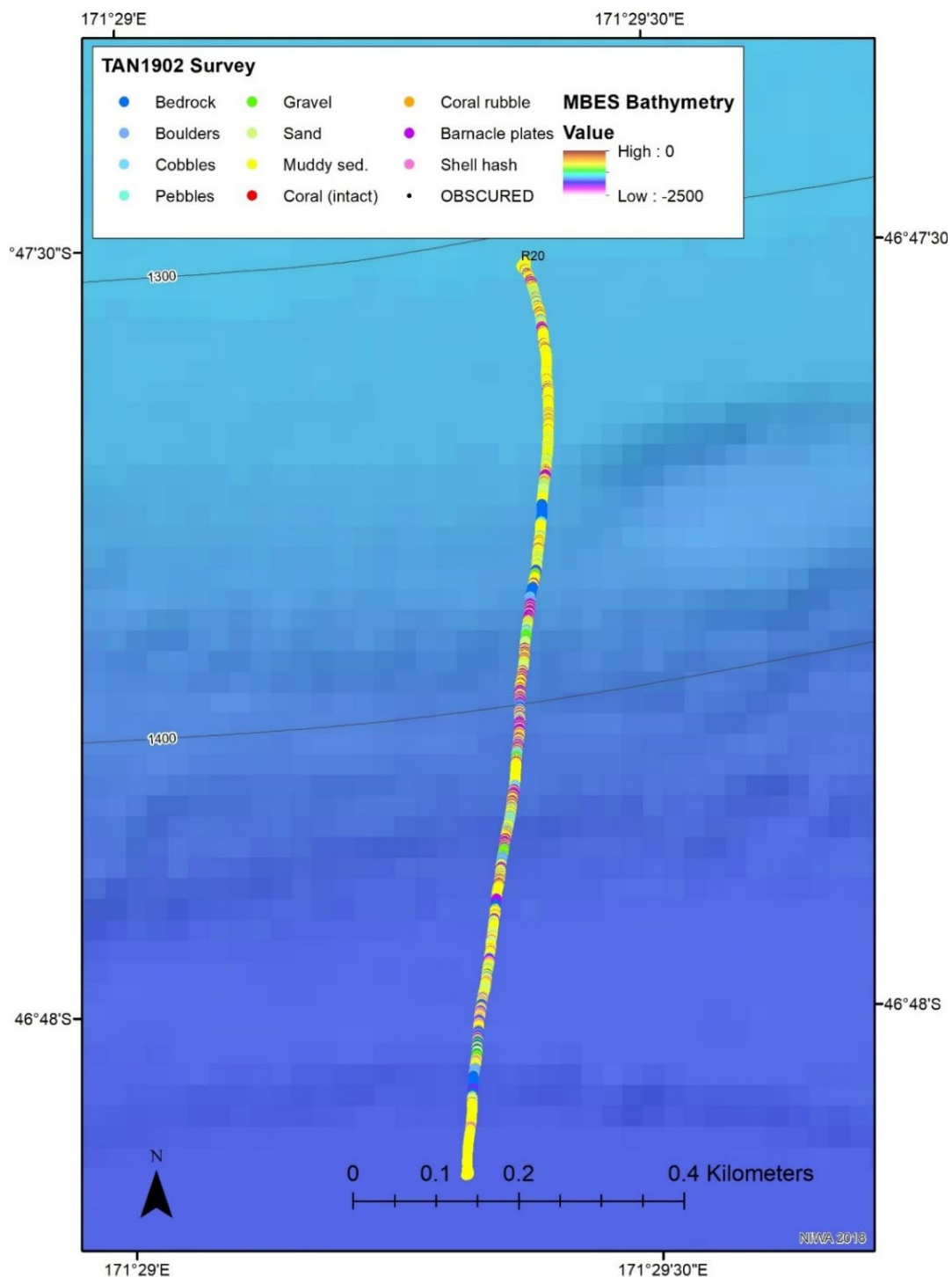


Figure 3-12: Example of a DTIS transect at a channel site in the 2019 baseline survey. Channel sites were heterogeneous with respect to substrate. Soft or muddy sediments dominated the start and end of the transects with steep channel sites with ledges and boulders in between. Figure created for OMV NZ Ltd.

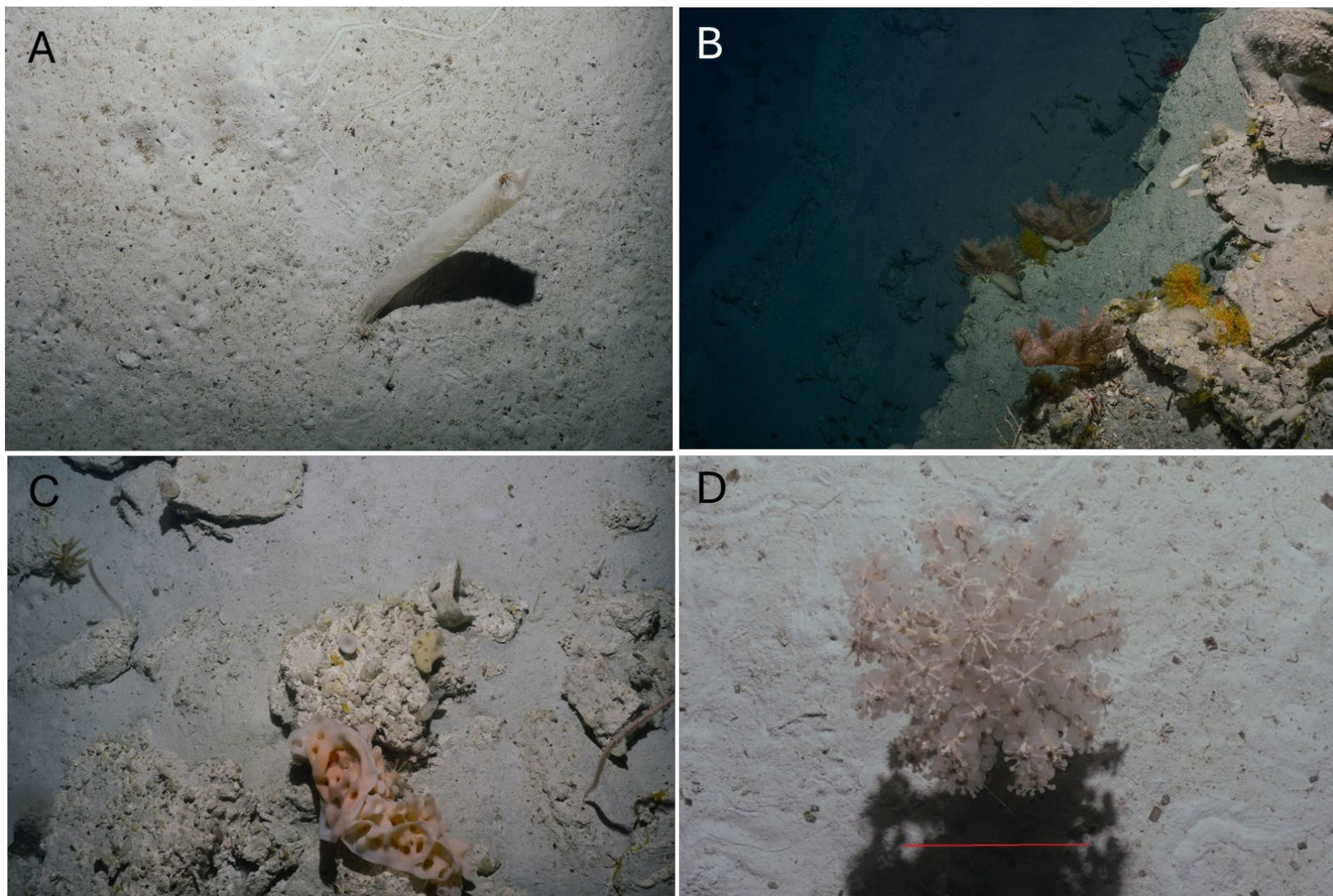


Figure 3-13: Example images from channel sites from the 2019 baseline survey. A) Muddy sediments on the channel levee showing a large hexactinellid sponge (*Euplectella imperialis*) with a cidarid urchin (pencil urchin) at the top. B) Encrusting fauna include gorgonians, sponges, barnacles, soft corals, and ascidians. Mobile fauna includes crinoids and squat lobsters. C) Large and encrusting sponges, whip-like gorgonians, crinoids (feather stars) and the occasional hydroid. D) DTIS image (cropped) of carnivorous sponge, *Chondrocladia* sp. nov. The red scale bar drawn between laser beams is 20 cm.

Seamount features

The seamount features were dominated by hard substrates, with dense layers of barnacle plates in places (Figure 3-14). Bedrock and boulders were often colonised by gorgonians, barnacles, sponges, stylasterid hydrocorals, rock pens (large sea pens associated with hard substrates) and other encrusting fauna (e.g., Figure 3-15). Thickets of apparently dead branching stony coral were observed on three of the four seamount features studied, with live colonies of branching stony coral observed at one seamount site.

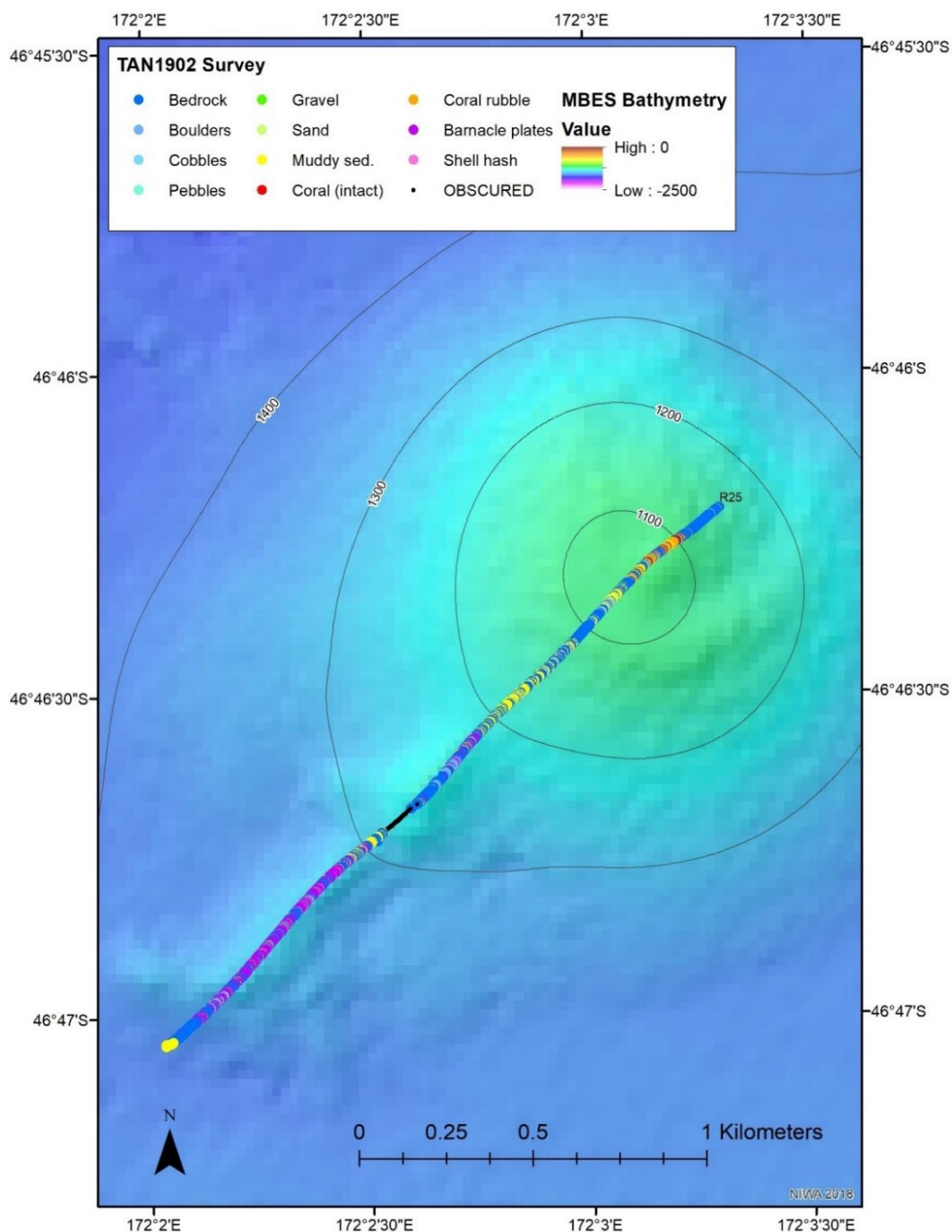


Figure 3-14: Example of a DTIS transect at a seamount site from the 2019 baseline survey.

Seamount features were dominated by hard substrates (e.g. bedrock) and biogenic substrates such as barnacle plates. Figure created for OMV NZ Ltd.

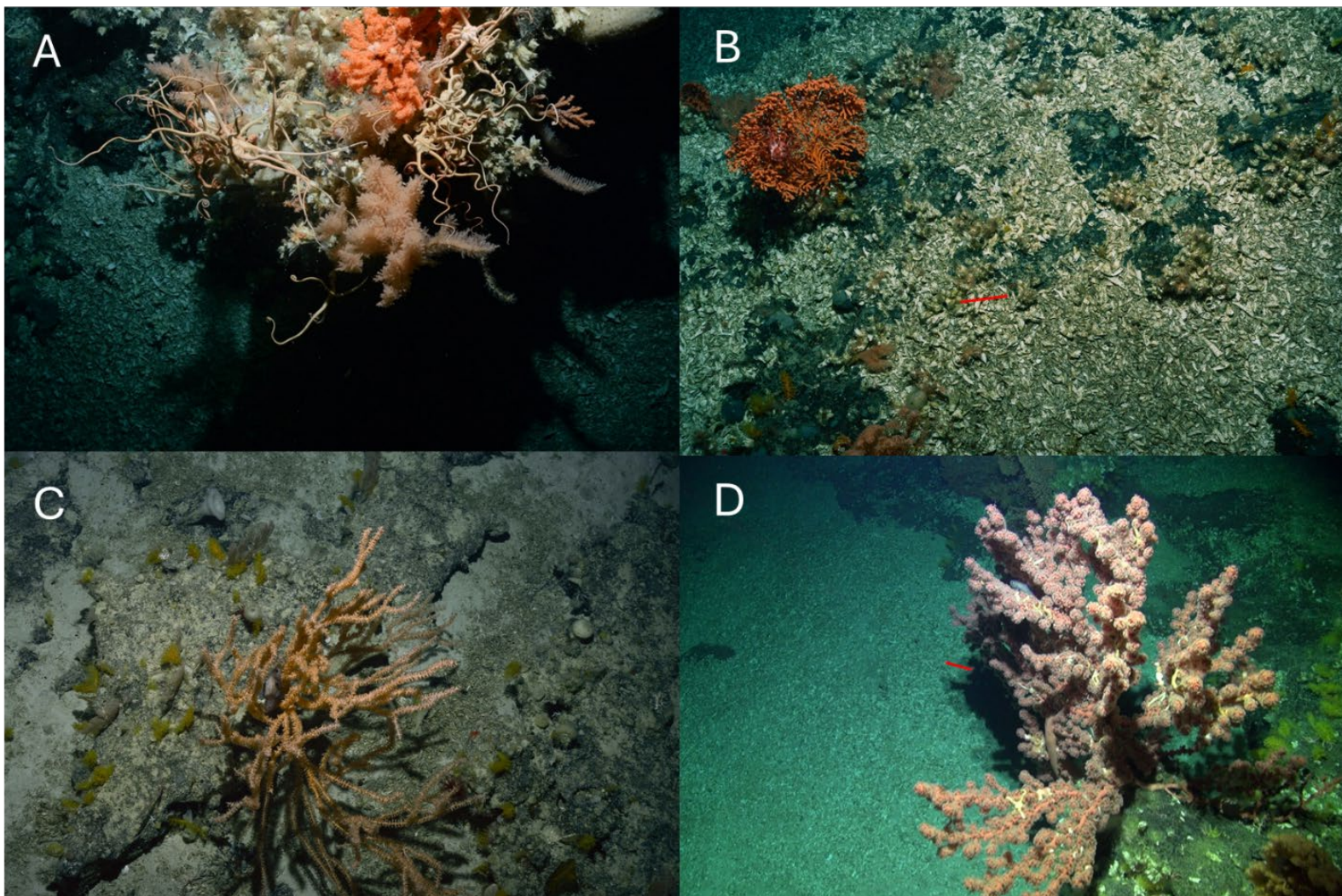


Figure 3-15: Example images from seamount sites from the 2019 baseline survey. A) Primnoid gorgonians and associated snake stars (Gorgonocephalidae). Barnacles can be seen attached to both rock and gorgonians. B) Large primnoid sea-fan with a king crab, snake stars and ophiuroids amongst the branches and a small octopus to the right of the primnoid. Barnacle plates form a biogenic habitat amongst the rock. C) Large branching bamboo coral with a fish, probably *Guttigadus* sp., using the coral as a refuge. D) Large bubblegum coral (*Paragorgia* sp.) providing habitat for snake stars and a small fish taking shelter amongst the branches. The red scale bars drawn between laser beams, where available, are 20 cm.

Biogenic habitats

Wood and Probert (2013) described the bryozoan thickets on the Otago shelf (e.g., Figure 3-16) as providing habitat for a variety of macroinvertebrates, with the distribution varying in relation to the different habitat-forming colony forms. For example, bushy colonies of rough, cylindrical, bifurcating branches (e.g. *Cinctipora elegans*) provides attachment points and physical protection for taxa such as ascidians. Bryozoans with coarse foliaceous “honeycomb” growth forms, such as *Hippomenella vellicata*, provide habitat for mobile species such as munidid squat lobsters. Morrison et al. (2023) described bryozoan-associated species at the Cornish Head Canyon site (Otago shelf) as including sponges, anemones, dredge oysters (*Ostrea chilensis*), starfish, horse mussels, and crayfish (*Jasus edwardsii*).



Figure 3-16: Macroinvertebrates such as *Ophiocoma/Ophiopertis* spp. using bryozoan colonies. Sediment heterogeneity is visible as sandy substratum to the right of the photo and gravel to the left. Photo credit E. Jones. Image copied from Wood and Probert (2013).

Jones et al. (2018) described a number of biogenic habitats on the Otago shelf, at the western edge of the benthic AOI (see Figure 3-8). At the Cornish Head Canyon area, Jones et al. (2018) observed large *Hippomenella vellicata* bryozoan colonies, with a number of large rock lobsters associated with them in over 200 m water depth (Figure 3-17). A range of sponges, bryozoans, and anemones covered the rock surfaces, although habitat types varied greatly over short distances. A crab (probably *Leptomithrax longipes*) was observed in notable abundances and small squat lobsters (*Munida gregaria*) were also commonly observed.

Areas of Chaetopteridae worms known by local fishers as the “Hay Paddock”, due to polychaete worms being like straw (Figure 3-17), had an associated fauna including sponges, ascidians, nudibranchs, anemones, holothurians and starfish, as well as fish species such as red cod (*Pseudophycis bachus*), sea-perch (*Helicolenus percoides*), blue cod (*Parapercis colias*) and snipe fish (*Macroramphosus scolopax*). At an area marked as queen scallop (*Zygochlamys delicatula*) grounds (Figure 3-8) Jones et al observed live and dead scallops with associated tube worms, sponges bryozoans, crabs and squat lobsters (Figure 3-17).

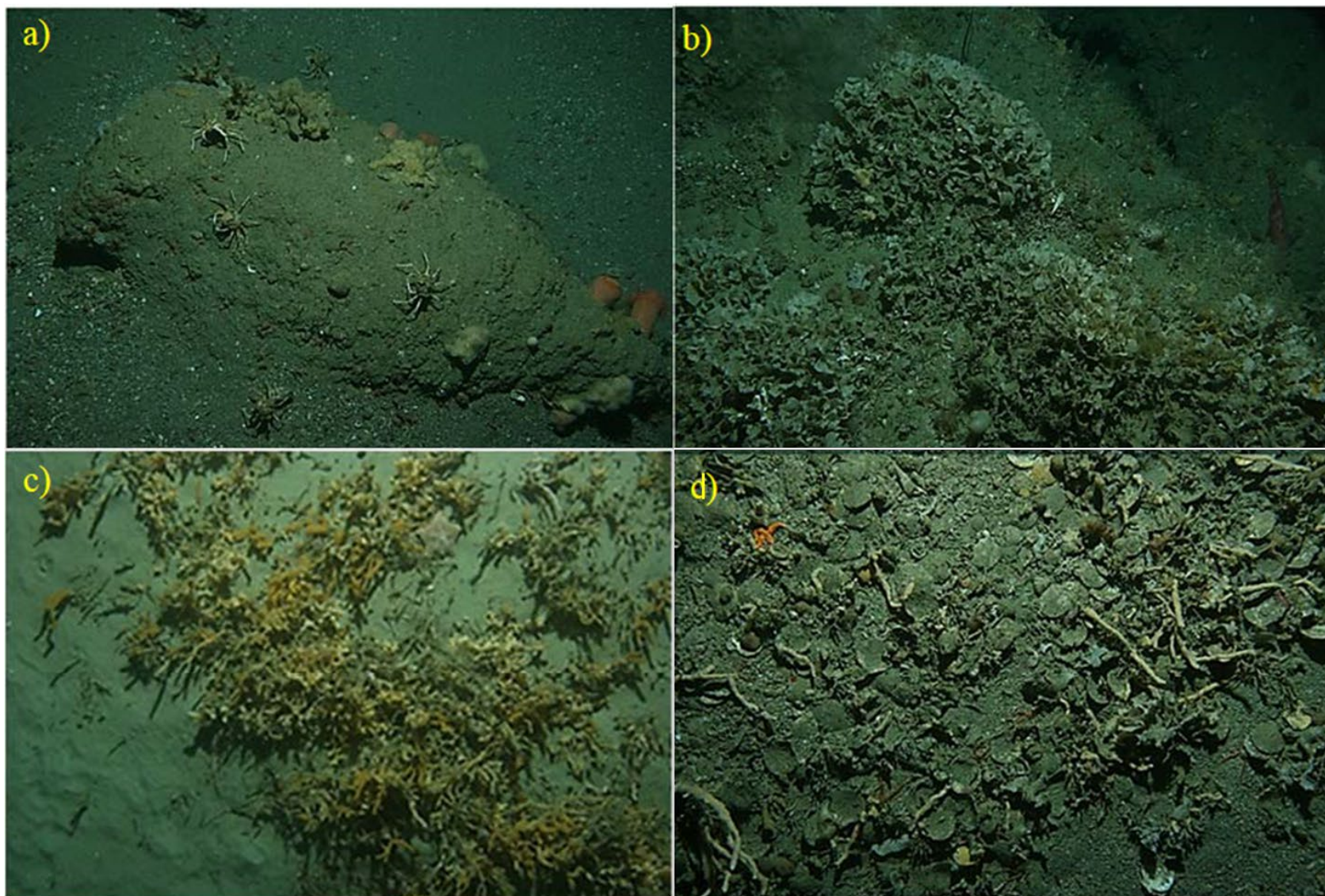


Figure 3-17: Example images of biogenic habitats. Images taken from Jones et al. (2018). a) Boulder with sponges and crabs (probably *Leptomitrax longipes*) (Fig 47, Jones et al. 2018), b) Bryozoan (*Hippomenella vellicata*) colonies and a rock lobster (Fig 47, Jones et al. 2018), c) Hay paddock, Chaetoptera (wire weed) with associated sponge assemblage with anemones, ascidians and starfish (Fig 43, Jones et al. 2018), d) scallop shell debris, sponges and bryozoans (Fig 52, Jones et al. 2018).

3.4 Dissolved oxygen data from historic CTD casts.

The distribution of all known CTD casts within the benthic AOI is shown in Figure 3-18. The 208 historic CTD casts within the NIWA database were collected between 1992 and 2019, with an additional four casts taken during an RV *Sonne* voyage (SO309) in January 2025. Note that dissolved oxygen (DO) data may not have been collected in all of the 208 historic CTD casts.

Most of the historic data were not readily available and would need significant data checks and grooming prior to use. However, DO data were available for twenty-one CTD casts within the benthic AOI (Figure 3-18); five in a survey for Shell NZ (now part of OMV New Zealand Ltd.) in 2013, 12 in the 2019 baseline survey and four, including a 12 hour “YoYo-CTD”, in January 2025 on the RV *Sonne* SO309 voyage. The 2013 (TAN1303) and 2019 (TAN1902) CTD data, both collected using Earth Sciences NZ’s CTD rosette, are shown in Figure 3-19. DO measurements in the 1,000–1,500 m depth range are between 150 and 200 $\mu\text{mol/kg}$ (or approximately 4 mL/l), which is consistent with the oxygen minimum layer of the Upper Circumpolar Deep Water (UCDW) and North Pacific Deep Water (NPDW) intermediate depths (~1,200-1,500 m) south of the Chatham Rise (see Ingels 2025).

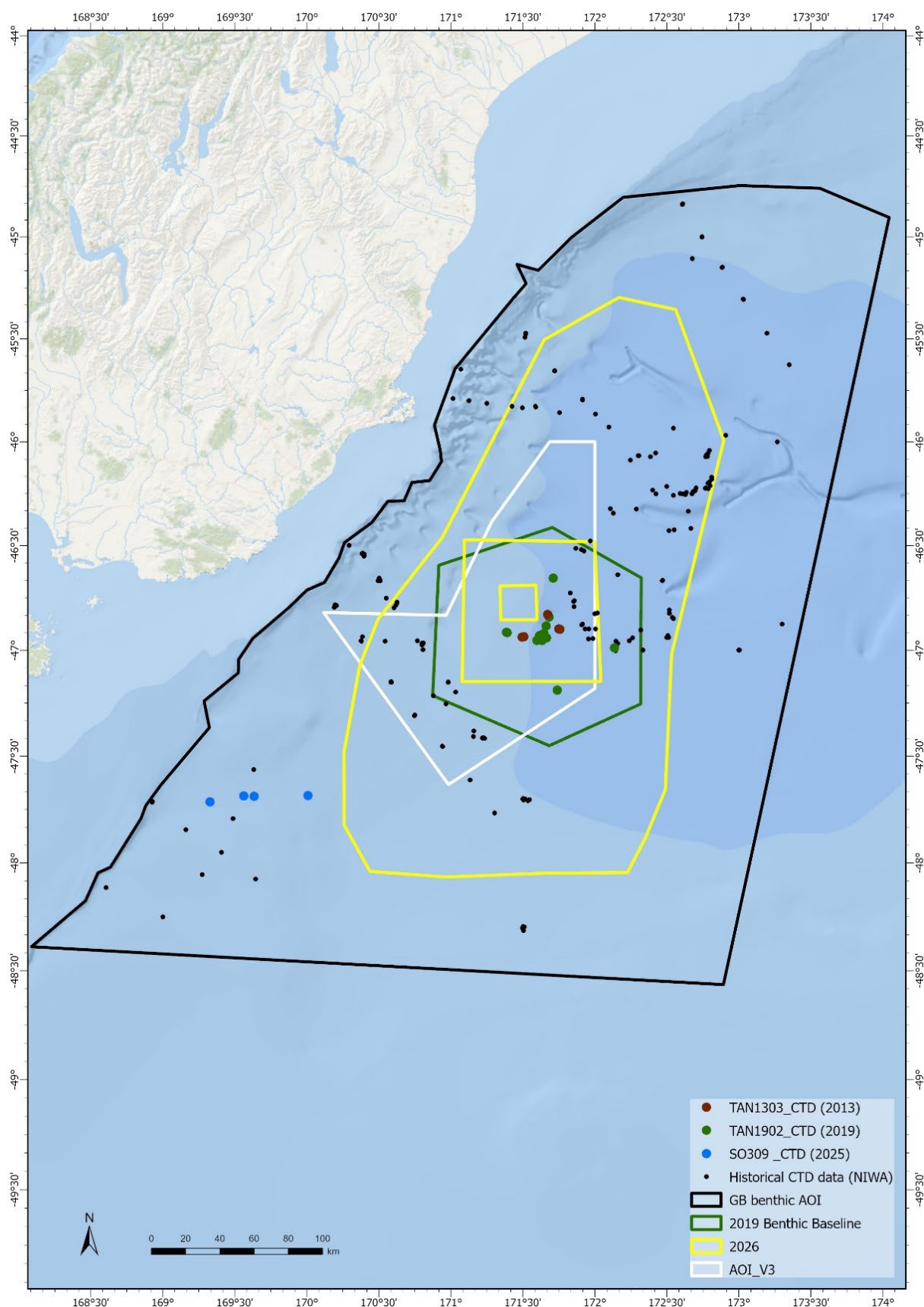


Figure 3-18: CTD casts within the benthic AOI. TAN1303 casts were taken in March 2013 for Shell (now OMV New Zealand Ltd.), TAN1902 casts were taken as part of the 2019 baseline survey, RV *Sonne* SO309 casts were taken in January 2025. Black dots show the location of historic CTD casts within the benthic AOI. Red dots are the 2013 data, green dots are the 2019 data and blue dots are the 2025 data.

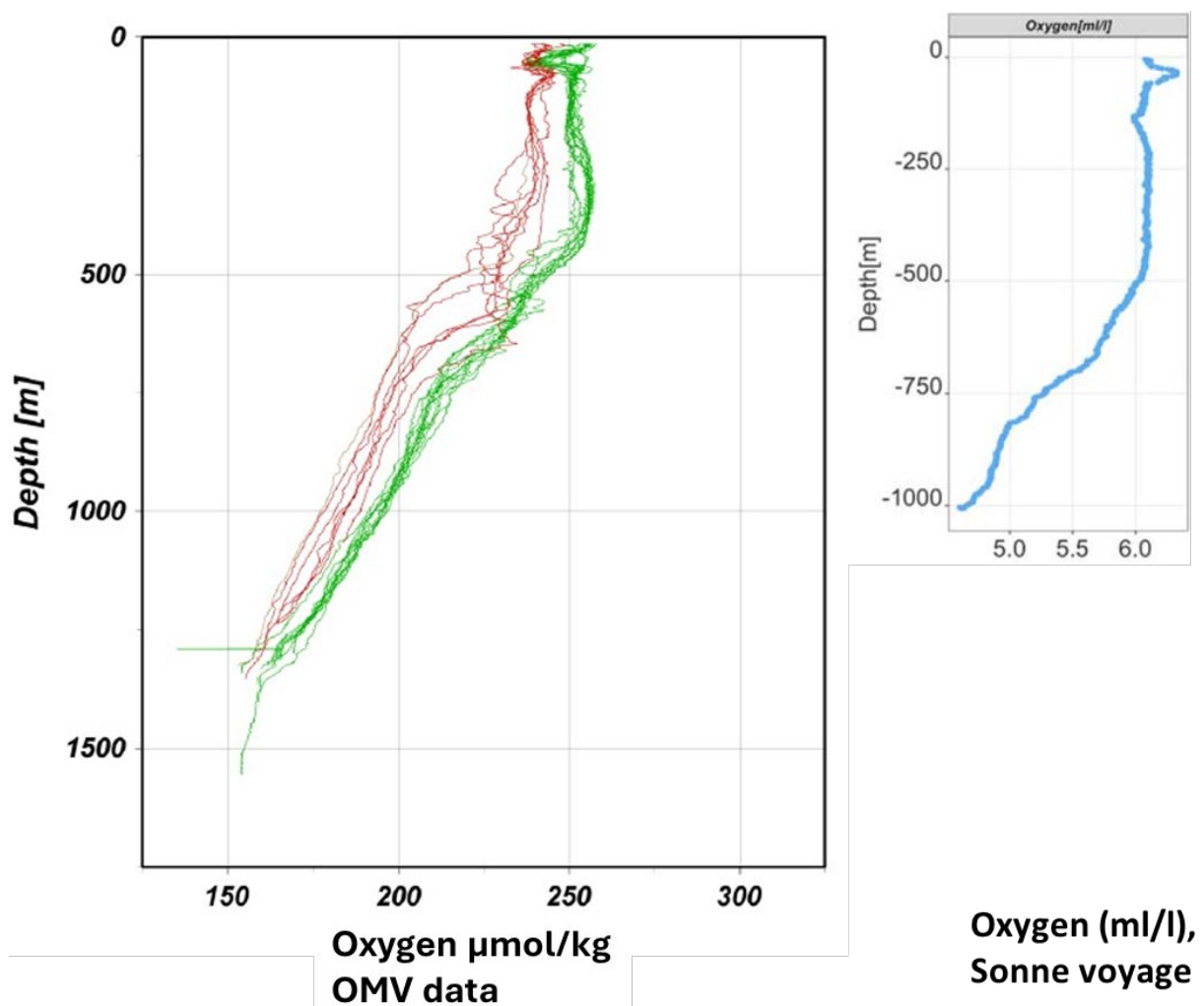


Figure 3-19: Dissolved oxygen profiles from CTD casts. Left: TAN1303 (2013) data in red, TAN1902 (2019) data in green. Measurements in $\mu\text{mol/kg}$. Data collected for Shell NZ and OMV New Zealand Ltd. respectively. Both voyages were in March of their respective years. Right: RV *Sonne* SO309 data from a single CTD cast to 1,000 m in January 2025 (Freiwald et al. in press). Measurements in ml/l.

3.5 Interstitial measurement of pore-waters.

Sediment porewater data have been previously collected from the Canterbury Bight (e.g., Marsaglia et al. 2017; Micallef et al. 2022). However, neither paper included mention of DO concentrations.

A global database of sediment community oxygen consumption rates has records from the Aotearoa New Zealand region, but these are limited mainly to the Chatham Rise and Challenger Plateau (Stratmann et al. 2019). No data were available from within the benthic AOI (Figure 3-20). Values collected in ex-situ samples collected using multicores and water bath incubations from the Chatham Rise data ranged from $1.3\text{--}6.58 \text{ mmol O}_2 \text{ m}^{-2} \text{ d}^{-1}$.

Hale et al. (2025) used an oxygen needle micro-probe (Unisense A/S microelectrode OX-N) to measure DO in sediment samples collected from the Chatham Rise. Measurements were taken at 1 mm increments into the sediment to 10 mm depth and 5 mm increments to 40 mm to determine oxygen penetration depth (Figure 3-21). However, it should be noted that these data were collected from sediments with very different composition to those within the benthic AOI with respect to both water depth and organic content.

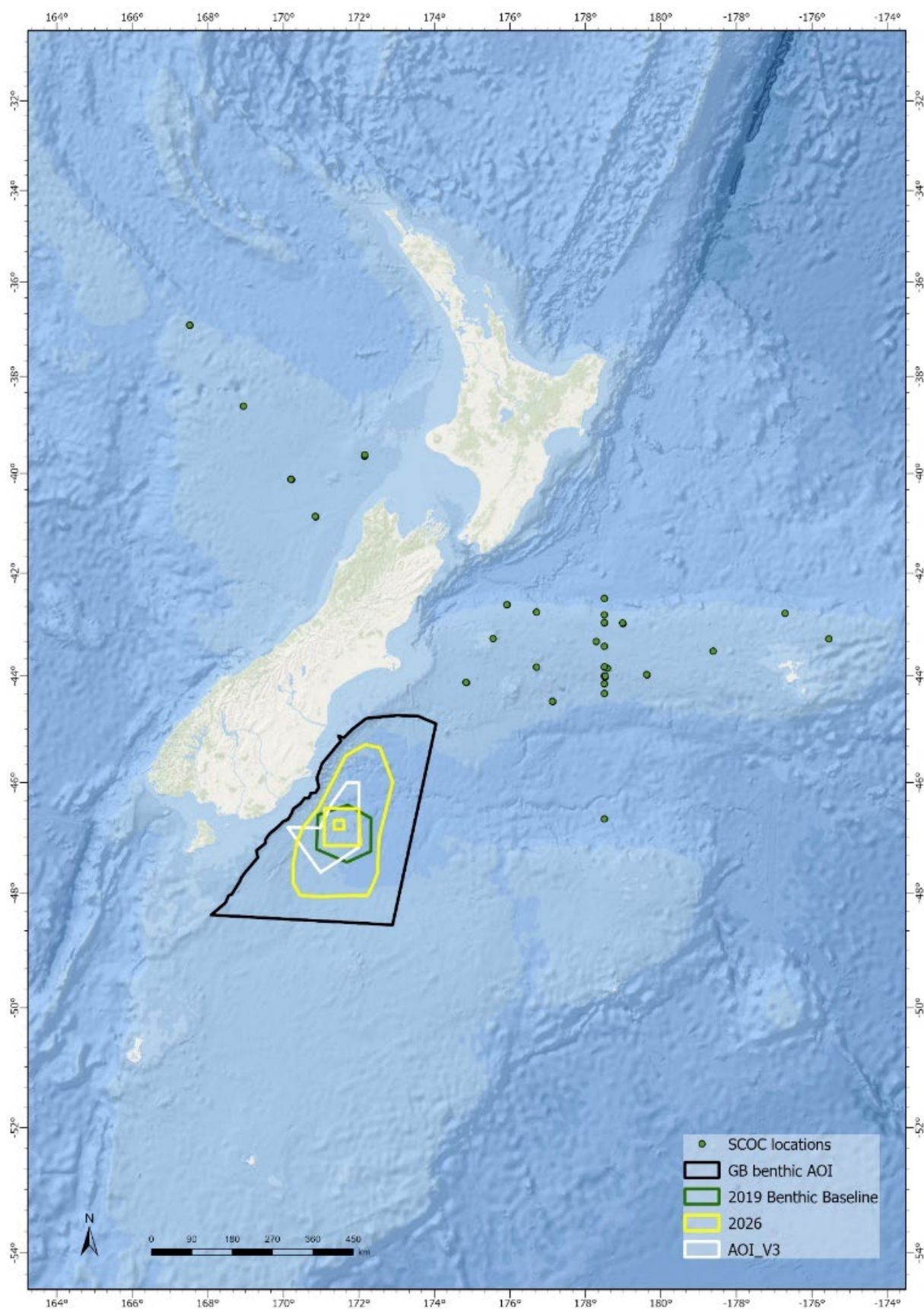


Figure 3-20: Sediment community oxygen consumption (SCOC) data locations (Stratmann et al. 2019) in the Aotearoa New Zealand region.

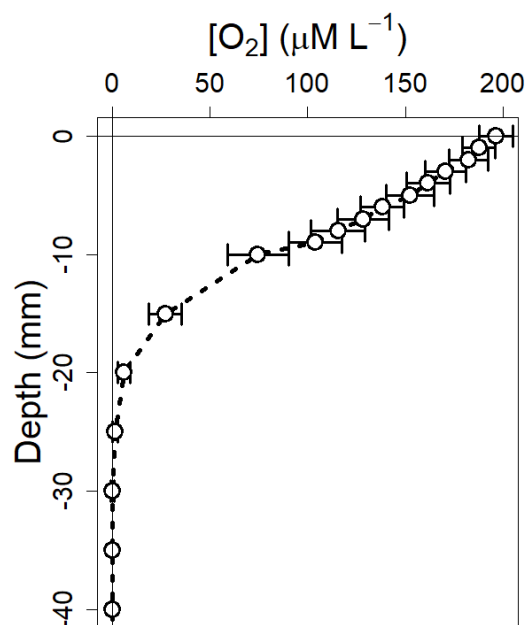


Figure 3-21: Sediment oxygen profiles from retrieved cores taken at Butterknife sites, Chatham Rise. Figure from Hale et al. (2025). Note that these data were collected from sediments with very different composition than those within the benthic AOI with respect to both water depth and organic content.

3.6 Xenophyophore still image analysis

This section relates to Task 6, the analysis of existing images from the most recent Great South Basin (GSB) survey conducted in 2023 to quantify and validate the abundances of xenophyophores.

The 2023 survey within the GSB was conducted for OMV New Zealand Ltd. as part of their post-consent monitoring requirements after an exploratory drilling programme. As such this survey was a smaller subset of the 2019 baseline survey, in the vicinity of an oil and gas drill site.

All images captured during the 2023 survey (RV *Tangaroa* voyage TAN2303) were analysed for xenophyophore abundance and densities except for those which were obscured due to the height above seabed (too close or too far), poor lighting on the image (e.g., strobe failure), or where no scaling lasers were visible (one transect only). The Tawhaki-1 sites are the location of a drill site with a localised area of disturbed seabed sediments which may have resulted in localised reduced abundances of xenophyophores.

The area of seabed covered by each image was determined using Fiji ImageJ software (Fiji ImageJ, Schindelin et al. 2012), before counting the abundance of xenophyophores. A density of xenophyophores (individuals per m²) was then determined for each image. These data were used to calculate both an average and maximum density of xenophyophores per m² for each site.

The highest density of xenophyophores, at the scale of a full transect, was 0.47 inds./m². This is below the threshold of a sensitive environment for xenophyophore beds. However, maximum densities, at the scale of an image, ranged from 0.46 to 8.81 inds./m², with 14 of the 19 sites recording maximum densities above the sensitive environment threshold of one xenophyophore per m² (Table 3-6). The percentage of images within a transect meeting the sensitive environment threshold ranged from 0 to 20.8%.

Table 3-6: Xenophyophore densities from 2023 survey. Mean and maximum densities recorded at each site where images were available. * indicates previously disturbed site (drill site location). Values in bold exceed the threshold for a sensitive environment (≥ 1 ind. m^{-2}).

Site	Mean density (inds./ m^2)	SE	Max density (inds./ m^2)	Count >0.95 inds./ m^2	Images analysed	Percentage of images > 1 ind./ m^2
TAN2303_007_Tawhaki-1_SN*	0.08	0.03	0.80	0	56	0.0
TAN2303_005_Tawhaki-1_EW*	0.17	0.04	1.60	1	53	1.9
TAN2303_005_NE250	0.33	0.05	1.81	5	57	8.8
TAN2303_007_SE250	0.28	0.04	1.71	3	55	5.5
TAN2303_005_SW250	0.32	0.05	1.53	3	55	5.5
TAN2303_007_NW250	0.31	0.05	1.26	5	55	9.1
TAN2303_005_NE500	0.27	0.03	1.07	1	57	1.8
TAN2303_007_SE500	0.23	0.03	1.00	1	65	1.5
TAN2303_005_SW500	0.30	0.05	1.97	5	58	8.6
TAN2303_007_NW500	0.19	0.04	0.87	0	51	0.0
TAN2303_42_NE1000	0.04	0.01	0.46	0	55	0.0
TAN2303_004_SW1000	0.47	0.09	3.77	11	53	20.8
TAN2303_062_NW1000	0.28	0.06	2.49	2	54	3.7
TAN2303_42_NE2000	0.06	0.02	0.48	0	60	0.0
TAN2303_004_SW2000	0.23	0.05	1.20	3	50	6.0
TAN2303_062_NW2000	0.27	0.04	0.93	0	56	0.0
TAN2303_089_FFC_NE	0.20	0.03	1.26	2	62	3.2
TAN2303_057_FFC_SW	0.41	0.15	8.81	5	59	8.5
TAN2303_003_FFC_W	0.21	0.04	1.47	2	57	3.5

3.7 Occurrence of any sensitive environment communities or protected species.

3.7.1 Sensitive environments

Schedule 6 of the EEZ and Continental Shelf (Environmental Effects - Permitted Activities) Regulations 2013 (hereafter referred to as Schedule 6) defines a number of sensitive environments within the Aotearoa New Zealand marine benthic environment. These are: stony coral thickets or reefs, xenophyophore (sessile protozoan) beds, bryozoan thickets, calcareous tube worm thickets, Chaetopteridae worm fields, sea pen fields, rhodolith (maerl) beds, sponge gardens, beds of large bivalve molluscs, macro-algal beds, brachiopods, deep-sea hydrothermal vents, and methane or cold seeps.

Interpretation of the Schedule 6 criteria was aided here by reference to, and discussions with the lead author of, a report defining sensitive habitats (MacDiarmid et al. 2013).

Available data on the sensitive environment species are presented below. Note that sensitive environment thresholds were examined during the 2019 baseline survey but have not been investigated, as far as we are aware, for other data presented here. It is, therefore, important to note that these assessments have been made on the limited available information.

Stony coral thickets or reefs

Deep-sea stony corals provide important biogenic habitats through the provision of complex three-dimensional branching or clumped structure and shelter for other organisms (Anderson et al. 2019). Deep-sea corals are slow growing, long-lived, mostly colonial animals and the structures they form can be associated with high biodiversity (e.g. MacDiarmid et al. 2013). A stony coral reef or thicket (as defined by Schedule 6) exists if “a colony of a structure-forming species (i.e., *Madrepora oculata*, *Solenosmilia variabilis*, *Goniocorella dumosa*, *Enallopsammia rostrata*, *Oculina virgosa*) covers 15% or more of the seabed in a visual imaging survey of 100 m² or more”.

From a report entitled ‘Sensitive Marine Benthic Habitats Defined’ (MacDiarmid et al. 2013), stony coral reefs or thickets can be deemed to exist when either live or dead colonies of structure-forming species dominate the seabed.

Within the available macrofaunal invertebrate (physical specimen) location records for the benthic AOI, there were a total of 89 records of branching Scleractinia, species with the potential to form stony coral thickets or reefs (Figure 3-24). These included records of the species *Madrepora oculata*, *Enallopsammia rostrata*, *Enallopsammia pusilla*, *Solenosmilia variabilis* and *Goniocorella dumosa*.

Analyses of available DTIS imagery data showed live branching Scleractinia present at only a single site, on a seamount, observed during the 2019 baseline survey (Figure 3-24). Still images from DTIS were analysed to determine percent cover of live and dead intact stony coral thickets. Sensitive environments for stony coral thickets or reefs were identified at three seamount sites (between 18.8% and 41% cover over seabed areas of 100 m², see Figure 3-41 below). Live coral was observed at one of the seamounts and dead coral matrix observed at the remaining two seamounts (the current presence of live coral at these seamounts remains unknown).

KEA species distribution models showed relatively high predicted probability of occurrence for *Madrepora* spp., *Solenosmilia* spp. and *Enallopsammia* spp. within the benthic AOI (Figure 3-25), and a moderate probability of occurrence for *Goniocorella* spp.

Species distribution modelling conducted in the current study, using abundance data from seafloor imagery rather than the presence only data used in the KEA models and more focussed on the project area, also predicts the presence of reef-forming Scleractinia within the benthic AOI (see Section 4 and Figure 4-8).



Figure 3-22: DTIS image showing branching stony coral at a seamount site within the benthic AOI. This was the only site where live branching stony coral was observed. The red scale bar is drawn between laser beams which are 20 cm apart.

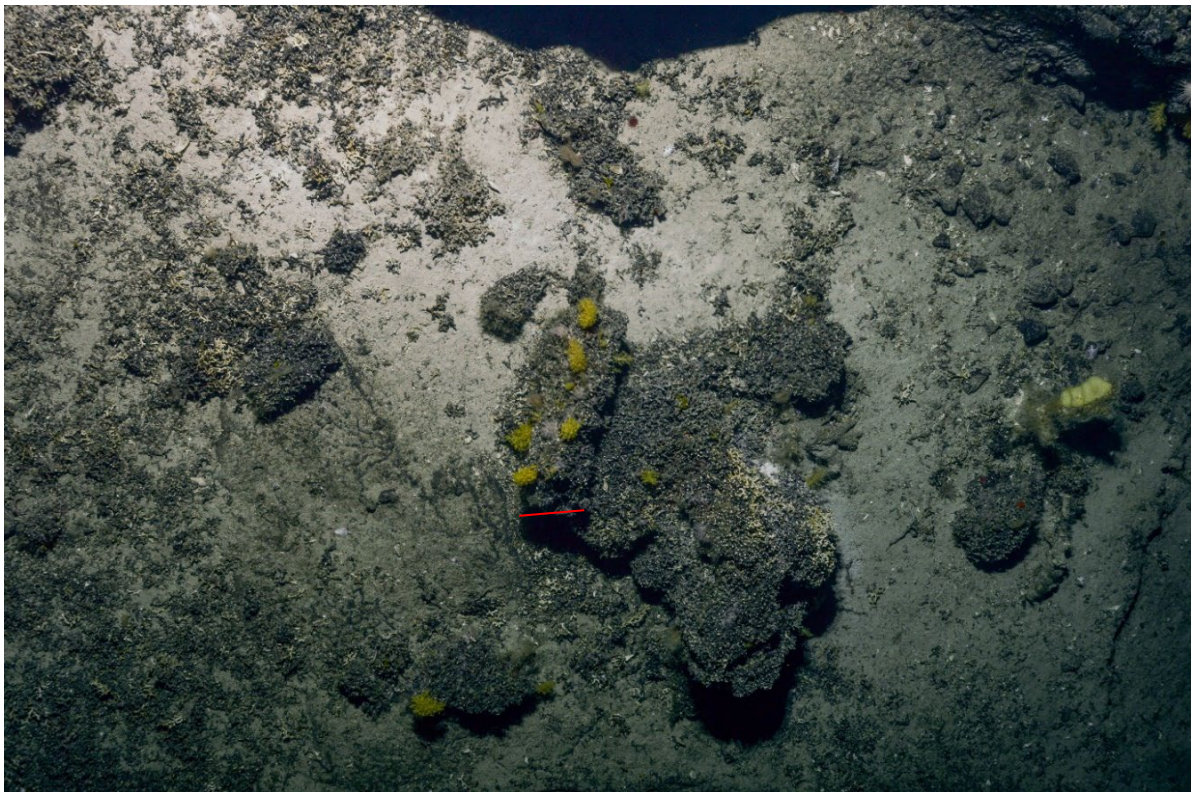


Figure 3-23: DTIS image showing intact, but dead, branching stony coral (with yellow primnoid sea fans (gorgonians)) at a seamount site within the benthic AOI. The red scale bar is drawn between laser beams which are 20 cm apart.

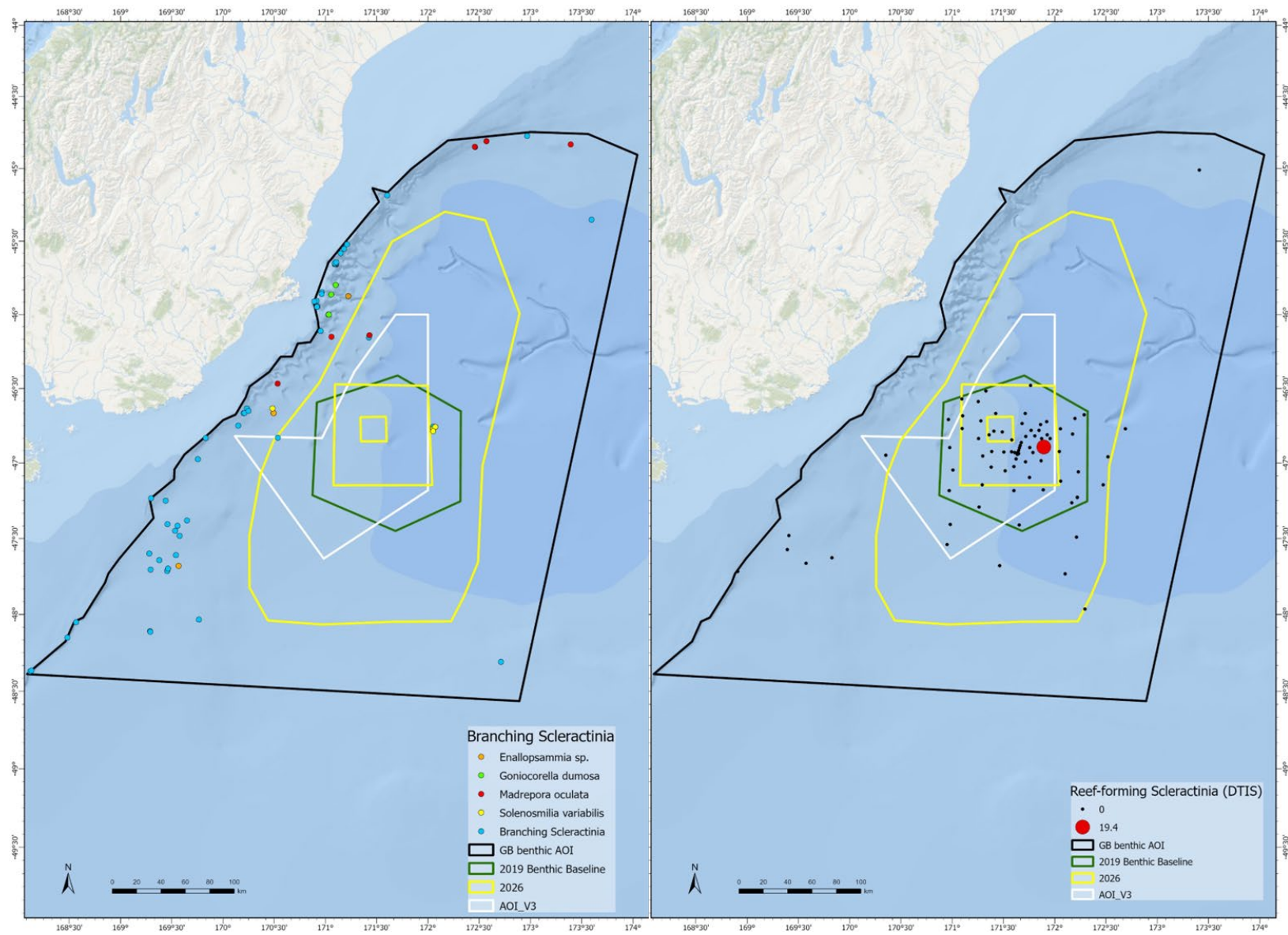


Figure 3-24: Distribution of records of live branching stony corals within the benthic AOI. Left: physical specimen species location records from SPECIFY, OBIS, and MPI observer data exports. Right: imagery (DTIS) abundance data (inds. 1,000 m⁻²).

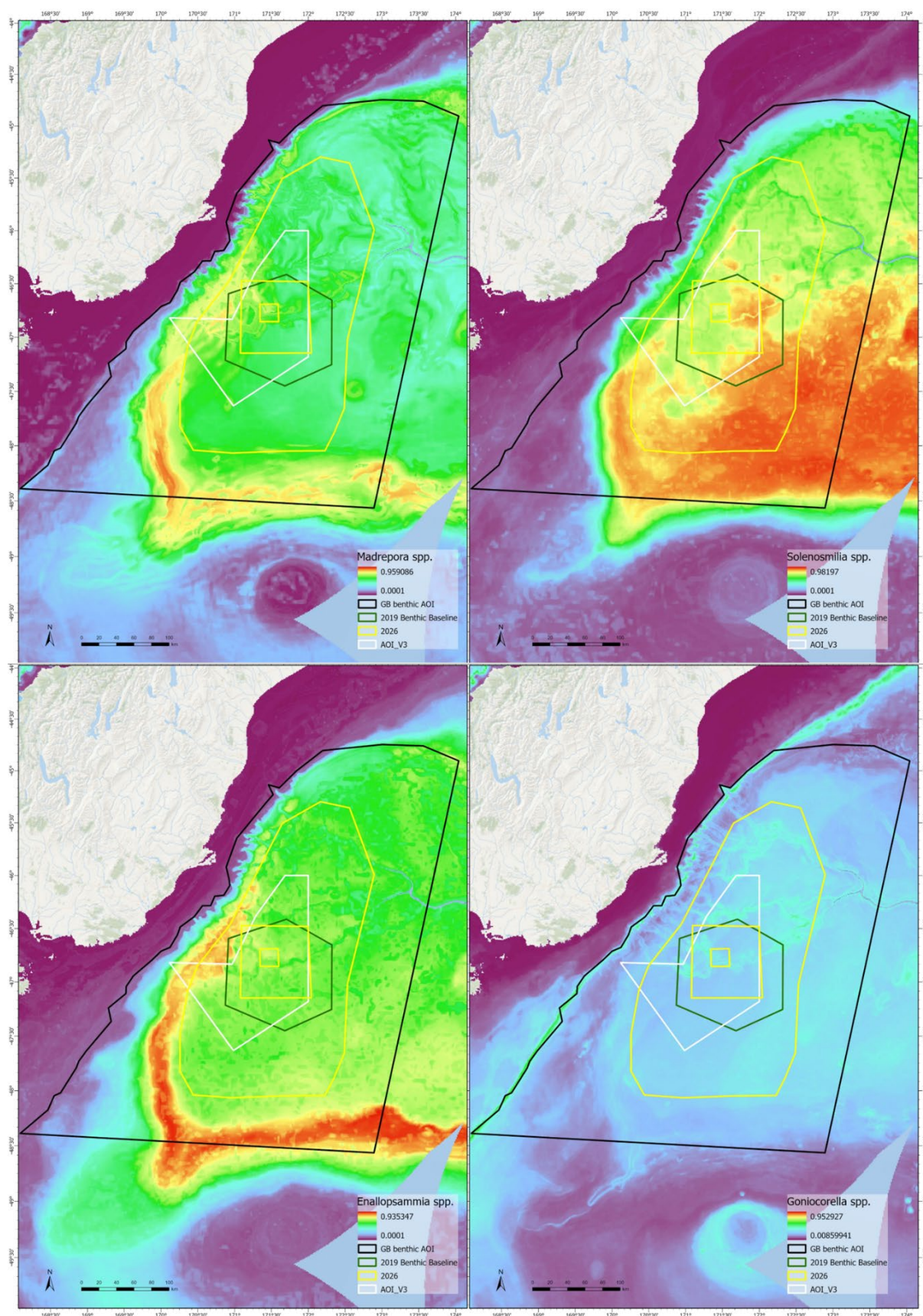


Figure 3-25: KEA species distribution models: branching stony corals. *Madrepora* spp., *Solenosmilia* spp., *Enallipsammia* spp., and *Goniocorella* spp. Note that this modelling used all available presence data from physical captures, not abundance data focussed on the benthic AOI as in the current modelling study.

Xenophyophore beds

Xenophyophores are giant deep-sea protists that build agglutinated tests and range in size from ~1 cm to greater than 20 cm (Gooday et al. 2011). They are thought to be associated with areas of high surface productivity or where the flux of organic matter is enhanced by topography (Tendal 1972; LevinThomas 1988). Xenophyophores have been recorded on continental slopes of New Zealand and on the Chatham Rise in depths of 500-1,300 m (MacDiarmid et al. 2013 and references therein).

A xenophyophore bed (as defined by Schedule 6) exists if average densities of all species of xenophyophore found (including fragments) equal or exceed 1 specimen per m² sampled. Example images of xenophyophore beds taken during the 2019 survey are given in Figure 3-26.

A total of 38 records of physical specimens of foraminifera have been recorded from within the AOI, of which 20 were xenophyophores (Figure 3-27). Note that xenophyophores are likely to be grossly under-sampled by most capture methods because of the difficulties in collecting whole specimens of these very fragile protozoans. Records from imagery, however, show that xenophyophores were widespread throughout the benthic AOI, in densities up to 100 inds. 1,000 m⁻². It is important to note that xenophyophores are also difficult to observe during video imagery surveys, due to their small size and inconspicuous form, and were often below Earth Sciences NZ's normal threshold of 4 cm for standard video analysis. Only the largest and most obvious xenophyophores were able to be recorded from video analysis, resulting in an unknown under-estimate of abundances and associated density estimates.

Xenophyophore beds (meeting the criteria for a sensitive environment as defined in Schedule 6) were observed at 11 sites within the 2019 baseline survey (Figure 3-28). These were widespread across the baseline survey area and included broad slope basin sites to the south and west of the South Channel, seamount sites, and channel sites.

Mean xenophyophore densities from a more recent survey in 2023 (see Section 3.6) were all below 1 per m² at the scale of a full transect. However, maximum recorded densities within transects, at the scale of an image, ranged from 0.46–8.81 xenophyophores per m² (Figure 3-28).

Species distribution modelling conducted in this study, using latest available data relevant to the project area, also predicts the widespread presence of xenophyophores within the benthic AOI (see Section 4 and Figure 4-9).

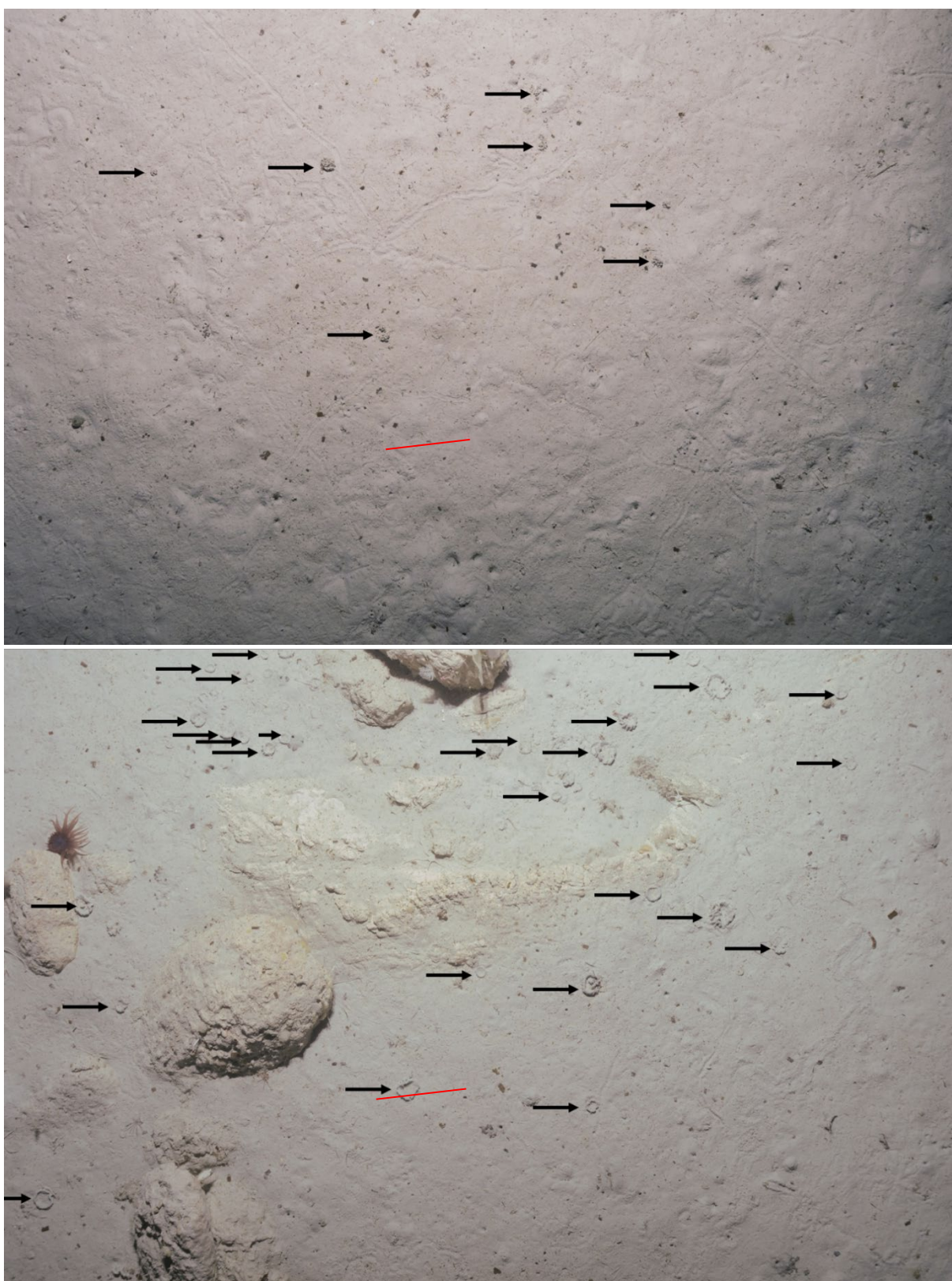


Figure 3-26: DTIS images showing xenophyophore beds observed within the benthic AOI. Images taken during the 2019 baseline survey. The top image was taken on the broad slope basin. The bottom image was taken on the southern flank of the main axis of the South Channel. Xenophyophores are indicated by a black arrow. The red scale bars are drawn between laser beams which are 20 cm apart.

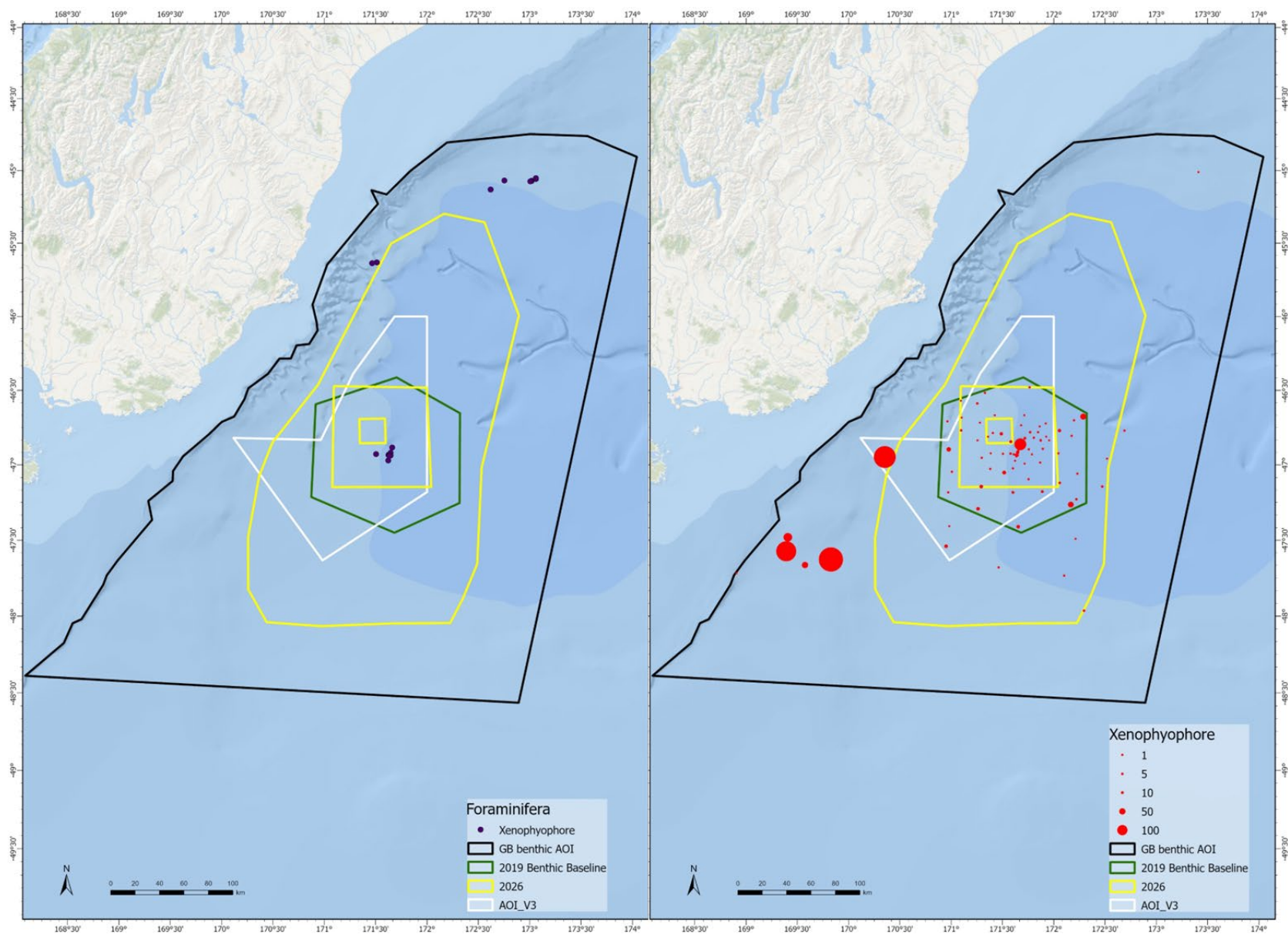


Figure 3-27: Species location records of xenophyophores within the benthic AOI. Left: species location records from SPECIFY data exports. Right: imagery (DTIS) abundance data (inds. 1,000 m⁻²).

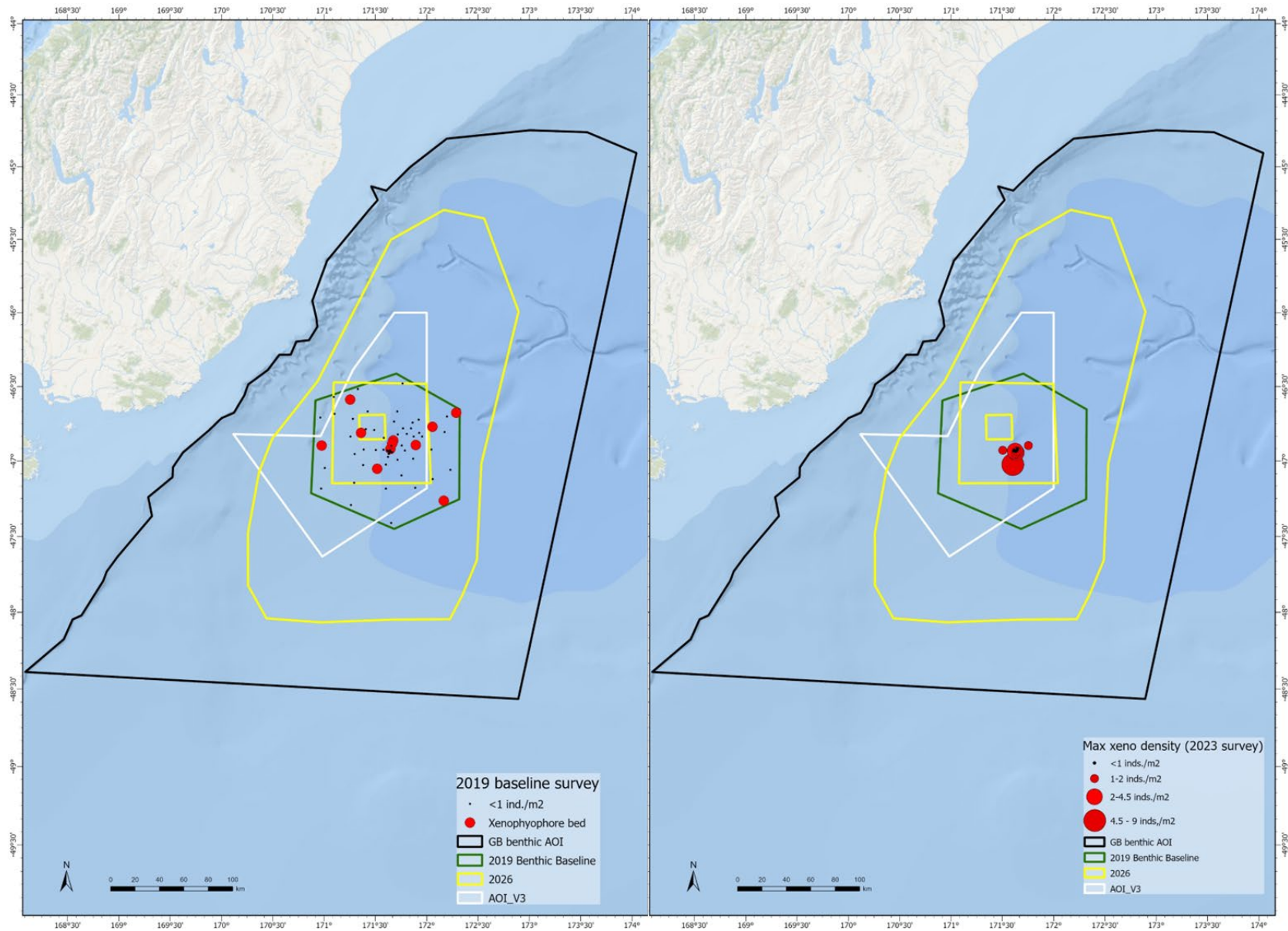


Figure 3-28: Known sensitive environments for xenophyophore beds within the benthic AOI. Left: Xenophyophore beds observed during the 2019 survey. Right: maximum densities ($\geq 1 \text{ ind. m}^{-2}$) recorded in images from the 2023 survey.

Bryozoan thickets

Bryozoans, also known as moss animals or lace corals, can form colonies that provide biogenic habitat. Colonies can range from 0.2 mm to 2 m in size. Bryozoans have a broad depth range from the intertidal to deep sea and occur on stable substrata (e.g., hard substrates, algae and on other organisms) in places where water movement is relatively fast and consistent (MacDiarmid et al. 2013).

A bryozoan thicket (as defined by Schedule 6) exists if:

- Colonies of large frame-building species cover at least 50% of an area between 10 m² and 100 m²; or
- Colonies of large frame-building species cover at least 40% of an area that exceeds 10 km²; or
- A specimen of a large frame-building species is found in a sample collected using towed gear; or
- One or more large frame-building bryozoan species is found in successive point samples.

There was a total of 393 records of bryozoans collected from within the benthic AOI, some of which were habitat-forming species (marked in orange in Figure 3-29). Bryozoans were also recorded in imagery across the 2019 baseline survey, in densities up to 43 inds. 1,000 m⁻². Note that bryozoans recorded in imagery include all bryozoans, not just the frame-building species.

KEA species distribution models showed relatively high predicted probability of occurrence for the frame-building bryozoan species *Cellaria* spp., *Galleopsis* spp., and *Hornera* spp. on the western boundary of the benthic AOI (Figure 3-30), and moderate probability of distribution widespread across the benthic AOI for *Galleopsis* spp. and to a lesser extent for *Cellaria* spp. and *Hornera* spp.

Species distribution modelling conducted in this study, using latest available data relevant to the project area, predicts high abundances of bryozoans in the northern half of the benthic AOI (see Section 4 and Figure 4-3).

Extensive areas of habitat-forming bryozoans are known to be present on the Otago Shelf and the western extent of the benthic AOI (e.g., Wood and Probert 2013; Jones et al. 2018, and see Figure 3.8). Although no formal analyses have been carried out to assess these biogenic habitats against the Schedule 6 thresholds for bryozoan thickets, it may be considered likely that a sensitive environment for bryozoan thickets exists within, or in close proximity to, the benthic AOI.

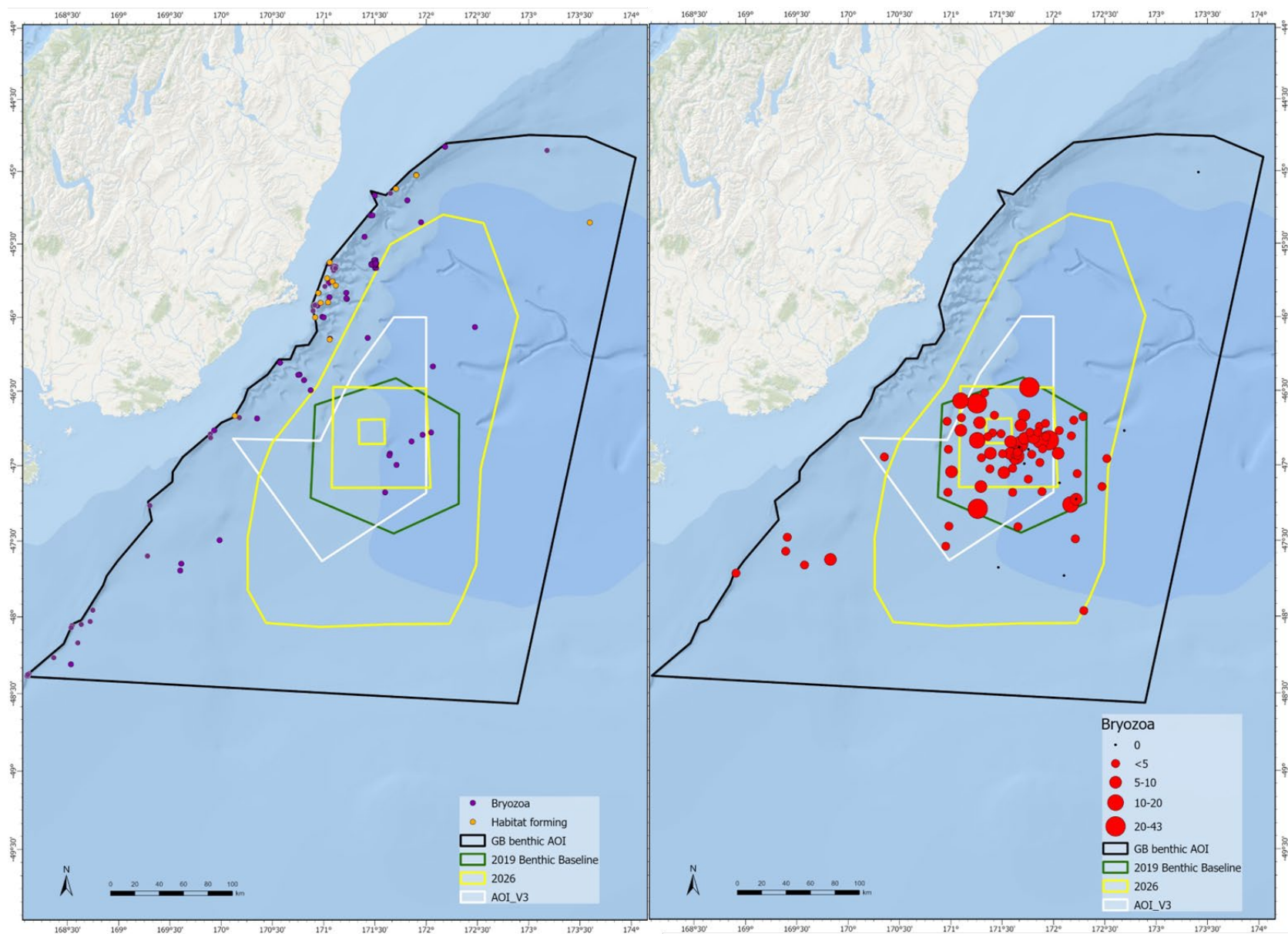


Figure 3-29: Specimen location records of Bryozoa within the benthic AOI. Left: species location records from SPECIFY, OBIS, Te Papa and MPI observer catch data exports. Habitat-forming genera/species marked in orange. Right: imagery (DTIS) abundance data of all Bryozoa (inds. 1,000 m⁻²).

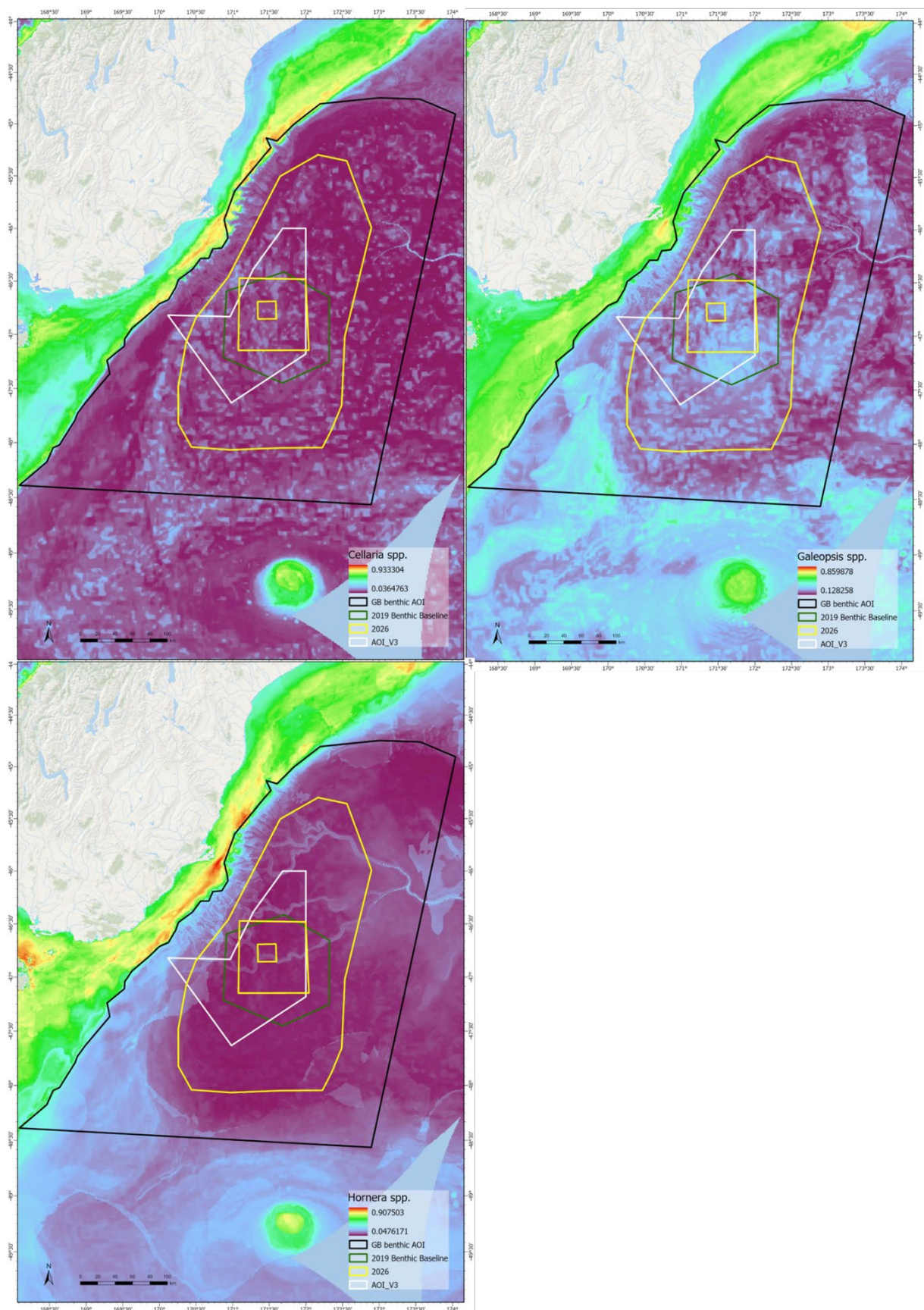


Figure 3-30: KEA species distribution modelling: habitat-forming Bryozoa. *Cellaria* spp., *Galeopsis* spp., and *Hornera* spp. Note that this modelling used all available presence data from physical captures, not abundance data focussed on the benthic AOI as in the current modelling study.

Calcareous tube worm thickets

Calcareous tubeworms can create large three-dimensional reefs that provide biogenic habitat. In Aotearoa New Zealand the serpulid polychaete worm *Galeolaria hystrix* is the most significant aggregating species, that can grow in large colonies creating reef mounds (MacDiarmid et al. 2013; Anderson et al. 2019). The calcareous tubes persist after the worm has died, providing long-term biogenic habitat for other species

A sensitive calcareous tube worm thicket (as defined by Schedule 6) exists if:

- One or more tube worm mounds per 250 m² are visible in a seabed imaging survey; or
- Two or more specimens of a mound-forming species of tube worm are found in a point sample; or
- Mound-forming species of tube worm comprise 10% or more by weight or volume of a towed sample

Calcareous tubeworms can create large three-dimensional reefs that provide biogenic habitat. In Aotearoa New Zealand the serpulid polychaete worm *Galeolaria hystrix* is the most significant aggregating species, that can grow in large colonies creating reef mounds (MacDiarmid et al. 2013; Anderson et al. 2019).

Calcareous tube-forming species occur from the intertidal to abyssal depths but are most common in coastal waters. They inhabit both soft and hard substrate environments but require a hard structure on which to initially establish (e.g., a dead shell in soft sediment environments) (MacDiarmid et al. 2013).

No calcareous tube worm thickets are known to be present within the benthic AOI.

Chaetopteridae worm fields

A sensitive Chaetopteridae worm field (as defined by Schedule 6) exists if worm tubes or epifaunal species:

- Cover 25% or more of the seabed in a visual imaging survey of 500 m² or more; or
- Make up 25% or more of the volume of a sample collected using towed gear; or
- Are found in two successive point samples

There have been only eight records of Chaetopteridae specimens from within the benthic AOI. No Chaetopteridae were recorded in imagery data from within the benthic AOI. Although extensive fields of Chaetopteridae are known to occur on the north Otago shelf (see Section 3.3), these have not been assessed in relation to the Schedule 6 sensitive environment thresholds.

While no sensitive environments for Chaetopteridae have been determined from available data the presence of this taxon within the benthic AOI, together with observations on the north Otago shelf, indicates that it is likely a sensitive environment could exist within, or in close proximity to, the benthic AOI.

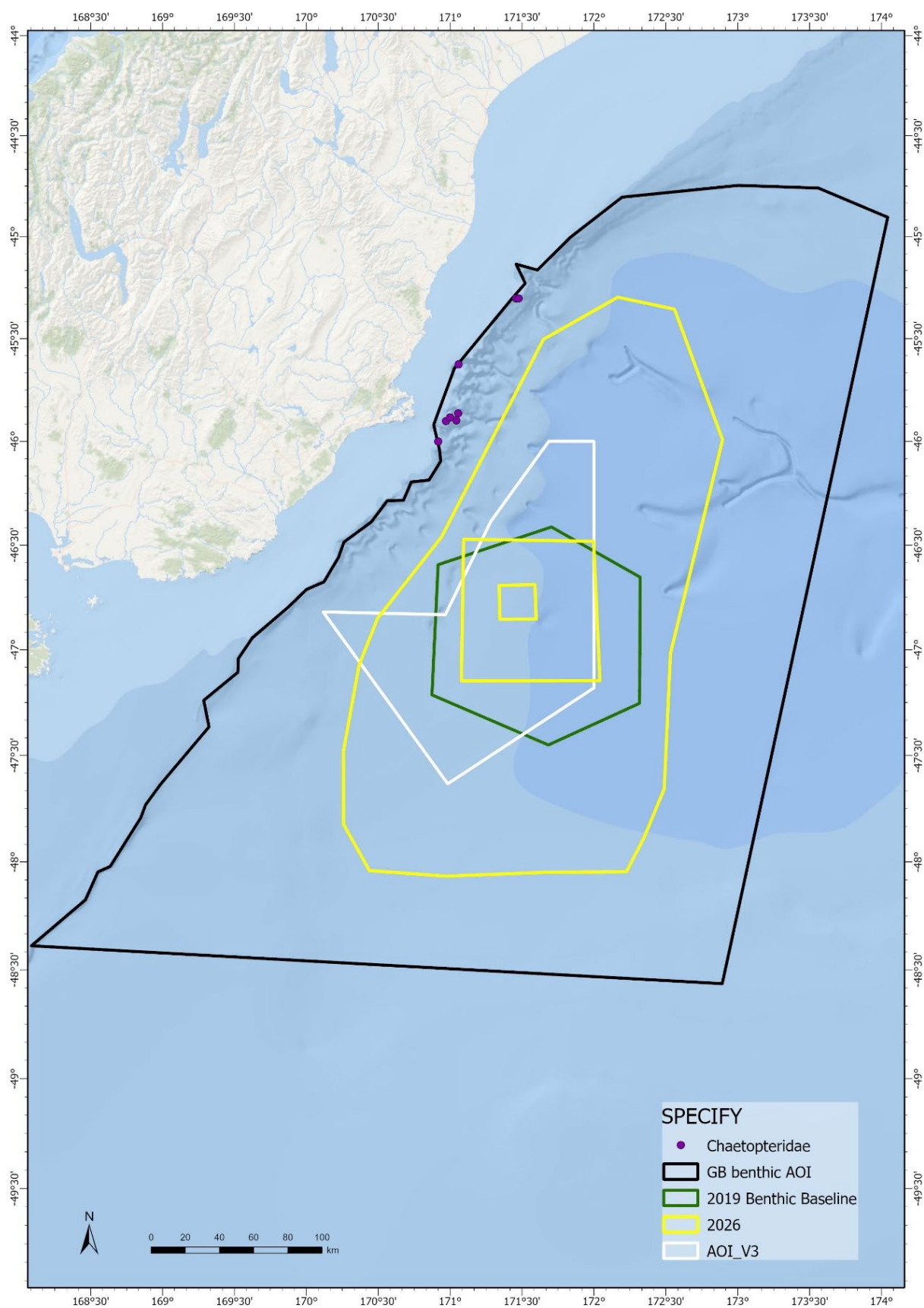


Figure 3-31: Spatial location of Chaetopteridae records within the benthic AOI. Species location records from a SPECIFY data export.

Sea pen field

Sea pens are specialised benthic colonial marine organisms. They occur on soft sediments in deeper water of the continental shelf, slope, and abyssal plains (MacDiarmid et al. 2013) anchoring themselves with a stem holding feeding polyps that extend into the overlying water column. There is also one New Zealand deep-sea species of sea pen which attaches to hard substrates (known as a rock pen).

A sea pen field (as defined by Schedule 6) exists if:

- A specimen of sea pen is found in successive point samples; or
- Two or more specimens of sea pen per m² are found in a visual imaging survey or a survey collected using towed gear

A total of 17 physical specimen location records of sea pens lie within the benthic AOI (Figure 3-32), and they were widespread in the available imagery data, with densities up to 142 inds. 1,000 m⁻². In addition, KEA species distribution modelling showed a high probability of occurrence in the channel and channel surrounds within the benthic AOI for *Anthoptilum* spp. (Figure 3-33).

Species distribution modelling conducted in this study, using latest available data relevant to the project area, predicted high abundances of sea pens in the north of the benthic AOI, particularly in/near channel features (see Section 4 and Figure 4-7).

While no sensitive environment for sea pens has been identified from available data, the presence of relatively high abundances of sea pens in some areas indicates that the presence of a sensitive environment may be possible within the benthic AOI.

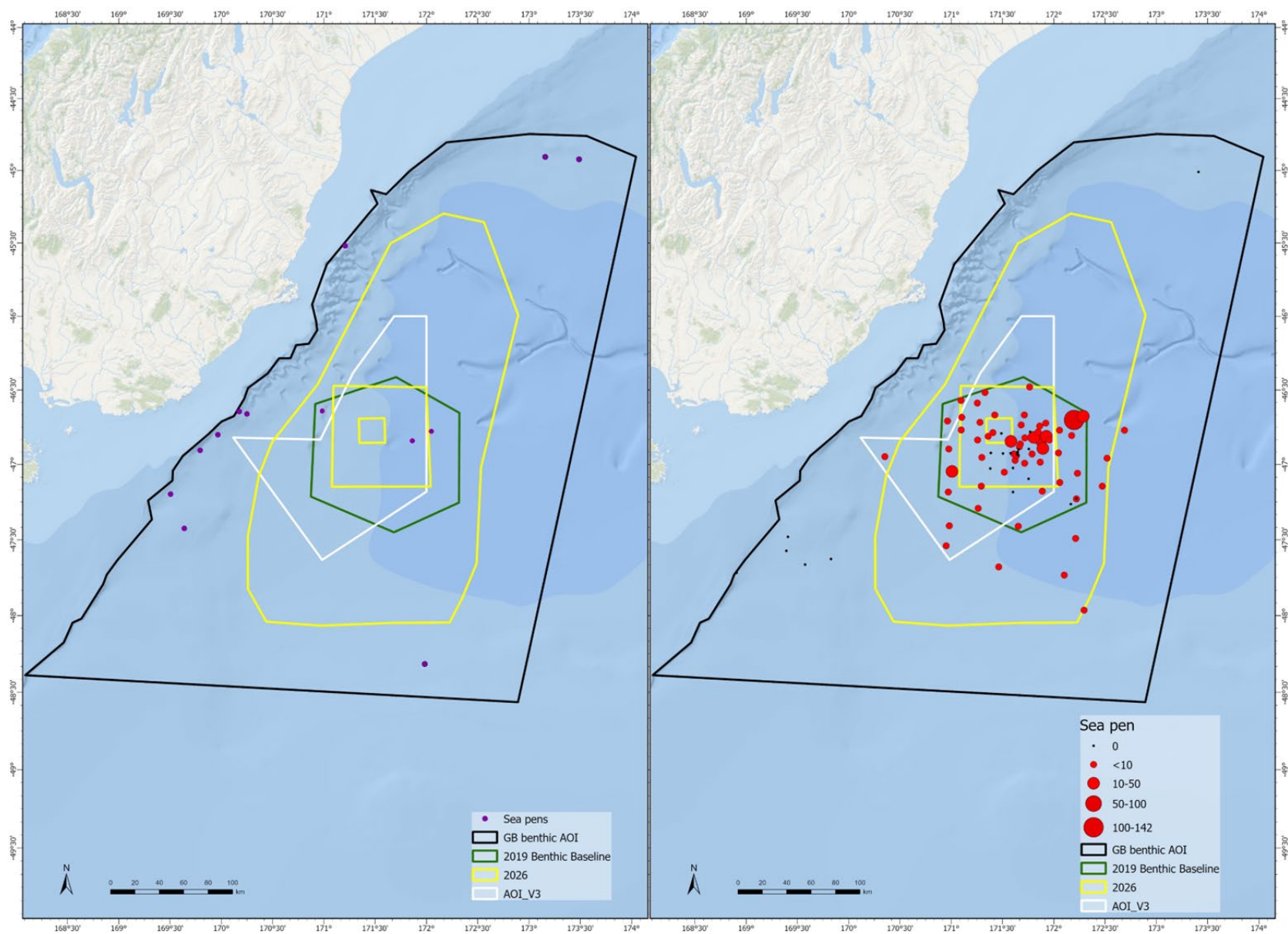


Figure 3-32: Spatial distribution of sea pen records within the AOI. Left: species location records from SPECIFY, OBIS, and MPI observer catch data exports. Right: imagery (DTIS) abundance data (inds. 1,000 m⁻²).

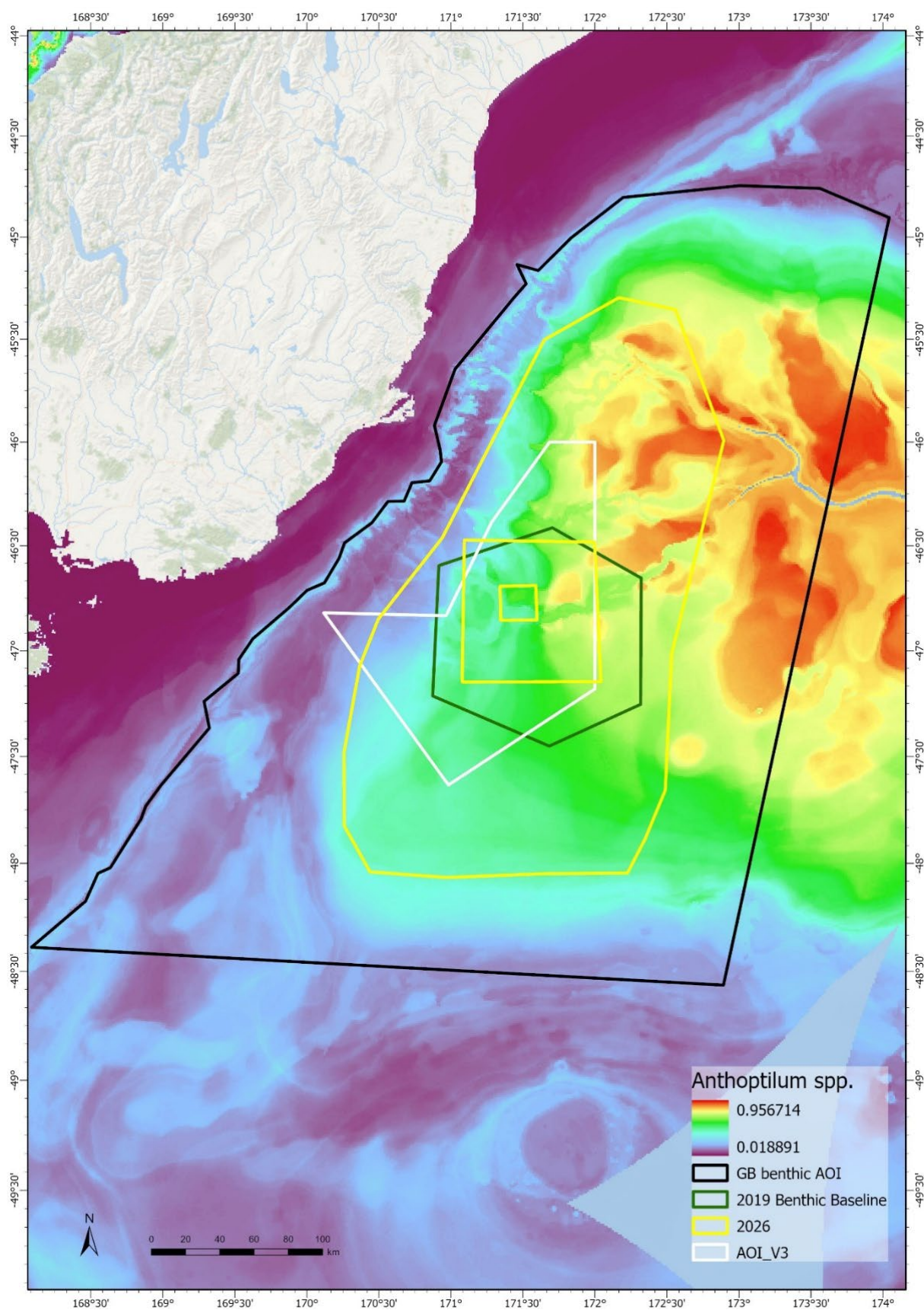


Figure 3-33: KEA species distribution models: sea pen. *Anthoptilum* spp. Note that this modelling used all available presence data from physical captures, not abundance data focussed on the benthic AOI as in the current modelling study.

Rhodolith beds

Rhodoliths are spherical or nodular calcareous structures formed by crustose, benthic marine red algae. They live unattached on the seafloor in shallow marine environments, supporting diverse communities and contributing to sediment stabilisation.

A rhodolith bed (as defined by Schedule 6) exists if:

- Living coralline thalli are found to cover more than 10% of an area in a visual imaging survey; or
- Is to be taken to exist if a single specimen of a rhodolith species is found in any sample

No rhodolith beds are known from within the benthic AOI.

Sponge gardens

Sponges are a common feature of rocky reef habitats but are also known to grow in soft sediments where there are hard surfaces such as living or dead shells, coarse grains, or rubble available for colonisation. Where sponges grow in abundance and form the dominant cover of the sea floor they provide a three-dimensional physical structure and refuge for other benthic organisms, thus forming a biogenic habitat supporting additional organismal biodiversity (MacDiarmid et al. 2013; Anderson et al. 2019). Sponges inhabit a wide depth range, from the intertidal to abyssal and trench (hadal) environments (MacDiarmid et al. 2013).

A sponge garden (as defined by Schedule 6) exists if metazoans of classes Demospongiae, Hexactinellidae, Calcarea, or Homoscleromorpha:

- Comprise 25% or more by volume of successive point samples; or
- Comprise 20% or more by volume of any sample collected using towed gear; or
- Cover 25% or more of the seabed over an area of 100 m² or more in a visual imaging survey.

A total of 1861 species location records of Porifera were available within the benthic AOI, most of which were located towards the western boundary around the shelf edge (Figure 3-34). Sponges were also widespread in imagery data within the benthic AOI, with up to 877 inds. 1,000 m⁻² recorded. In addition, KEA species distribution modelling showed a moderate to high probability of occurrence in the channel and slope environments for *Callyspongia* spp within the benthic AOI (Figure 3-35).

Species distribution modelling conducted in this study, using latest available data relevant to the project area, predicted high abundance of sponges within the benthic AOI, particularly associated with channel features (see Section 4 and Figure 4-6).

No sensitive environment for sponge gardens has been identified from available data, but it is possible that a sensitive environment could exist within the benthic AOI.

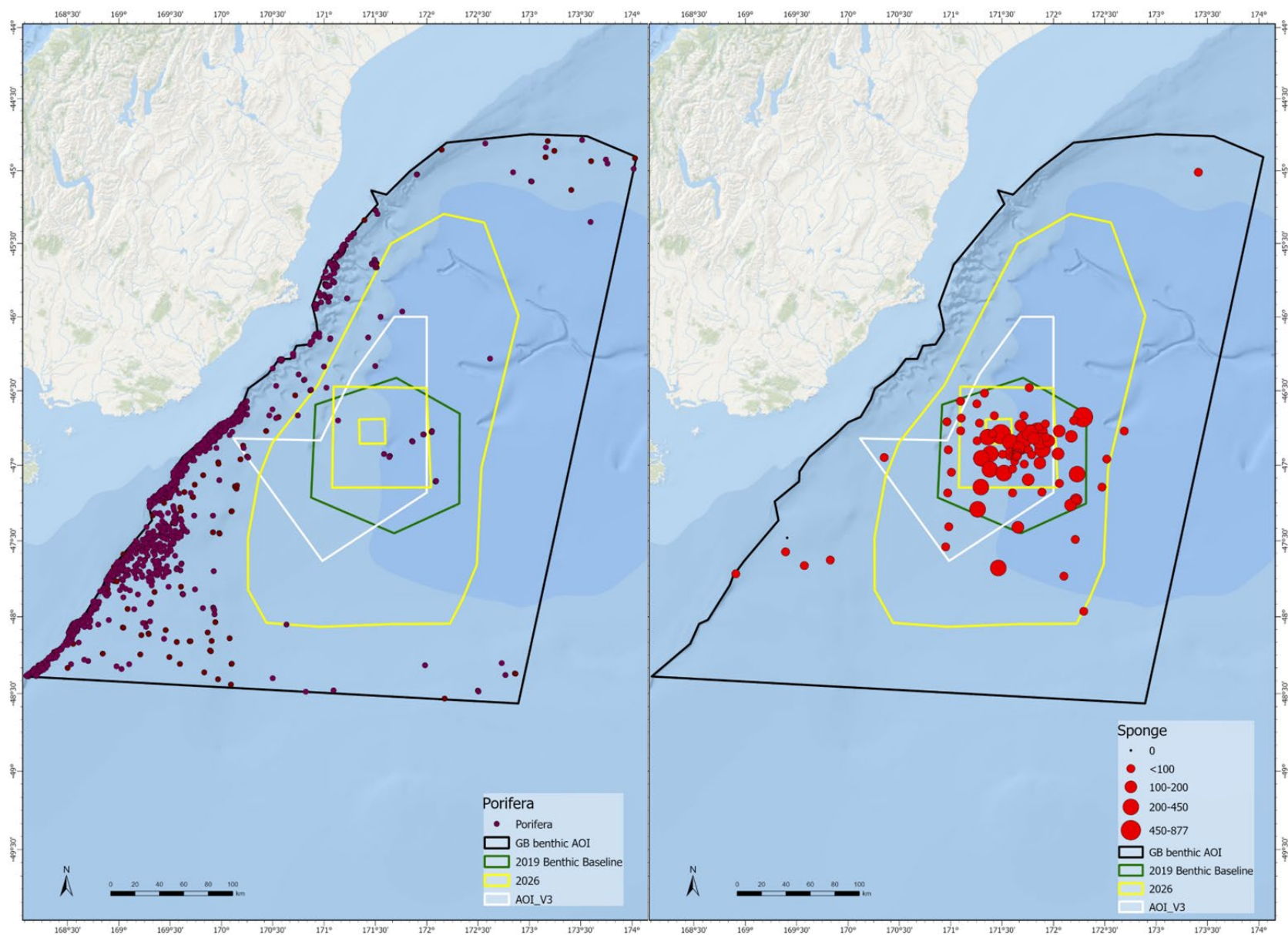


Figure 3-34: Spatial distribution of Porifera (sponge) records within the benthic AOI. Left: species location records from SPECIFY, OBIS, Te Papa and MPI observer catch data exports. Right: imagery (DTIS) abundance data (inds. 1,000 m⁻²).

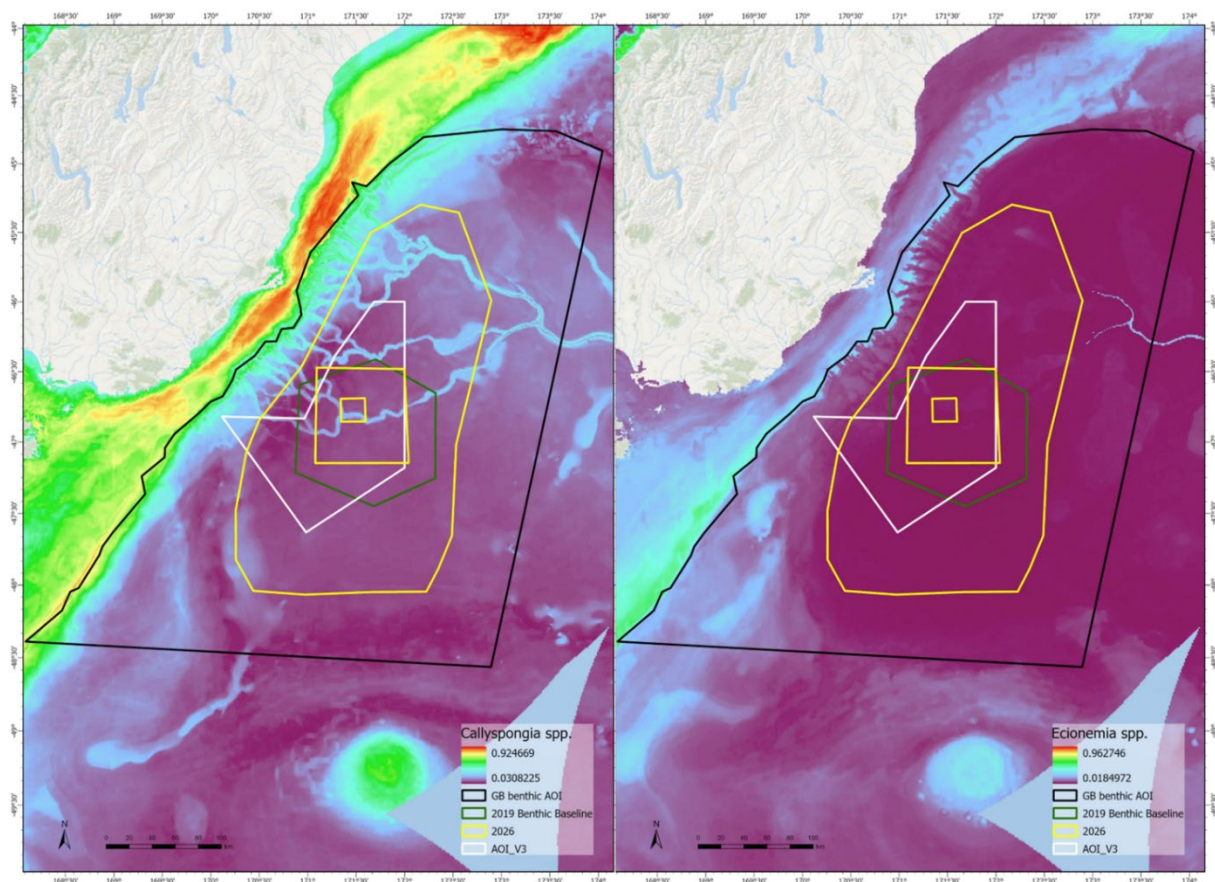


Figure 3-35: KEA species distribution modelling: sponges. *Callyspongia* spp. and *Ecionemia* spp. Note that this modelling used all available presence data from physical captures, not abundance data focussed on the benthic AOI as in the current modelling study.

Beds of large bivalve molluscs

Bivalves are an important component of Aotearoa New Zealand’s soft sediment coastal communities and habitats. At high densities these bivalve beds can support a wide range of associated species as they stabilise the seabed, provide hard substrate for colonisation, and provide other ecosystem services. Relict shells from dead individuals may also provide biogenic habitat for settlement and can be colonised and consolidated by other biogenic species (Anderson et al. 2019).

In Aotearoa New Zealand, beds of large bivalves are mostly in depths less than 250 m (MacDiarmid et al. 2013) and are more likely to occur on the continental shelf than on the continental slope or in abyssal depths (Rowden et al. 2012).

A bed of large bivalve mollusc (as defined by Schedule 6) exists if living and dead specimens:

- Cover 30% of more of the seabed in a visual imaging survey; or
- Comprise 30% of more by weight or volume of the catch in a sample collected using towed gear; or
- Comprise 30% of more by weight or volume in successive point samples.

Habitat-forming species of bivalve were found to be present within the AOI, with 119 species location records situated within the study area, mostly on the shelf slope along the western boundary of the AOI. Species present included the following genera/species: *Tawera* spp., *Ostrea chilensis* (dredge oyster), *Panopea smithae* (geoduc), *Tucetona laticostata* (dog cockle), *Atrina zelandica* (horse mussel), and *Zygochlamys delicatula* (queen scallop). No imagery data were available specifically for habitat-forming species of bivalves.

In addition, KEA species distribution modelling showed a moderate probability of occurrence in the channel and slope environments for *Pecten* spp. (scallops) and a moderate to high probability of occurrence for *Tawera* spp. in the southern extent of the benthic AOI as well as on slope and channel features (Figure 3-37).

No sensitive environments for beds of large bivalve molluscs have been identified from the available data, however, the presence of habitat-forming species indicates that is possible a sensitive environment could exist within the benthic AOI.

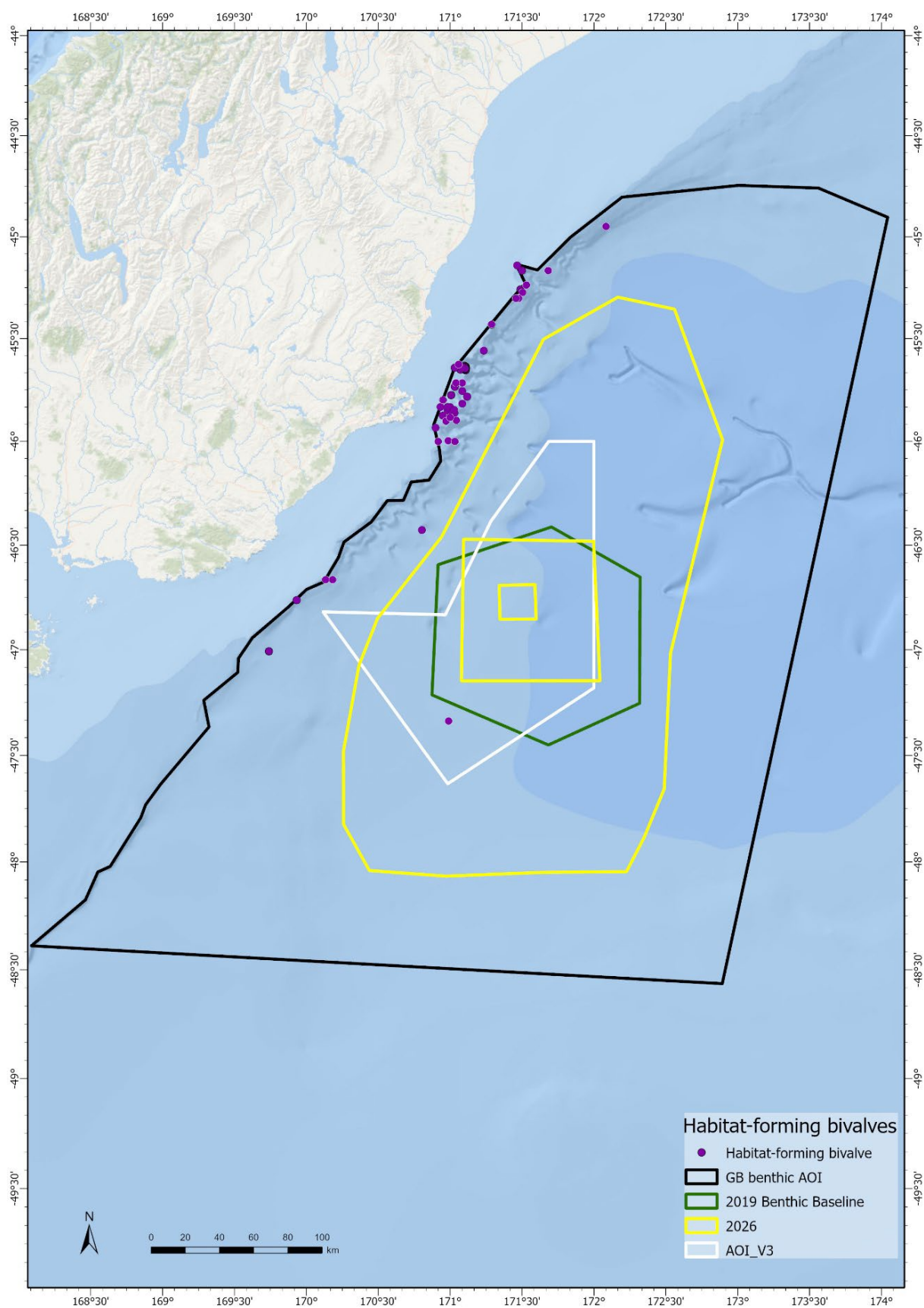


Figure 3-36: Spatial distribution of habitat-forming bivalve records within the benthic AOI. Species location records from SPECIFY, OBIS, Te Papa and MPI observer catch data exports.

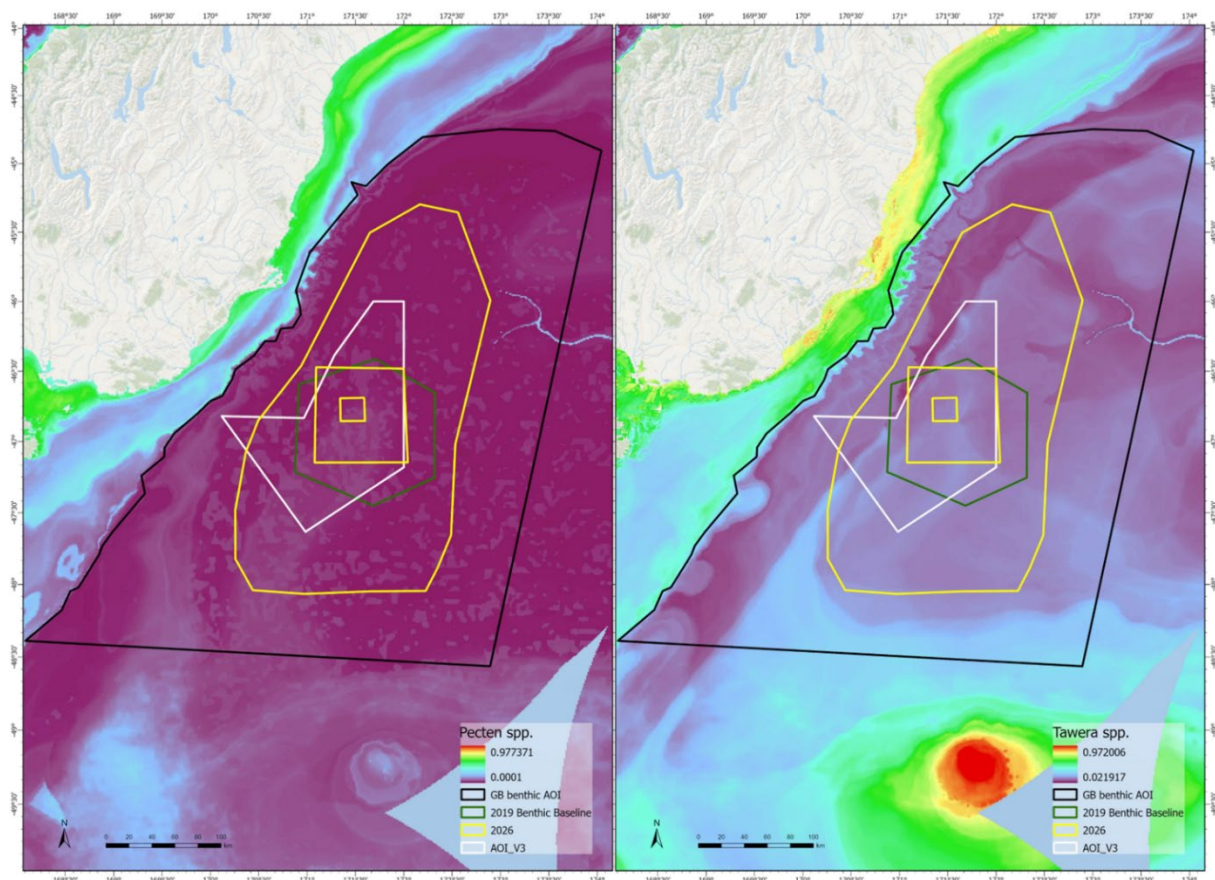


Figure 3-37: KEA species distribution modelling: bivalves. *Pecten* spp. and *Tawera* spp. Note that this modelling used all available presence data from physical captures, not abundance data focussed on the benthic AOI as in the current modelling study.

Macro-algae beds

Macroalgae are generally limited in depth to the photic zone, and are rarely found deeper than about 100 m. A macro-algal bed (as defined by Schedule 6) exists if a specimen of a red, green, or brown macro-algae is found in a visual imaging survey or any sample.

No macro-algal beds are known to be within the benthic AOI.

Brachiopods

Brachiopods, or lamp shells, are small bivalve-like filter feeders. Within Aotearoa New Zealand, they occur from the intertidal to the abyss and are normally attached to hard substrates such as rock, gravel, or shell debris by a muscular stalk though in one genus the adults may be free living (MacDiarmid et al. 2013).

A brachiopod bed (as defined by Schedule 6) exists if one or more live brachiopods:

- are found per m² sampled using towed gear; or
- are found in successive point samples.

A total of 59 brachiopod records were available within the benthic AOI (Figure 3-39). These were mostly distributed on the shelf edge, with a few scattered records throughout the AOI.

Brachiopods are small (typically 5–50 mm) and hard to identify from video or still imagery (e.g. Figure 3-38). It is also very difficult to determine whether the brachiopods observed are live animals or empty shells. MacDiarmid et al. (2013) stated that “in images of the seabed taken at the standard (Earth Sciences NZ towed camera protocol) survey height of 2.0–2.5 m, brachiopods may be difficult to distinguish because of their small size and overgrowth of other organisms. Only at very high densities might beds of brachiopods be readily identified. For this reason, standard sea floor imaging should not be used to determine the occurrence of brachiopod beds, in particular their potential absence”.

However, a brachiopod bed was incidentally observed at a seamount site during examination of still images to aid with species identifications and for the determination of percent cover of sponge and stony coral thickets during analyses of the 2019 baseline survey. The sensitive environment for brachiopods is indicated in Figure 3-39. Note that brachiopods live attached to hard substrates and so, if present, would be expected to be observed at rocky channel and/or seamount sites rather than on broad slope basin sites that are muddy-sandy sediments.

In addition, KEA species distribution modelling showed a high probability of occurrence on slope environments within the benthic AOI for *Neothyris* spp. and a moderate probability of occurrence in channel features and in the south western extent of the AOI for both of the modelled genera (*Calloria* and *Neothyris*) (Figure 3-40).



Figure 3-38: DTIS image showing a brachiopod bed amongst barnacle plates at a seamount within the benthic AOI. Image taken during the 2019 baseline survey. Black arrows point to three brachiopods identified as being alive. The red scale bar is drawn between laser beams which are 20 cm apart.

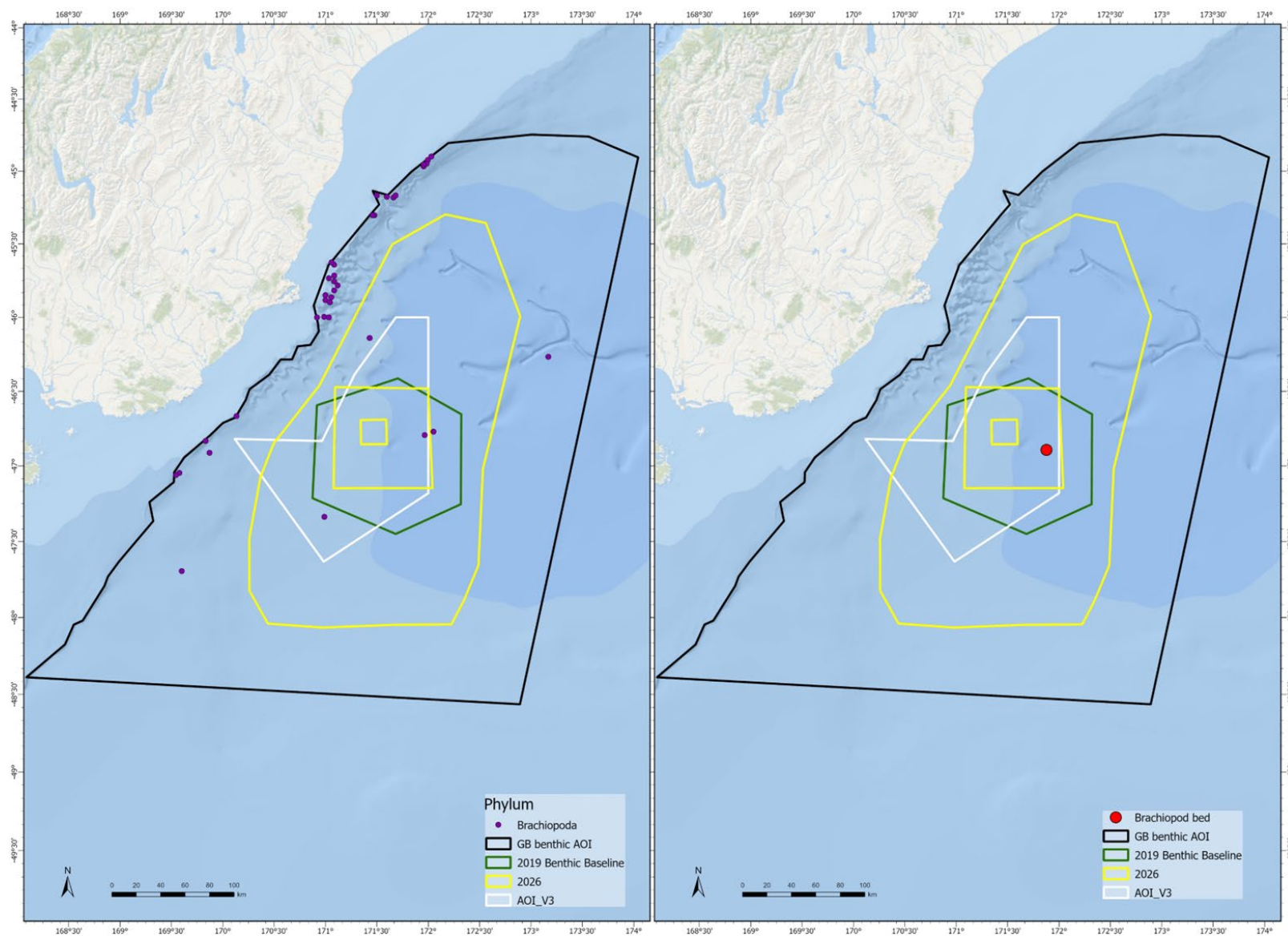


Figure 3-39: Spatial distribution of Brachiopoda within the benthic AOI. Left: Species location records from SPECIFY, OBIS, Te Papa and MPI observer catch data exports. Right: location of known sensitive environment for brachiopod beds.

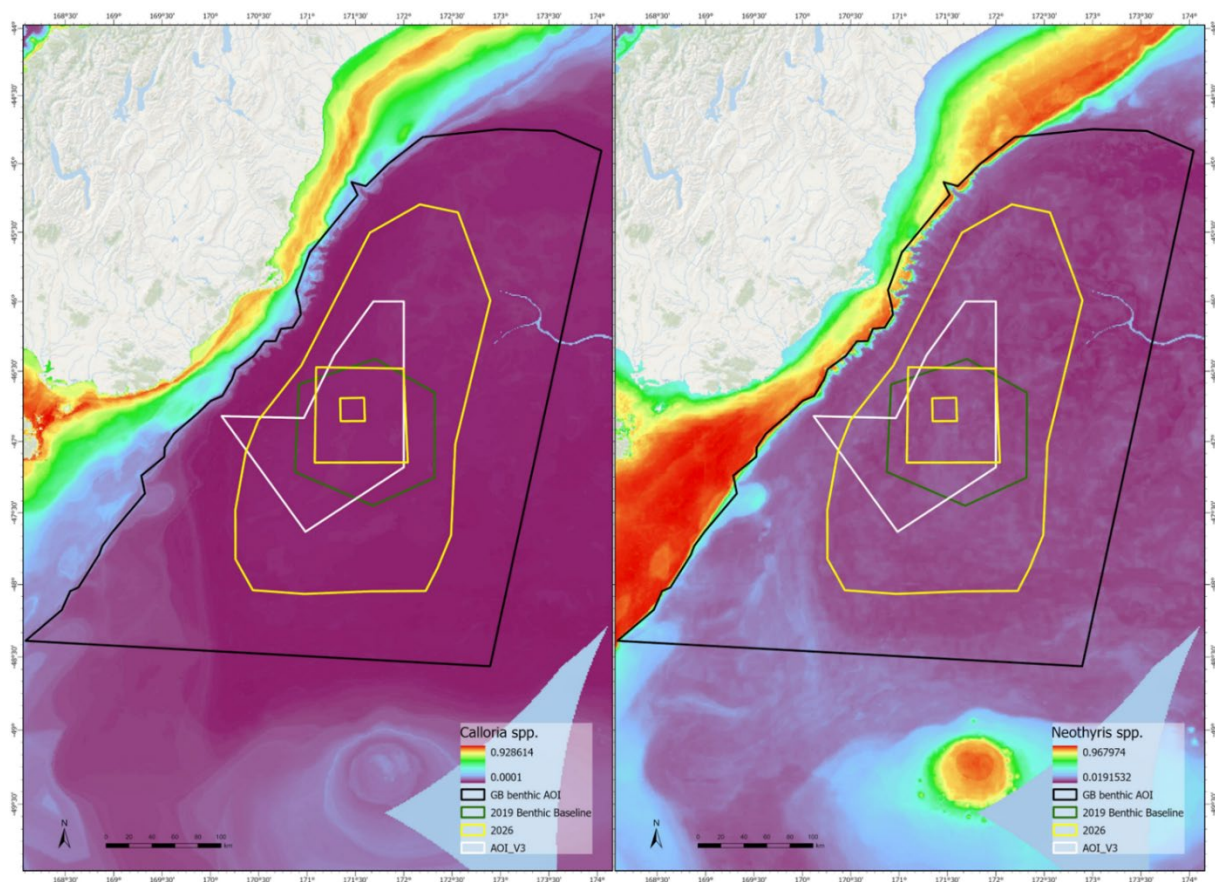


Figure 3-40: KEA species distribution modelling: brachiopods. *Calloria* spp. and *Neothyris* spp. Note that this modelling used all available presence data from physical captures, not abundance data focussed on the benthic AOI as in the current modelling study.

Deep-sea hydrothermal vents

A deep-sea hydrothermal vent is a sea floor fissure through which heated, mineral-rich water is released into the ocean. They can support unique, chemosynthetic-based ecosystems. In Aotearoa New Zealand, hydrothermal vents occur in shallow shelf waters of the Bay of Plenty (8-200 m) and in deeper waters on the seamounts of the Kermadec Volcanic arc (up to 1,800 m) (MacDiarmid et al. 2013 and references therein).

A sensitive hydrothermal vent (as defined by Schedule 6) exists if a live specimen of a known vent species is found in a visual imaging survey or any sample. The following vent species are known to exist in Aotearoa New Zealand waters:

Vulcanopsis osheai; *Ashinkailepas kermadecensis*; *Gigantidas gladius*; *Vulcanidas insolatus*; *Alvinocaris niwa*; *A. longirostris*; *A. alexander*; *Lebbeus wera*; *Nautilocaris saintlaurentae*; *Gandalfus puia*; *Xenograpsus ngatama*; *Parolomis hirtella*; *Bathyaustriella thionipta*; *Sibloglimum* sp.; *Oasisia fujikurai*; *Lamellibranchia juni*; *Sclerasterias eructans*; *Parachnoidea rowdeni*; *Pyrolycus moelleri*; *Symphurus thermophilus*

No deep-sea hydrothermal vents are known to exist within the benthic AOI.

Methane or cold seeps

Cold seeps occur where methane-rich fluids escape into the water column from underlying sediments and typically occur in water depths of at least 500 m (MacDiarmid et al. 2013).

A methane or cold seep (as defined by Schedule 6) exists if a single occurrence of one of the following taxa is found in a visual survey or any sample:

Large siboglinid tubeworms *Lamellibranchia* sp.; vesiocomyid clams *Calypptogena* sp.; mussels in the family Bathymodiolinae; solemyid clams (*Archarax clarificata*); the sponges *Stelletta* n. sp. and *Pseudosuberites* sp; ampharetid, dorvilleid, and pogonophoran (*Siboglinum* sp.) polychaete worms.

There is evidence of previous cold-seeps within the benthic AOI (e.g., LewisMarshall 1996; Orpin 1997), however no active methane or cold seeps are known to be present within the benthic AOI.

Sensitive environment summary

These investigations have confirmed that three sensitive environments are present within the benthic AOI: stony coral thickets or reefs, xenophyophore beds, and brachiopod beds (Table 3-7, Figure 3-41). In addition, it is possible or likely (but not confirmed) that there are sensitive environments of the following: bryozoan thickets, sea pen fields, sponge gardens, beds of large bivalve molluscs, and Chaetopteridae worm fields.

Many of the sensitive environment taxa were particularly associated with the shelf slope, channel and seamount habitats within the benthic AOI. However, note that xenophyophores (sensitive environment) were present in high densities on the muddy sediments of the broad slope basin.

Table 3-7: Summary of known sensitive environments within the benthic AOI.

Sensitive environment	Present within AOI	Comment
Stony coral thickets or reefs	Yes	Identified during the 2019 baseline survey. Observed at three sites. One site had live coral, only dead coral matrix was observed in the single transects at each of the other two sites
Xenophyophore beds	Yes	Identified during the 2019 baseline survey.
Brachiopod beds	Yes	Identified during the 2019 baseline survey. Note that brachiopods are difficult to identify during imaging surveys so likely more areas of sensitive environment undetected.
Bryozoan thickets	Likely	Large areas of high-density bryozoans known from the Otago shelf
Chaetopteridae worm fields	Likely	Large areas of high-density Chaetopteridae known from the Otago shelf
Sea pen field	Possible	Numerous records from physical sampling and imaging surveys
Sponge gardens	Possible	Numerous records from physical sampling and imaging surveys
Beds of large bivalve molluscs	Possible	A range of habitat-forming bivalve species have been recorded from the shelf
Calcareous tube worm thickets	Unlikely	Only a few records from physical samples and not recorded in imagery surveys
Rhodolith beds	No	Likely too shallow
Macroalgal beds	No	Likely too shallow
Deep-sea hydrothermal vents	No	None reported
Methane or cold seeps	No	No active seeps reported

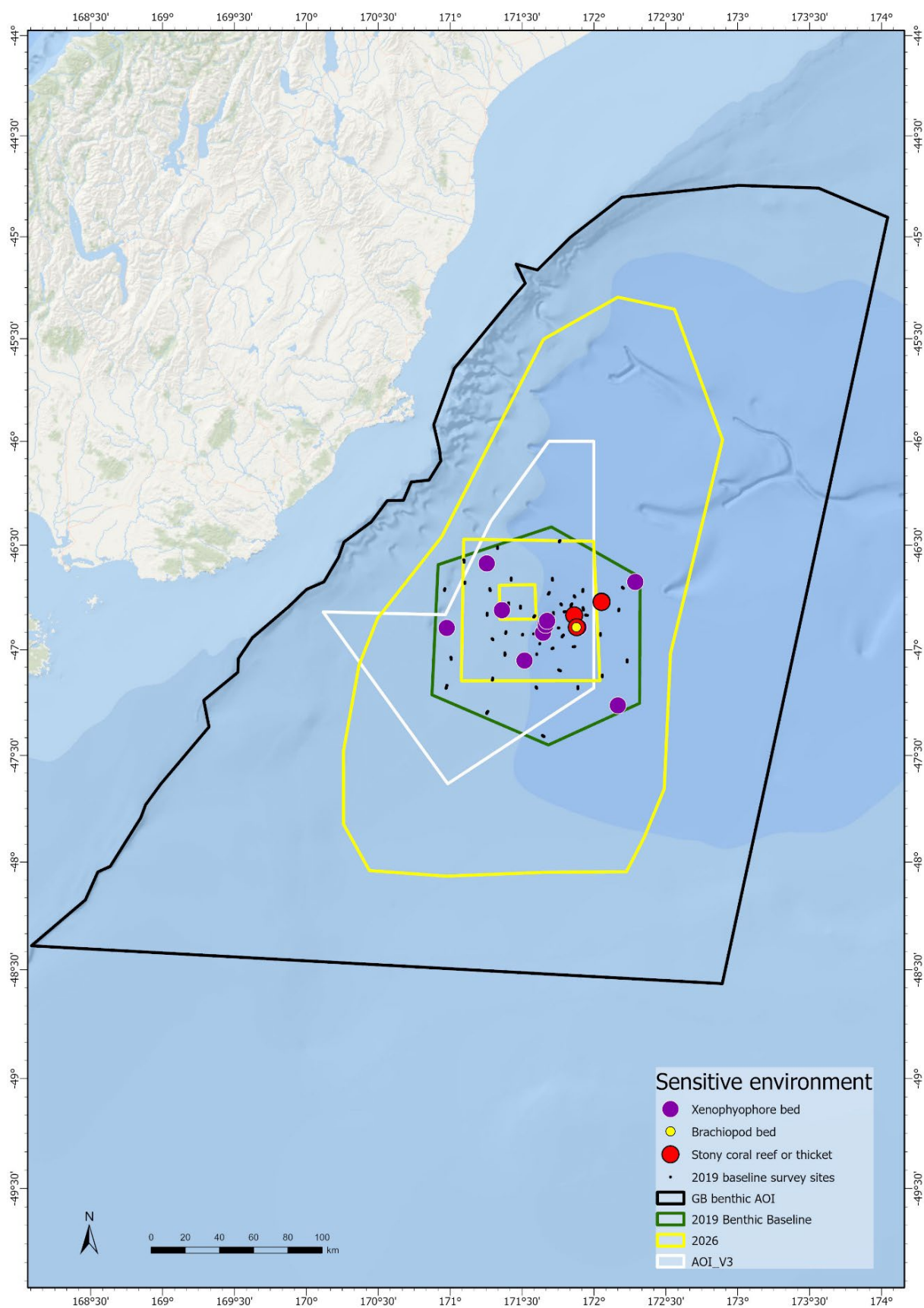


Figure 3-41: Location of known sensitive environments present within the benthic AOI. As defined by Schedule 6. Note that only data collected during the 2019 baseline survey have been assessed regarding the sensitive environment thresholds.

3.7.2 Protected species

In addition to the sensitive environments defined by Schedule 6 in the EEZ Permitted Activities Regulations, intentional damage and removal of the following taxa is prohibited under Schedule 7A of the Wildlife Act 1953⁴:

Anthozoa (corals and sea anemones):

- Black corals – all species in the order Antipatharia
- Gorgonian corals –species formerly in the order Gorgonacea (now Malacalcyonacea + Scleralcyonacea that include the non-protected soft corals)
- Stony corals – all species in the order Scleractinia

Hydrozoa (hydra-like animals):

- Hydrocorals – all species in the family Stylasteridae

Details of the specific protections afforded to these corals is covered more precisely in the Act.

Antipatharia

Antipatharians or black corals are colonial corals that form non-calcareous skeletons composed of protein and chitin that are quite flexible (Opresko et al. 2014). There are approximately 58 species within Aotearoa New Zealand waters and most live in the deep-sea on seamounts and other underwater features between 200 and 1,000 m depth (Tracey et al. 2011).

Antipatharians have been recorded within the benthic AOI (Figure 3-42), with three records from OBIS, three from SPECIFY, four records from the MPI observer database and observations from video imagery. In addition, KEA distribution modelling predicts relatively high occurrences of *Bathypathes* spp. across much of the AOI (Figure 3-43).

⁴ <https://www.legislation.govt.nz/act/public/1953/0031/latest/whole.html>

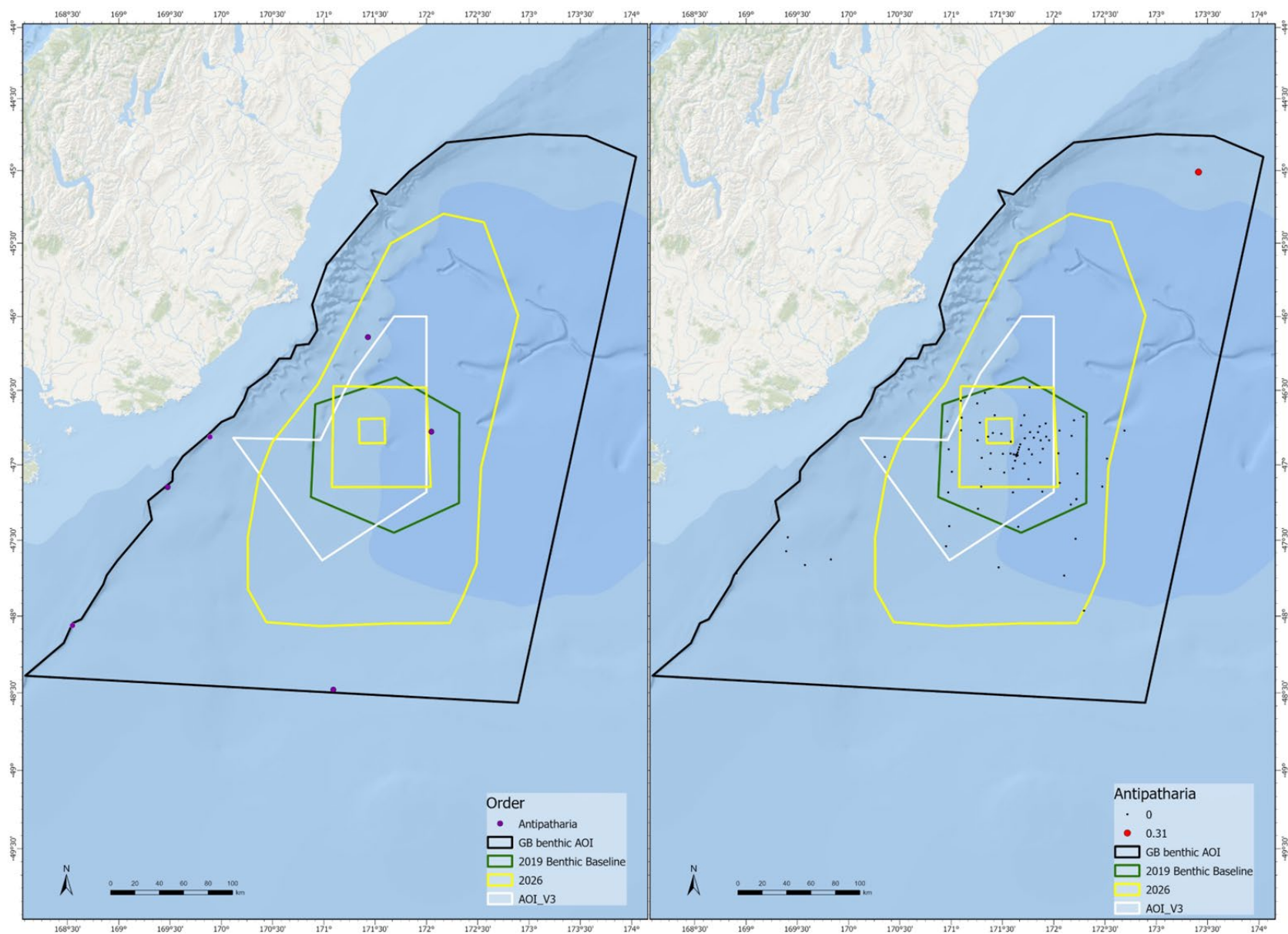


Figure 3-42: Spatial distribution of Antipatharia records within the benthic AOI. Left: species location records from SPECIFY, OBIS, and MPI observer data exports. Right: imagery (DTIS) abundance data (inds. 1,000 m⁻²).

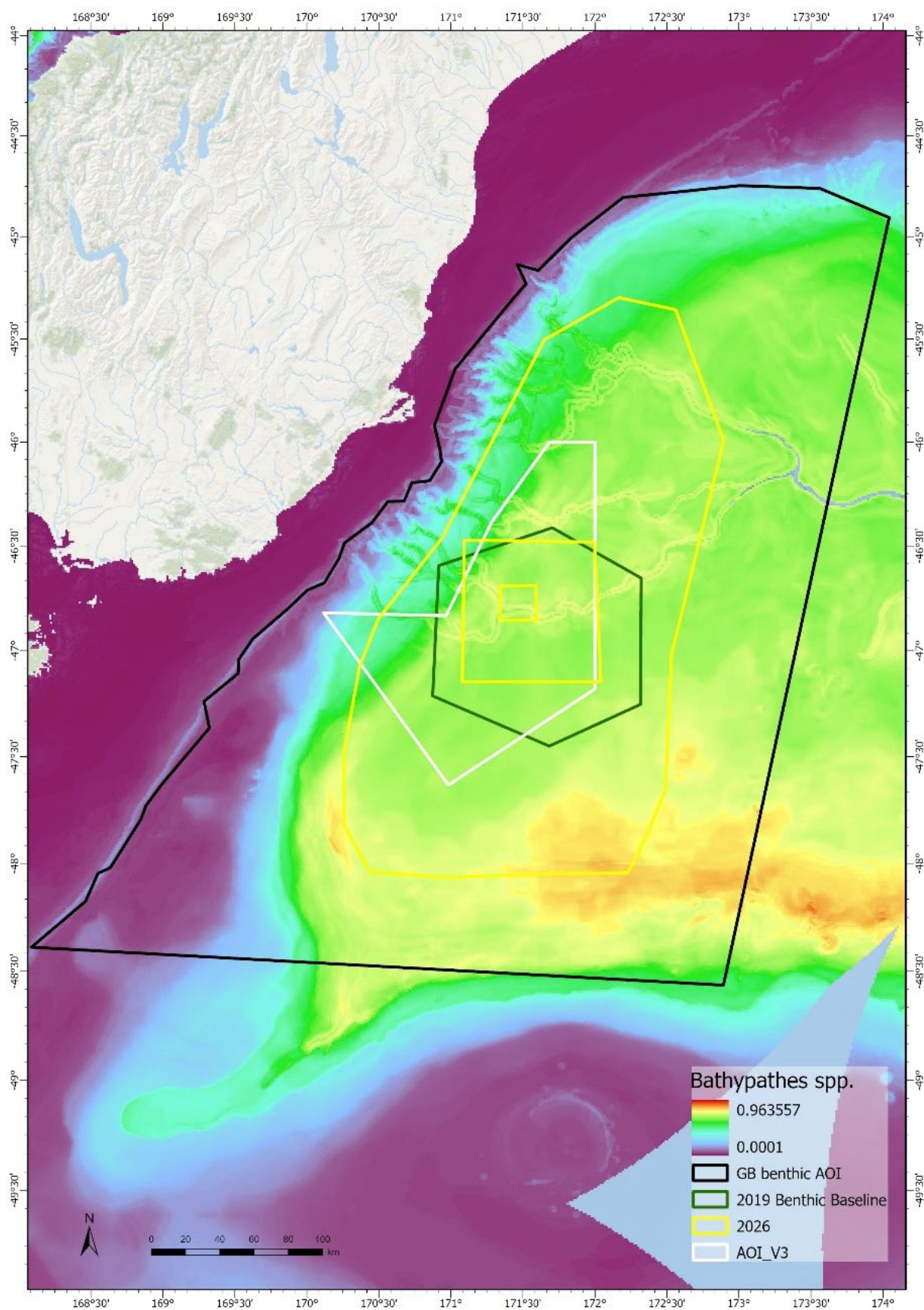


Figure 3-43: KEA species distribution modelling: black coral. *Bathypathes* spp. Note that this modelling used all available presence data from physical captures, not abundance data focussed on the benthic AOI as in the current modelling study.

Gorgonian corals

Gorgonian corals have a widespread distribution in Aotearoa New Zealand with depth ranges recorded from 37-2,407 m (Tracey et al. 2011).

Gorgonians are present within the benthic AOI (Figure 3-44) with 228 records from the MPI observer database, 68 records from OBIS, 170 from SPECIFY, and one record from Te Papa. Observations of Gorgonians from video imagery showed particularly high abundances at channel and seamount features. In addition, KEA species distribution modelling predicted a high probability of occurrence across much of the benthic AOI for *Keratoisis* spp. and *Paragorgia* spp. (Figure 3-45).

Species distribution modelling conducted in this study, using latest available data relevant to the project area, predicted the highest abundance of gorgonian corals to be in the north and east of the benthic AOI, and showed a particular association with channel features (see Section 4 and Figure 4-5).

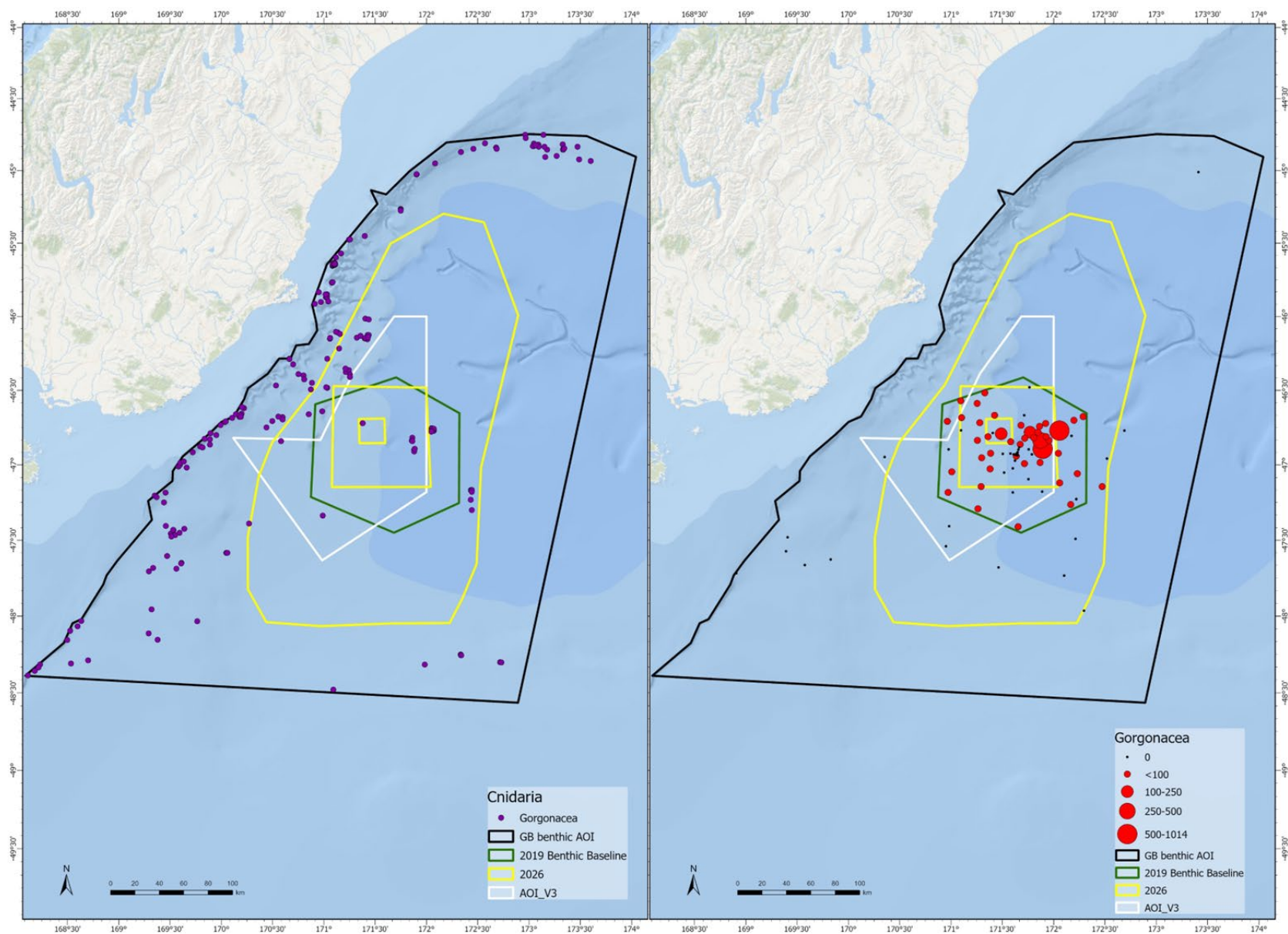


Figure 3-44: Spatial distribution of "Gorgonacea" (gorgonian corals) records within the benthic AOI. Left: species location records from SPECIFY, OBIS, Te Papa and MPI observer data exports. Right: imagery (DTIS) abundance data (inds. 1,000 m⁻²).

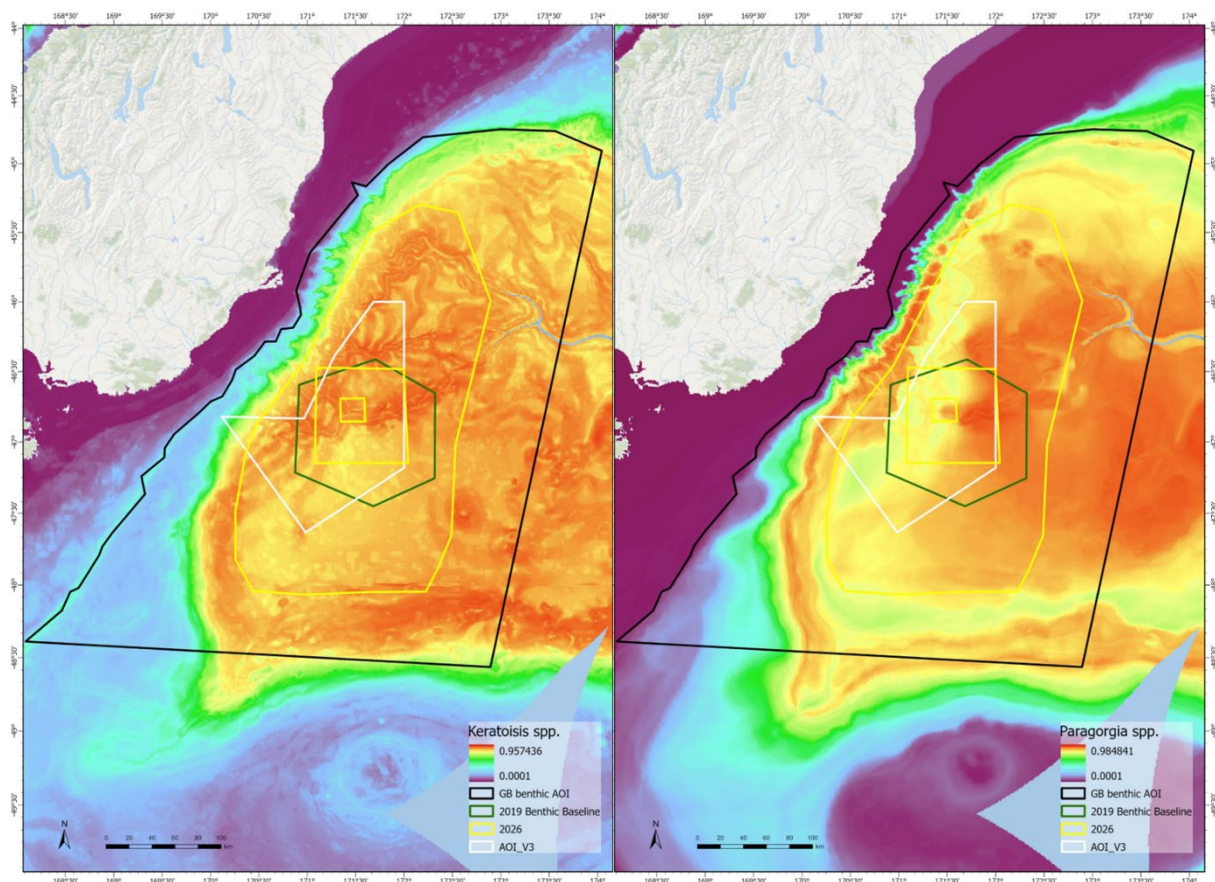


Figure 3-45: KEA species distribution modelling: gorgonians. *Keratoisis* spp. and *Paragorgia* spp. Note that this modelling used all available presence data from physical captures, not abundance data focussed on the benthic AOI as in the current modelling study.

Scleractinia

Thicket-forming stony corals are discussed in section 3.7.1 (sensitive environments) and are known to be present on seamount features within the benthic AOI. Here we also present data on protected solitary scleractinian cup coral species.

Many species of solitary cup corals are associated with hard substrates. However, some species are known to inhabit soft sediments (e.g. *Flabellum* spp. and *Stephanocyathus* spp.). The depth distribution of cup corals ranges from the shallow to the deep sea. For example, *Desmophyllum dianthus* has been recorded between 35 m to 2,460 m (Tracey et al. 2011).

There was a total of 319 records of scleractinian (both branching and solitary species) within the benthic AOI (Figure 3-46). Observations from video imagery also showed high numbers of Scleractinia within the AOI, the highest abundances of which were the soft-sediment-dwelling cup coral *Stephanocyathus platypus* with densities of up to 1,000 inds. 1,000 m².

In addition, KEA species distribution models showed relatively high predicted probability of occurrence for both branching scleractinian corals and a solitary coral (*Flabellum* spp.) within the benthic AOI (Figure 3-25 and Figure 3-47 respectively).

Species distribution modelling conducted in this study, using all imagery data relevant to the project area, predicted high abundances of cup corals in the centre of the benthic AOI (see Section 4 and Figure 4-4).

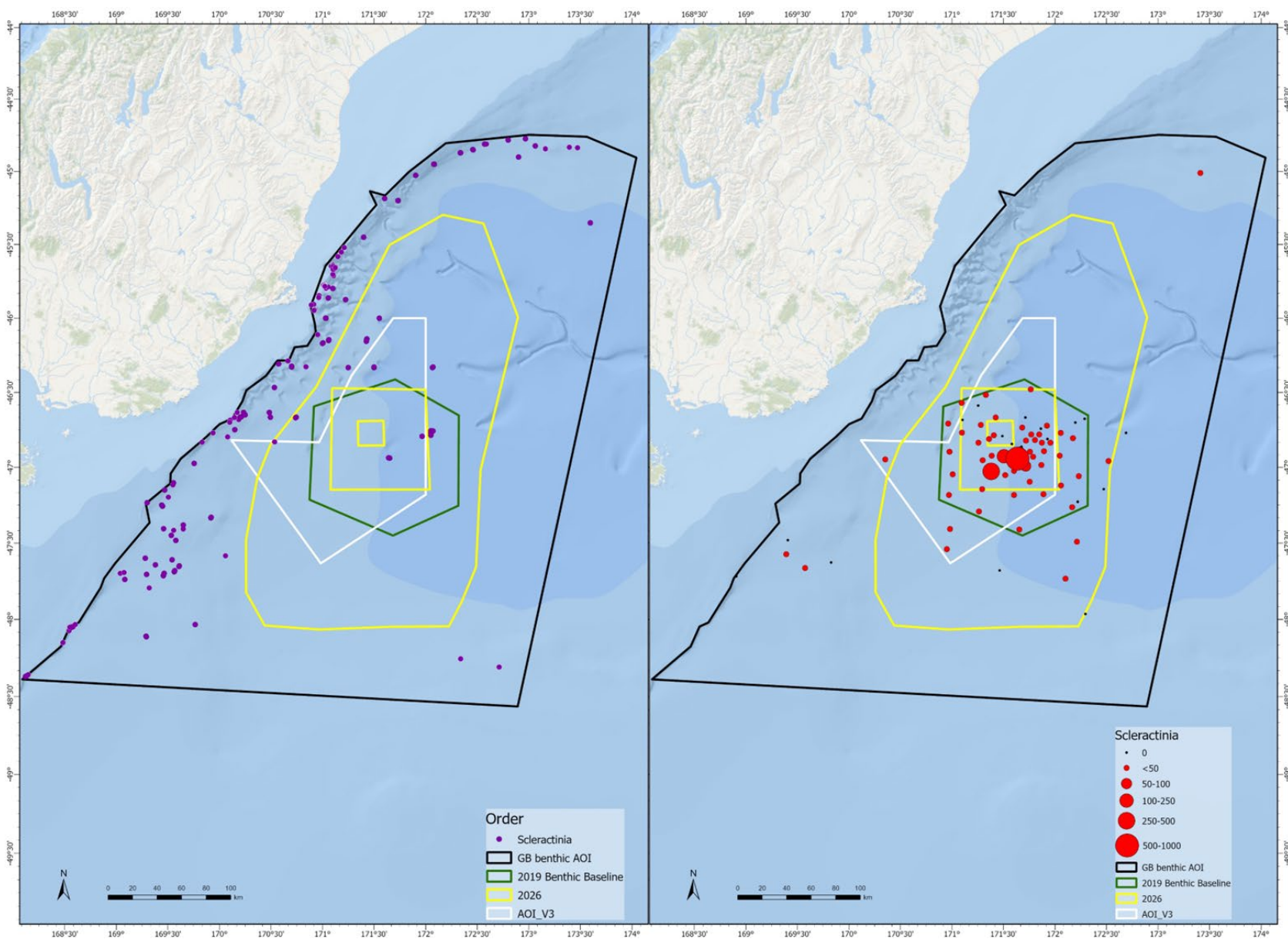


Figure 3-46: Spatial distribution of Scleractinia records within the benthic AOI. Includes branching stony corals and solitary cup corals. Left: species location records from SPECIFY, OBIS, and MPI observer data exports. Right: imagery (DTIS) abundance data (inds. 1,000 m⁻²).

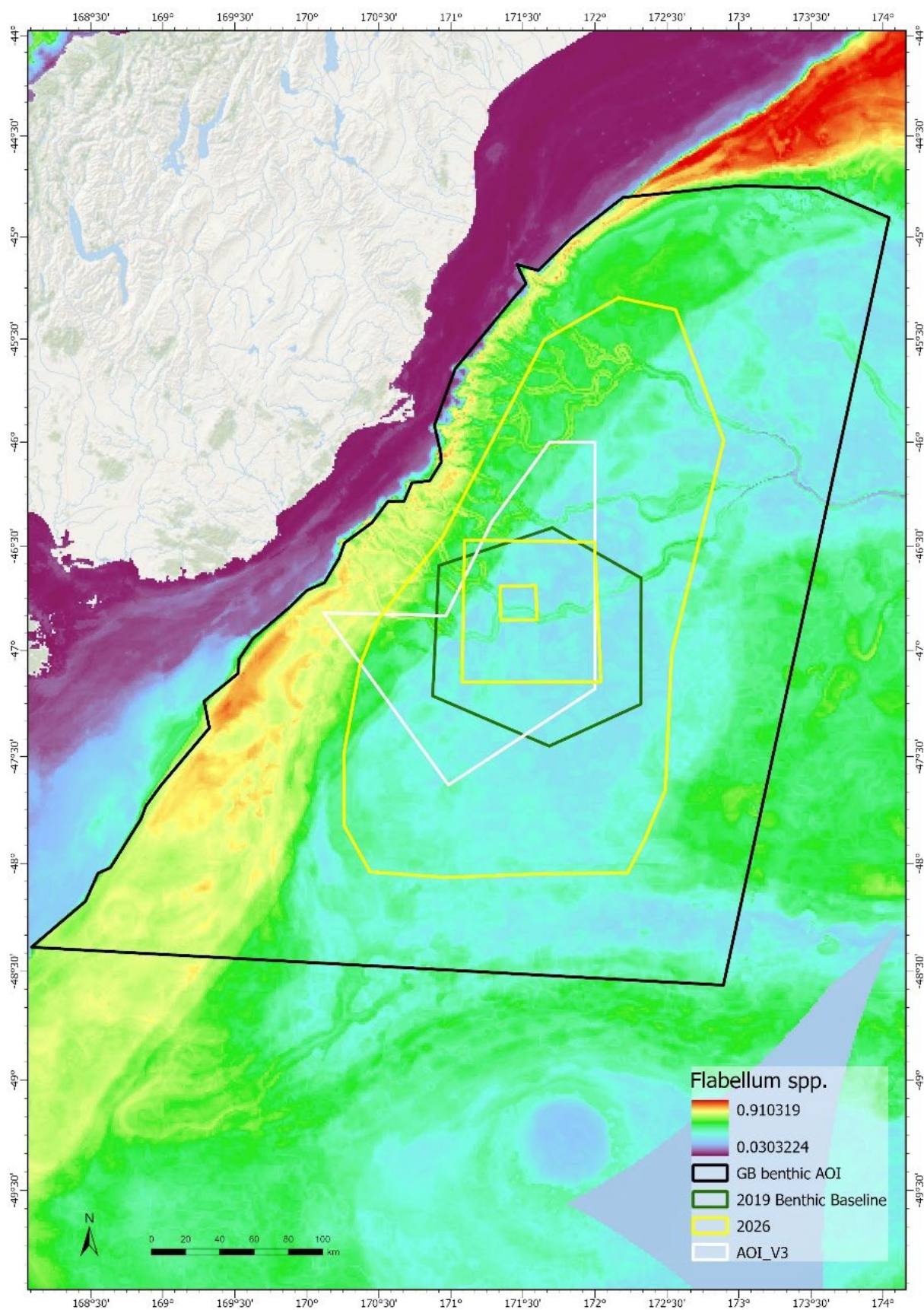


Figure 3-47: KEA species distribution modelling: scleractinian cup corals. *Flabellum* spp. Note that this modelling used all available presence data from physical captures, not abundance data focussed on the benthic AOI as in the current modelling study.

Stylasteridae

Stylasterid hydrocorals are associated with hard substrates and have a broad depth range. For example, the red hydrocoral (*Errina* spp.) has been recorded between 10 and 1,800 m and the spiny white hydrocoral (*Lepidothea* spp.) in depths ranging from 80 m to 2,010 m (Tracey et al. 2011).

Stylasteridae are present within the benthic AOI (Figure 3-48) with 77 specimen records. Video imagery showed Stylasteridae (hydrocorals) to be present at seamounts and channel sites. In addition, KEA species distribution modelling predicted relatively high probability of occurrence of *Errina* spp. and *Stylaster* spp. within the benthic AOI (Figure 3-49).

Species distribution modelling conducted in this study, using latest available data relevant to the project area, predicted the highest abundance of Stylasteridae to the north east of the benthic AOI (see Section 4 and Figure 4-2), on the shelf edge and associated with channel features.

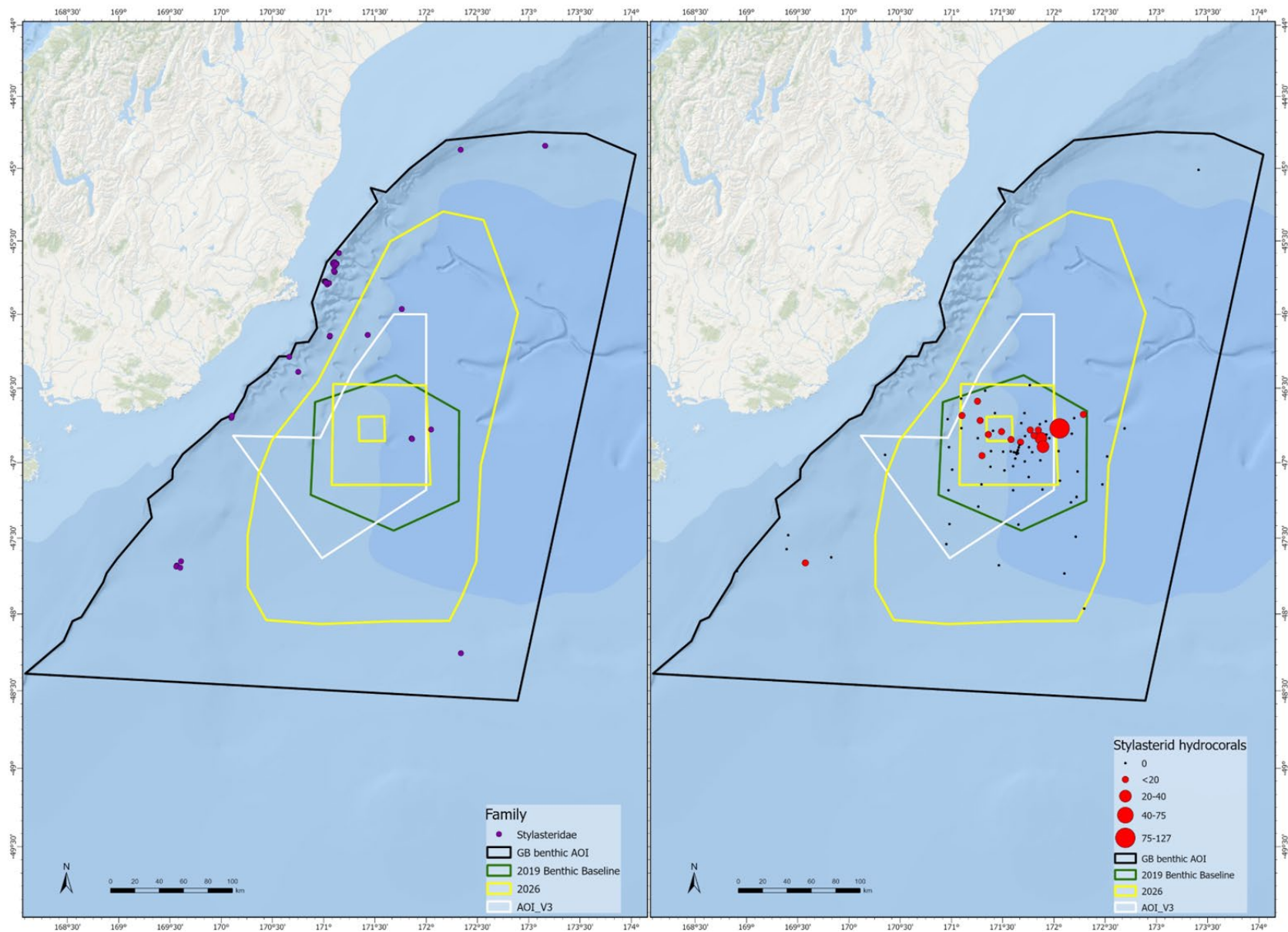


Figure 3-48: Spatial distribution of Stylasteridae (hydrocoral) records within the benthic AOI. Left: species location records from SPECIFY and MPI observer data exports. Right: imagery (DTIS) abundance data (inds. 1,000 m⁻²).

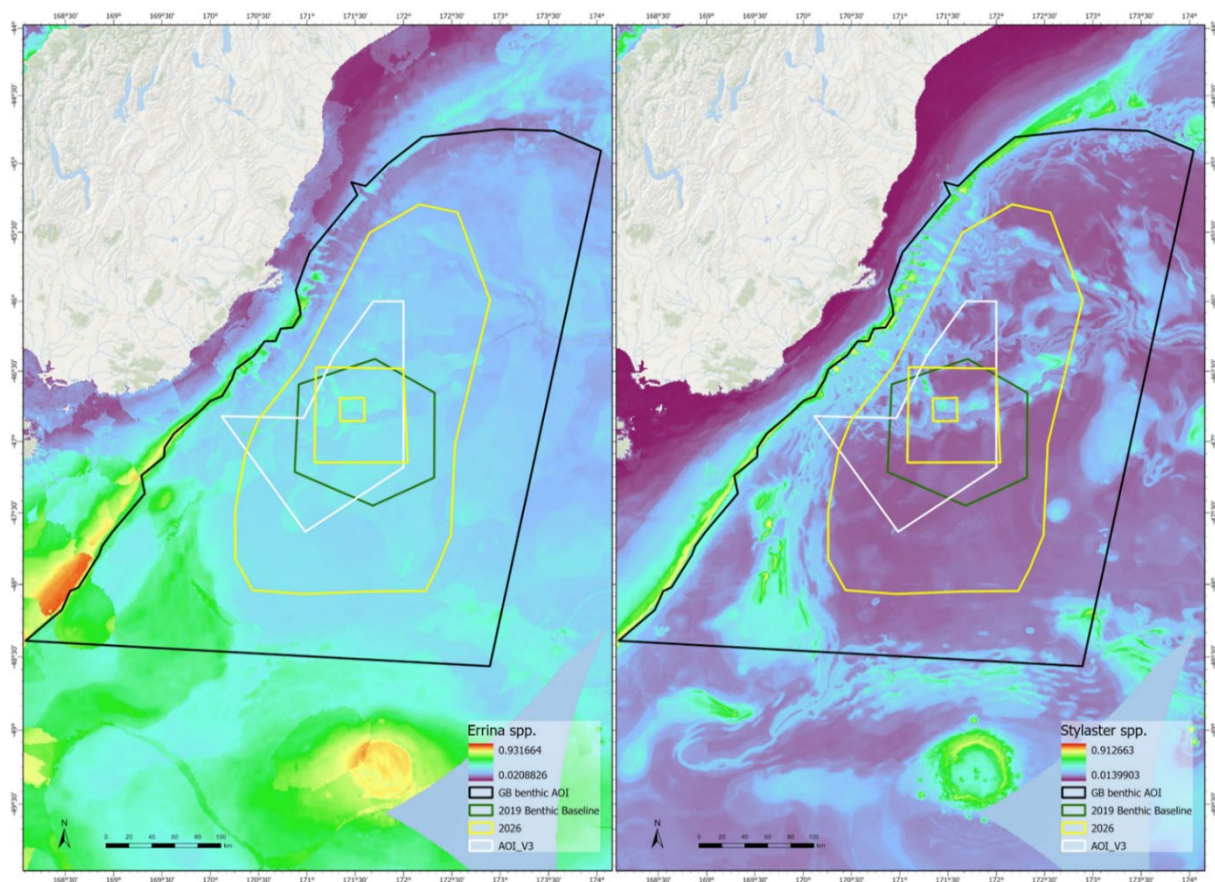


Figure 3-49: KEA species distribution modelling: Stylasteridae. *Errina* spp. and *Stylaster* spp. Note that this modelling used all available presence data from physical captures, not abundance data focussed on the benthic AOI as in the current modelling study.

Protected species summary

All four protected cnidarian groups (Antipatharia, gorgonians, Stylasteridae and Scleractinia) are present within the benthic AOI (Table 3-8).

As with sensitive environment taxa, many of the protected species were particularly associated with the shelf slope, channel and seamount habitats within the benthic AOI. However, note that scleractinian cup corals were present in high densities on the muddy sediments of the broad slope basin.

Table 3-8: Summary of protected cnidarian groups.

Protected species/group	Present within the benthic AOI?
Antipatharia	Yes
Gorgonacea	Yes
Stylasteridae	Yes
Scleractinia	Yes

3.7.3 Threatened and At Risk species

A report on the conservation status of New Zealand marine invertebrates (Funnell et al. 2023) lists a number of invertebrates identified as Data Deficient, Threatened (Nationally Critical, Nationally Endangered, Nationally Vulnerable), and At Risk (Declining, Naturally Uncommon).

None of the taxa/species present within the benthic AOI were listed as Threatened. However, 43 species/taxa were listed as At Risk – Naturally Uncommon (Table 3-9), and 11 species/taxa present are listed as At Risk – Declining (Table 3-10).

In addition, the following genera listed within the AOI include species listed as At Risk – Naturally Uncommon: Molluscs (Snails): *Alvania* spp., *Argalista* sp., *Besla* sp., *Brookula* sp., *Caecum* sp., *Merelina* sp.; Mollusca (Chitons): *Chiton* spp.; Arthropoda (Shrimps): *Lebbeus* sp., *Makrokyllindrus* sp.; Cnidaria (sea fans): *Calyptophora* spp. The genus *Octopus* spp. was present within the AOI and includes species listed as At Risk – Declining, and the following Genera include species listed as Data Deficient: Crustacea (shrimps/amphipods): *Aplatysympus* sp., *Diastylis* spp., *Platytyphlops* sp., *Syrrhoe* sp.; Sponges: *Farrea* spp., *Janulum* sp.; Holothurians: *Psolus* sp.; Corals (sea fans): *Calyptophora* spp.

Table 3-9: At Risk - Naturally Uncommon. Species classified as At Risk – Naturally Uncommon known to be present within the benthic AOI.

Taxon	Common name	Taxon	Common name
<i>Acanella</i> spp.	bubblegum coral	<i>Kaiparapelta</i> sp.	limpet
<i>Aforia watsoni</i>	sea snail	<i>Lithodes robertsoni</i>	king crab
<i>Bathycuma dayae</i>	comma shrimp	<i>Mysella</i> sp.	clam
<i>Belomitra</i> sp.	whelk	<i>Paralomis zealandica</i>	king crab
<i>Byblisoides richardi</i>	marine amphipod/sand hopper	<i>Pectunculina</i> sp.	clam
<i>Carinastele jugosa</i>	top shell	<i>Perrierina</i> sp.	clam
<i>Carinastele kristelleae</i>	top shell	<i>Pleuromeris</i> sp.	clam
<i>Chathamisis</i> spp.	bamboo coral	<i>Pteria</i> sp.	mussel
<i>Conchocele</i> sp.	clam	<i>Puncturella</i> sp.	limpet
<i>Condylocuna</i> spp.	clam	<i>Selastele kopua</i>	top shell
<i>Cyamiomactra</i> spp.	clam	<i>Serrata</i> sp.	sea snail
<i>Cyclaspis hayae</i>	comma shrimp	<i>Solariella</i> sp. A, B, C	top shell
<i>Cyclopecten fluctuosus</i>	scallop	<i>Thysanodonta</i> sp.	top shell
<i>Danilia</i> sp.	top shell	<i>Tugali</i> sp.	limpet
<i>Diastylopsis asparatilis</i>	comma shrimp	<i>Turbinellidae</i> sp.	whelk
<i>Diastylopsis bicarina</i>	comma shrimp	<i>Uroptychus bathamae</i>	squat lobster
<i>Errina bicolor</i>	red hydrocoral	<i>Uroptychus raymondi</i>	squat lobster
<i>Errina cheilopora</i>	red hydrocoral	<i>Uroptychus tracey</i>	squat lobster
<i>Gonaxia</i> sp.	hydroid	<i>Lissodendoryx</i> sp.	yellow slimey sponge
<i>Gonaxia australis</i>	hydroid	<i>Fissurellidae</i> sp. 1	limpet
<i>Hamacuna</i> spp.	clam	<i>Peltospiridae</i> sp. A, B, C	vent limpet
<i>Hunkydora rakiura</i>	clam		

Table 3-10: At Risk - Declining. Species classified as At Risk – Declining known to be present within the benthic AOI.

Taxon	Common name
<i>Chathamisis bayeri</i>	bamboo coral
<i>Chonelasma lamella</i>	glass sponge
<i>Enallopsammia pusilla</i>	stony branching coral
<i>Enallopsammia rostrata</i>	stony branching coral
<i>Goniocorella dumosa</i>	stony branching coral
<i>Gorgonocephalus dolichodactylus</i>	basket starfish
<i>Isidella</i> spp.	stony coral
<i>Keratoisis</i> spp.	bamboo coral
<i>Madrepora oculata</i>	coral
<i>Paragorgia arborea</i>	bubblegum coral
<i>Solenosmilia variabilis</i>	stony branching coral

3.7.4 Vulnerable marine ecosystems

Although not formally recognized in domestic regulations vulnerable marine ecosystems (VMEs) are an important consideration when assessing impacts from human activities, as is done by regional fisheries management organisations (RFMOs) that regulate fishing activities on the high seas.

VMEs are any deep-sea environments that are highly vulnerable to one or more kinds of fishing activity. Criteria for identifying VMEs include uniqueness or rarity of species or habitats, their functional significance, fragility, and structural complexity as well as life histories that limit the probability of recovery from disturbance (Rowden et al. 2013). Eight taxa have been identified as indicators of VMEs for the south Pacific Ocean based on a number of ecological criteria (Parker et al. 2009). These are: Actiniaria (anemones); Alcyonacea (soft corals); Antipatharia (black corals); Brisingida (a form of deep-sea sea star); Crinoidea (feather star/sea lily); Gorgonacea (sea fans/sea whips); Pennatulacea (sea pens); Porifera (sponges); Scleractinia (stony corals), and Stylasteridae (hydrocorals). All of these taxa are present within the benthic AOI.

3.8 Occurrence of organisms known or likely to be particularly vulnerable to variability in oxygen or particulate smothering

Ingels (2025) reviewed available literature on the vulnerability of deep-sea organisms to variability in DO concentrations and particulate smothering. The following taxa were deemed to be vulnerable to variability in DO: deep-sea corals, bryozoans, harpacticoid copepods, infaunal gastropods and crustaceans. In addition, while brachiopods and infaunal bivalves were considered to be tolerant of short-term changes in oxygen concentration they are sensitive to extended periods of oxygen reduction. Polychaetes and xenophyophores were deemed to have moderate sensitivity to changes in oxygen concentration.

Brachiopods, deep-sea corals, sponges, bryozoans, xenophyophores and infaunal harpacticoid copepods, bivalves, gastropods, and crustaceans were all considered to be vulnerable to particulate smothering ((Ingels 2025) and polychaete worms and nematodes were considered moderately vulnerable,

All of these taxa are present within the benthic AOI. The known distribution of deep-sea corals, bryozoans, xenophyophores, sponges and brachiopods have been described in section 3.6 above, as have the known distribution of Chaetopteridae, a type of polychaete, and large habitat-forming bivalves. Distributions of corals, bryozoans, xenophyophores, brachiopods are particularly associated with seamount and channel features. Bryozoans and xenophyophores are also found in high abundances on the shelf/shelf slope and muddy sediments of the broad slope basin, respectively.

Macro-infaunal bivalves, gastropods, polychaetes, nematodes and crustacean (copepods, amphipods, and isopods) were all present within multicore data collected from muddy sediments in the 2019 baseline survey. The occurrence of these taxa, together with specimen records where available, are shown in Figure 3-50 and Figure 3-51. Note that the specimen records data may include both infaunal and epifaunal species of these taxonomic groups.

Polychaetes, nematodes, bivalves, amphipods, isopods and copepods all had widespread distributions throughout the 2019 baseline survey, with specimen records also present mostly on the shelf slope but with some scattered records elsewhere within the benthic AOI (Figure 3-50). Gastropods had a similar distribution of specimen records, but with less widespread distribution within the 2019 baseline survey multicore data.

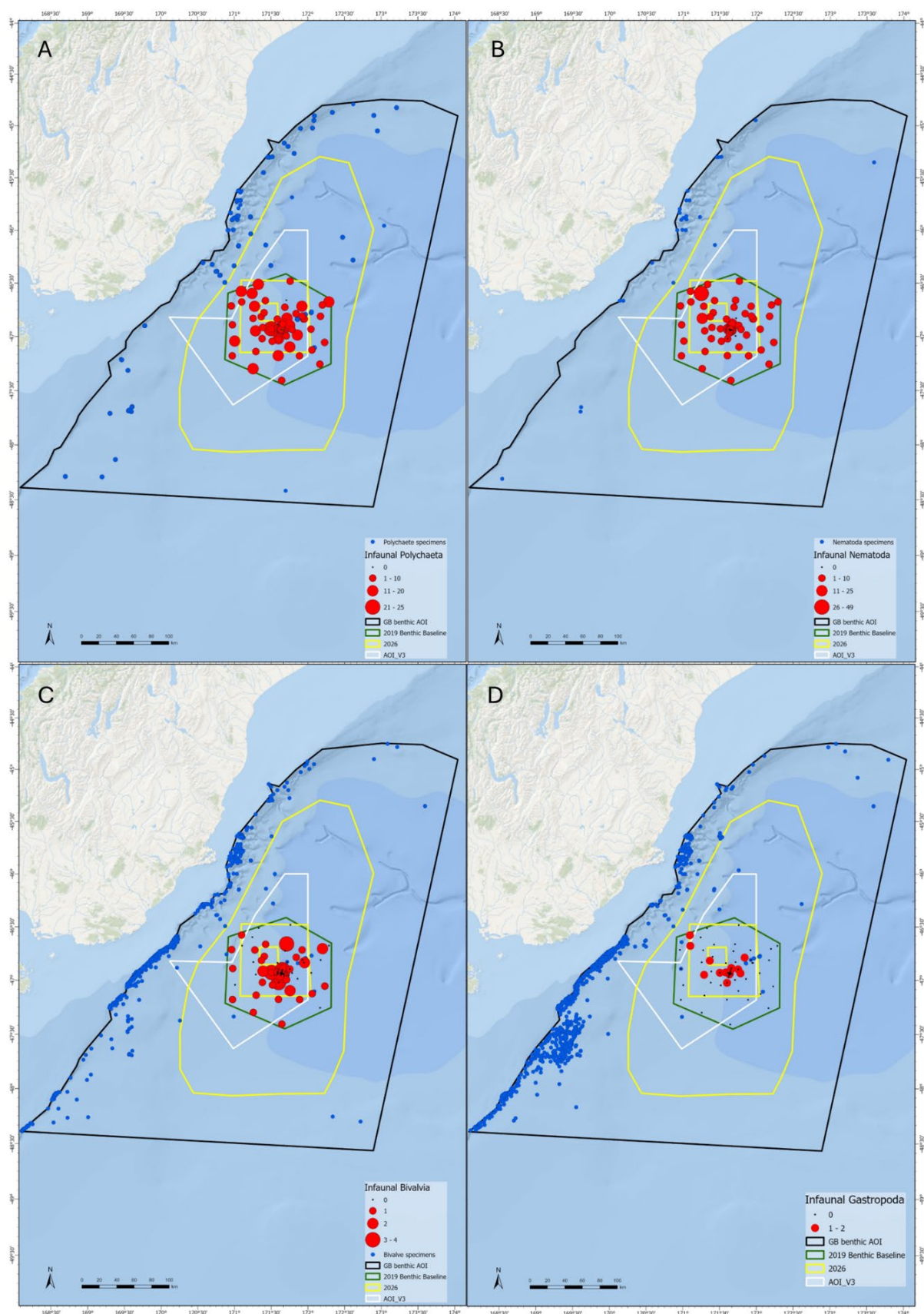


Figure 3-50: Macroinfaunal abundance of vulnerable taxa recorded within the benthic AOI.A)

Polychaetes, B) Nematodes, C) Bivalves, D) Gastropods. Red dots: infaunal data from multicore samples. Abundance per 0-5 cm core sample. Blue dots: specimen data (SPECIFY, Te papa, Auckland Museum, MPI observer, and OBIS data),

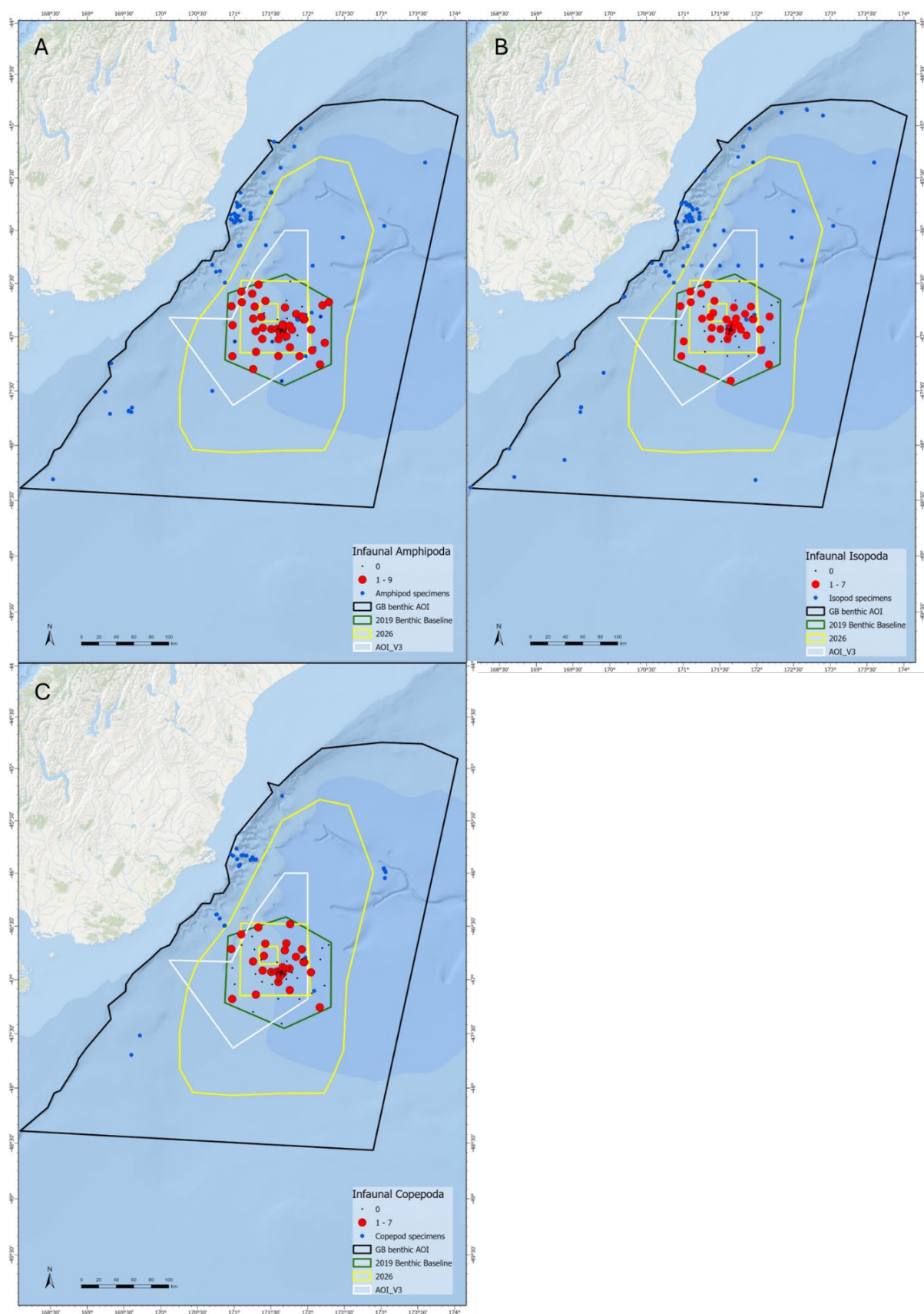


Figure 3-51: Macroinfaunal abundance of vulnerable taxa recorded within the benthic AOI. A) Amphipods, B) Isoipods, and C) Copepods. Red dots: infaunal data from multicore samples. Abundance per 0-5 cm core sample. Blue dots: specimen data (SPECIFY, Te papa, Auckland Museum, MPI observer, and OBIS data).

3.9 Review of seasonality (or lack thereof) and any long-term trends, where available

Seasonality in shallow marine environments is well documented but the link between seasonality and the deep sea is less clear, with the deep sea generally considered to be a stable environment (e.g., Billett et al. 1983) with temperature, light and salinity remaining relatively constant throughout the seasons.

However, the deep sea receives seasonal pulses of organic matter from surface waters which can result in an increase in benthic activity and changes in benthic communities (e.g., Wigham et al. 2003; Ruhl and Smith 2004, and see Ingels 2025). There are no seasonal data available from within the benthic AOI, with repeat surveys always having been conducted within the same season. During the March 2019 baseline survey, high densities of salp faecal pellets were observed in seafloor imagery and terebellid worms (polychaetes) were observed gathering these salp pellets (see Figure 3-52). Note that high densities of salp pellets were not observed in the February 2022 or March 2023 surveys and it is not known how often depositions of organic matter such as this occur. Salp faecal pellets, derived from surface plankton blooms, have also been observed in the gut contents of deep-sea holothurians in the northeast Atlantic Ocean (PfannkucheLochte 1993). At least some deep-sea species have also been shown to have seasonal reproduction linked to food availability (e.g., Tyler et al. 1982; Waller et al. 2023).

Temporal changes in abundance of benthic fauna were observed during repeat surveys for OMV New Zealand Ltd. within the benthic AOI, as recorded from video imagery. For example, there was a clear overall increase in ophiuroid abundance at most survey sites between March 2019 and February 2022 (Figure 3-53). However, seasonal changes in the abundance/diversity of most sessile fauna (e.g., most of the sensitive environment species and protected taxa) are considered unlikely due to their inability to move (or move fast) and likely slow growth rates.



Figure 3-52: Terebellid worm with gathered salp faecal pellets in its tentacles. DTIS image captured within the benthic AOI during the 2019 baseline survey. Salp faecal pellets are the brown rectangular objects. Red line is 20 cm long.

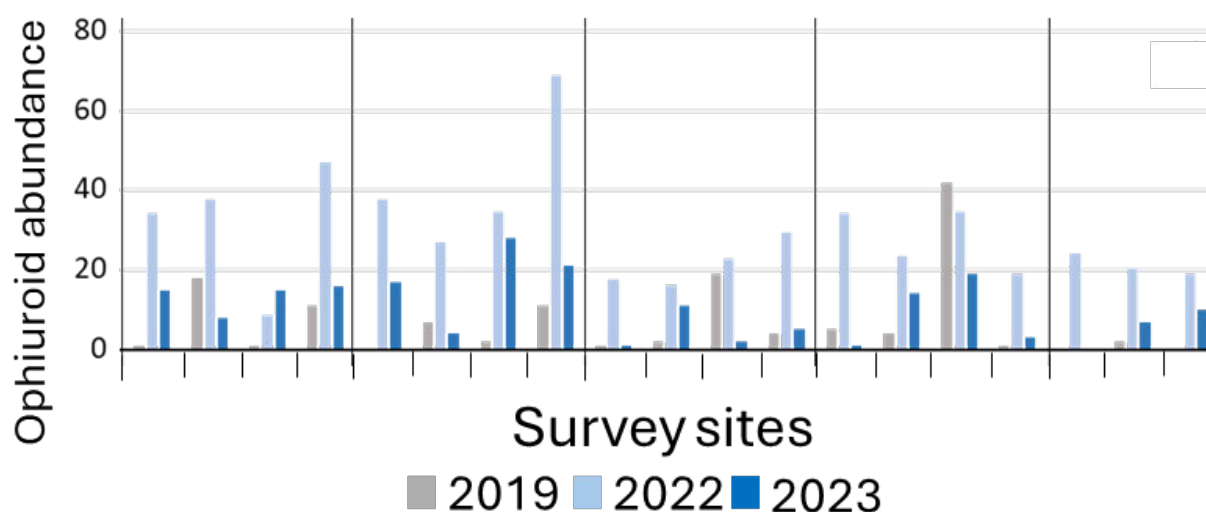


Figure 3-53: Temporal variation of ophiuroids in repeat surveys in the benthic AOI. Data collected for OMV New Zealand Ltd in March 2019 (grey), February 2022 (light blue) and March 2023 (dark blue), within the benthic AOI. Data from 19 undisturbed sites.

3.10 Identify any proxy data that might support assumptions in the absence of some data types

There were no available proxy data for making assumptions about benthic communities within the benthic AOI. The exception could be the environmental layers used in the species distribution modelling to predict abundances of key faunal groups (see Section 4, predictive benthic suitability modelling). Substrate type is a key predictor of habitat suitability for some taxa, especially those having strong associations with underwater topographical features such as channels, seamounts, ridges, etc. The spatial extent of all seamounts, hills, and knolls in the region is available as GIS shapefiles (Clark et al. 2022), which may provide a useful supplement to species distribution predictions. These topographic data were used to inform the species distribution modelling presented within this report.

3.11 Identify any local data gaps directly relevant to Gigablue’s AOI

As is evident from the spatial distribution plots in Sections 3.1 and 3.2, there are large areas within the benthic AOI for which there are no empirical faunal data (either imagery or specimen data) and/or no detailed multibeam bathymetry data. Benthic species distribution modelling goes some way to overcome some of these gaps, however, ground truthing of modelled predictions are needed to reduce uncertainty.

Beyond the localities of seamounts, hills, knolls, and channel systems in the benthic AOI, there is limited information on the specific nature of the sediment – whether it be exposed bedrock, mud, gravel, sand, or various combinations of these. Many taxa show strong affinities to particular substrate types and predictive models would be more accurate for these species if accurate, high-resolution spatial layers of substrate type were available. Existing spatial layers are based on interpolation of fairly sparse and unevenly distributed sample sites, and could be substantially improved if more data were available from as yet unsampled areas.

In addition, while knowledge of deep-sea benthic communities increases year on year, there remains an overall lack of knowledge of the life histories of many deep-sea fauna.

4 Task 5: Predictive benthic species distribution modelling

Species distribution models are statistical modelling tools increasingly being used to predict the environmental niches and distributions of species, and their abundance in cases where the amount of observational data available is insufficient on its own for this purpose. While there have been a range of different model types developed or adapted for this purpose, for most the statistical approach applied involves relating field observations of faunal presence or abundance and observed or inferred faunal absence to spatial representations of environmental predictor variables, yielding spatial predictions of taxon distributions and the underlying environmental drivers of their preferred habitat. Species distribution models are especially useful for characterizing benthic fauna in the deep sea, where it is particularly difficult to collect large amounts of observational data (Vierod et al. 2014).

For the modelling undertaken for benthic fauna in this case, we applied the widely used Random Forests (Breiman 2001) modelling approach, based on faunal abundance data collected during a range of historic seabed imaging surveys in the broader region surrounding the benthic AOI to predict the environmental niches and distributions of key taxa (sensitive species, protected species, vulnerable marine ecosystem indicator taxa) that may potentially be affected by the particle deployments.

4.1 Model extent and resolution

To provide sufficient sample data points to effectively train the models, faunal presence data from the imaging surveys were assembled alongside environmental predictor variables for a region of southeast Aotearoa New Zealand extending well beyond the benthic AOI. This comprised an area of about 2.4 million km², extending from the subantarctic plateaus in the south to the Chatham Rise in the north (approximately 166° E–174° W and 42–52° S, Figure 4-1). Model predictions were limited to the benthic AOI, however, a total area of about 130,500 km². The spatial resolution of the model outputs was set at 1 x 1 km, this being limited by the resolution of the environmental parameters and the need to match this to the typical length of a video sample transect (~ 1 km).

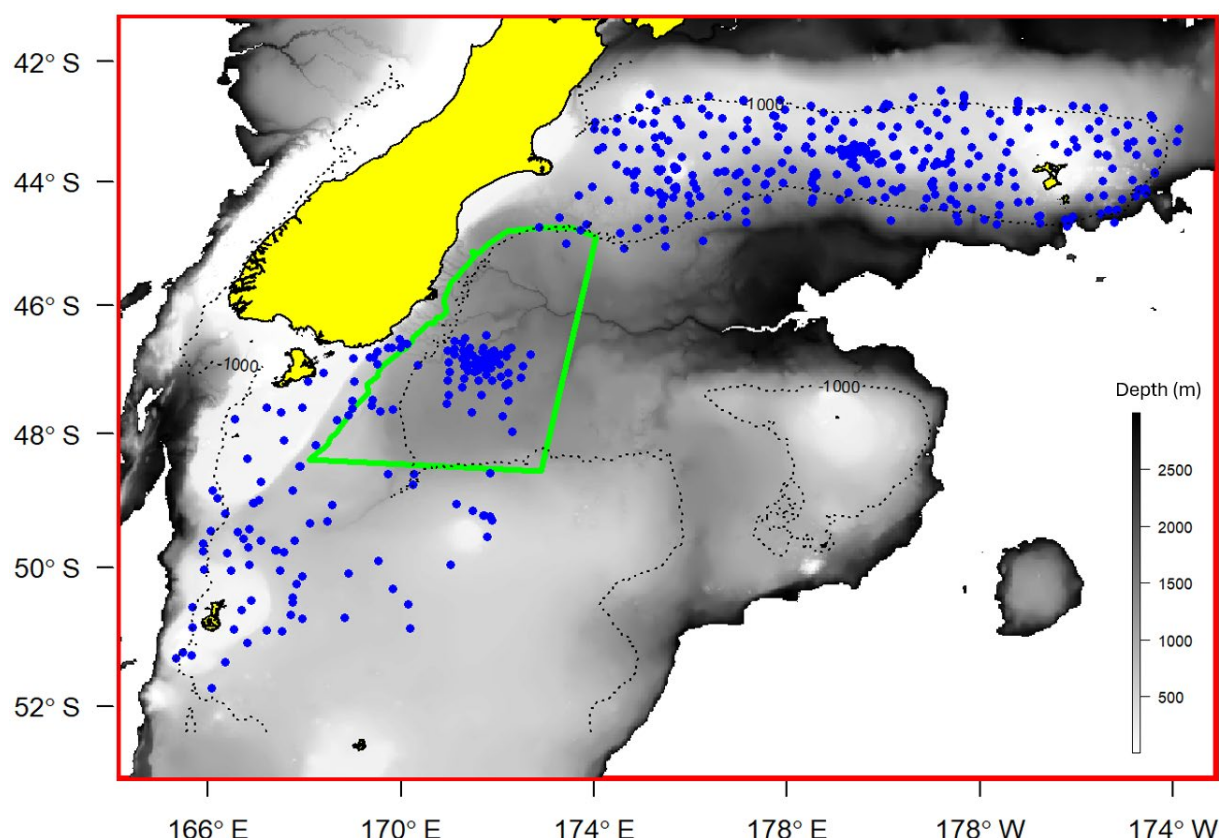


Figure 4-1: Study area showing the location of video transect sites used to train species distribution models. Overlaid on bathymetry to a maximum depth of 3,000 m (grey). Blue dots are video transect sites. The green polygon indicates the benthic AOI; the dashed lines indicate the 1,000 m contour.

4.2 Environmental data

An initial set of environmental predictor variables was assembled from various sources, as used for consideration in several recent modelling studies for benthic invertebrates in the Aotearoa New Zealand region (e.g., Georgian et al. 2019; Anderson et al. 2023). These predictor variables were gridded at a 1 x 1 km resolution and represent a combination of sea floor characteristics, water chemistry, and productivity.

Using predictor variables which are highly correlated with each other can adversely affect model performance and interpretation (Huang et al. 2011). Therefore, the initial set of 27 variables was reduced to a core set, excluding those most highly correlated with the remainder by calculating the variance inflation factor (VIF) for all variables using the R library HH (Heiberger 2011) and following the method described by Yesson et al. (2017). Firstly, values for each variable were determined for each of the 2.4 million cells of the model extent, and VIFs calculated. The variable with the highest VIF was then discarded and the process repeated with the remaining variables, continuing iteratively until all variables showed a VIF of less than five, reflecting a low level of co-linearity (Heiberger and Holland 2004).

4.3 Faunal data

Seabed video transects have been carried out around the wider Aotearoa New Zealand region by Earth Science NZ using DTIS to record data on benthic invertebrates since 2006. Standard DTIS transects are about 60 minutes in duration at a speed of 0.25–0.5 m s⁻¹, resulting in average transect lengths of 1,000–1,400 m. The altitude of the camera is typically 2–3 m above the seabed and two equidistant laser points (20 cm apart) allow estimation of size and area estimates (Hill 2009; Bowden and Jones 2016).

Low resolution sea floor video imagery sent to the ship from DTIS is logged in real time using the software OFOP. then later analysed in much finer detail post-voyage by examining high-definition files to provide accurate counts and taxonomic identification. A detailed methodology for these procedures is described in Bowden and Hewitt (2012) and Jones et al. (2018).

Using a database of benthic fauna observations collected by DTIS, we interrogated the distribution of transect stations deployed from Earth Science NZ's RV *Tangaroa* throughout the broader region surrounding the benthic AOI between 2006 and 2020. As well as transect sites within the benthic AOI there have been numerous DTIS surveys carried out in this quadrant of the Aotearoa New Zealand marine realm, including the Chatham Rise to the north and the Campbell Plateau and Stewart-Snares shelf in the south. In defining the region from which to select model input data, a balance was sought whereby a sufficiently large data set would be available to train the models most accurately, while limiting the sample sites to those near the AOI. This is important because, for modelled taxa comprising multiple species (e.g., sponges, bryozoans) with differing geographical ranges and environmental tolerances, the composition of each taxon is likely to alter in relation to the distance from the AOI, potentially affecting predictions. The area selected resulted in a total of 530 sample sites available to train the models. The boundaries of the area from which sample sites were selected, including the location of those sites, are shown in Figure 4-1.

Data were assembled for eight taxa (Table 4-1). These taxa were chosen as they are in any or all of the following three categories: 1) sensitive habitat fauna (as defined by MacDiarmid et al. (2013) and Schedule 6 ; 2) VME indicator taxa (as recognized by international authorities such as the United Nations Food and Agriculture Organization and the South Pacific Regional Fisheries Management Organisation (FAO 2009; SPRFMO 2023)); and 3) protected coral taxa under the Wildlife Act (1953). A few notable taxa in these categories (e.g., black corals) were not selected due to very few numbers of records in the sample data within the AOI.

Table 4-1: Taxa selected for species distribution modelling. Common and scientific names, the number of records available for the models, and status under Aotearoa New Zealand and international legislation.

Common name	Taxonomic name	Number of records (presence/absence)	Sensitive habitat	VME indicator	Protected coral
Stylasterid corals	Stylasteridae	124/406		Y	Y
Bryozoans	Bryozoa	338/192	Y	Y	
Cup corals	Scleractinia (solitary)	315/215			Y
Gorgonian corals	Gorgonian Alcyonacea	217/313		Y	Y
Sponges	Porifera	493/37	Y	Y	
Sea pens	Pennatulioidea	220/310	Y	Y	
Reef-forming stony corals	Scleractinia (colonial)	92/438	Y	Y	Y
Xenophyophores	Xenophyophorea	152/378	Y		

4.4 Model details

Random Forests are a classification tree-based method which iteratively splits input data by choosing an explanatory variable and value which explains the greatest amount of the residual variability in the data. At each split a random selection of the set of explanatory variables is provided to the model, then an internal bootstrapping approach is used to produce and combine many individual trees.

Models were built using the ‘randomForest’ package (Liaw and Wiener 2002) in R. Model tuning to set the optimum number of trees (*ntrees*) and explanatory variables selected at each step (*mtry*) was explored in initial models but this did not substantially improve on default settings. Therefore, all models were run with *ntrees* set at 501 and *mtry* set to $\sqrt{p}$ or $p/3$ (depending on model type, see below, and where p is the number of explanatory variables). To limit model complexity and overfitting, variable importance was ranked by first building models fitted with the predictors determined from VIF analyses and trial models, then refitted using only the six most influential predictors.

To deal with the taxon count data typical of photographic transect surveys, characterised by strongly over-dispersed and skewed distributions with an excess of zeros, we employed two-part ‘hurdle’ models (Cragg 1971), which have been shown to work well in these situations (Potts and Elith 2006; Dedman et al. 2015; Bennion et al. 2024). A hurdle model consists of two component models, a *binomial* model predicting probability of presence using the entire data set, and a *regression* model predicting abundance using only data from presence locations; the outputs of the two parts are multiplied to produce final abundance predictions.

Model performance was assessed using standard measures provided in the RF output. For the binary models this is the out-of-bag (oob) error rate, which is the percentage of instances where the model predicts presence in a test subsample when the actual observation is an absence, or vice versa – based on the internal bootstrap resampling to create the trees. For each model the area under the receiver operating characteristic curve (AUC) metric – a measure of the ability of the model to correctly rank occurrences above absences – was also calculated. A model with no explanatory power will have an AUC of 0.5, while AUC values greater than 0.7 indicate fair performance, and values greater than 0.8 indicate excellent performance (Hosmer Jr et al.

2013). For the regression models, model performance was measured as the percentage of variance explained – a measure of how well oob predictions explain the target variance of the training set.

To assess the relative confidence in predictions across the model extent, a bootstrap technique was used to produce spatially explicit uncertainty measures, after Anderson et al. (2016) and Georgian et al. (2019). This was done by drawing random samples of the input data, with replacement, and using these to construct multiple sets of binary and regression models using the same settings and predictors as the original models. Hurdle models were derived from each pair of models thus created, providing predictions of abundance in each cell of the model extent. This process was carried out for 200 samples, resulting in 200 separate estimates of abundance for each taxon in each cell. Spatial, cell-specific, measures of model uncertainty were then calculated as the coefficient of variation (CV) of the values in each cell.

4.5 Results

4.5.1 Selection of predictor variables

Initial assessment of the 27 available predictor variables using VIF resulted in a core set of 13 predictors with low correlation (Table 4-2), a combination of seafloor characteristics including bathymetry derived terrain variables, substrate types, water chemistry, and productivity variables.

Although three of the predictors are based on productivity models, there are fundamental differences between the Vertically Generalized Production Model (VGPM: chlorophyll-based) and Carbon-Based Productivity Model (CBPM: phytoplankton carbon-based) models that result in substantially different (and only weakly correlated) values (Westberry et al. 2008); and their means and standard deviation can have distinct biological relevance depending on individual species energetic requirements. Similarly, the five terrain shape variables selected each reflect unique types of seafloor heterogeneity which will have specific effects on species distribution among the taxa modelled.

Table 4-2: Environmental variables used for species distribution modelling, reduced from a larger set by eliminating those with greatest overall correlation. See text for more information.

Variable	Short name	Units	Reference
Seafloor Characteristics			
Percent mud	Mud	%	Bostock et al. (2018b, 2018a)
Percent gravel	Gravel	%	Bostock et al. (2018b, 2018a)
Slope	Slope	Degrees	Derived from bathymetry
Slope Standard Deviation	Slope-sd	Degrees	Derived from bathymetry
Vector Ruggedness Measure	VRM	-	Derived from bathymetry
Benthic Position Index (fine)	BPI-fine	-	Derived from bathymetry
Benthic Position Index (broad)	BPI-broad	-	Derived from bathymetry
Seamounts	Seamounts	Binomial	Clark et al. 2022
Water Chemistry			
Dissolved oxygen at depth	DO	ml l ⁻¹	(Garcia et al. 2013)
Salinity	Salinity	-	Zweng et al. (2013)
Productivity			
Eppeley-Vertically Generalised Production Model(mean)	EPGM-mean	mg C m ⁻² d ⁻¹	Oregon State University ¹
Carbon-Based Productivity Model (mean)	CBPM-mean	mg C m ⁻² d ⁻¹	Oregon State University ¹
Carbon-Based Productivity Model (Standard Deviation)	CBPM-sd	mg C m ⁻² d ⁻¹	Oregon State University ¹

¹ Data obtained from <http://www.science.oregonstate.edu/ocean.productivity>

4.5.2 Variable importance in the models

For the binomial model part of the abundance hurdle models, Dissolved Oxygen (DO) was the most informative predictor across the eight taxa. This predictor was the most informative for four of the taxa models and was only excluded from final models (not in the top six of most explanatory variables) for Bryozoa. Carbon-Based Productivity Model (Standard Deviation) (CBPM-sd) and benthic position index (broad) (BPI-broad) were also informative for seven of the eight taxa but were mostly second in importance to at least one other variable. Eppeley Vertically Generalized Production Model (mean) (EPGM-mean) was next most important, followed by Percent mud and BPI-fine. The remaining variables were selected for final models for fewer than half of the taxa modelled, although Vector Ruggedness Measure (VRM) was the most important for Stylasteridae and Slope Standard Deviation (Slope-sd) was the most important for gorgonians; CBPM-mean and Seamounts were not selected into any model (Table 4-3).

For the regression model part of the abundance hurdle models, CBPM-sd was the most informative predictor across the eight taxa, ranked first in 3 of the taxa models and only excluded in the model for sea pens. Five other variables were selected in five taxa models, but only slope (twice), salinity (twice), and DO (once) were the most informative predictor in a model. As for the binomial models, CBPM-mean and Seamounts were not selected into any of the regression models (Table 4-4).

Table 4-3: Binomial model variable selection. The numbers represent the rank of each variable in the RF model. Variables are ordered from top to bottom in the table, from most to least informative overall according to the mean of the numbers, assigning a value of 7 to unselected variables.

	Stylasterid corals	Bryozoans	Cup corals	Gorgonian corals	Sponges	Sea pens	Reef-forming stony corals	Xenophyophores
DO	6	–	1	4	6	1	1	1
CBPM-sd	–	1	2	6	4	5	2	4
BPI-broad	–	3	3	5	5	4	5	2
EPGM-mean	–	2	4	–	1	6	4	5
Percent mud	–	4	5	–	–	2	–	3
BPI-fine	4	6	–	–	3	–	3	6
VRM	1	–	–	2	–	–	6	–
Slope-sd	2	–	–	1	–	–	–	–
Gravel	–	–	6	–	2	3	–	–
Slope	3	–	–	3	–	–	–	–
Salinity	5	5	–	–	–	–	–	–
CBPM-mean	–	–	–	–	–	–	–	–
Seamounts	–	–	–	–	–	–	–	–

Table 4-4: Regression model variable selection. The numbers represent the rank of each variable in the RF model. Variables are ordered from top to bottom in the table, from most to least informative overall according to the mean of the numbers, assigning a value of 7 to unselected variables.

	Stylasterid corals	Bryozoans	Cup corals	Gorgonian corals	Sponges	Sea pens	Reef-forming stony corals	Xenophyophores
CBPM-sd	1	1	6	6	5	–	1	3
Slope	–	–	1	2	1	5	5	–
Salinity	2	5	–	5	–	1	–	1
DO	–	3	–	1	–	3	6	2
EPGM-mean	4	–	4	–	4	–	2	4
VRM	3	–	–	3	3	6	4	–
Slope-sd	–	–	3	4	2	4	–	–
BPI-fine	6	–	2	–	6	2	–	–
Percent mud	–	2	5	–	–	–	–	6
BPI-broad	5	4	–	–	–	–	–	5
Gravel	–	6	–	–	–	–	3	–
CBPM-mean	–	–	–	–	–	–	–	–
Seamounts	–	–	–	–	–	–	–	–

4.5.3 Model performance

Satisfactory models were not possible for all taxa, with model performance statistics showing a poor fit for the regression model for gorgonian corals. A negative value for explained variance in this case indicated model variance to be larger than total variance and therefore the model for gorgonians represented a poor fit to the data. Explained variance for the regression model for reef-forming stony corals was also low, but positive (Table 4-5). Although maps of predicted species abundance were produced for all taxa, those for these two taxa should be considered less reliable. Explained variance for the remaining models was considerably higher (21.5–62.6%). In the binomial models, oob errors were variable but in all cases indicated that correct predictions were far more frequent than incorrect predictions in the internal resampling, ranging from 7.4–30.8%. The AUC values for most models ranged from 0.51 to 0.83, indicating fair to excellent performance, although the AUC value of 0.51 for sponges indicates only slightly better than random assignment. The oob error rate was very low for this taxon, however, indicating good predictive power. Overall, performance statistics indicated acceptable binomial models.

Table 4-5: Performance metrics for the regression and binomial model components of the hurdle models for eight modelled taxa.

Taxon	Percent variance explained (regression model)	Out of bag error rate (binomial model)	AUC (binomial model)
Stylasterid corals	44.4	14.3	0.76
Bryozoans	62.6	31.1	0.65
Cup corals	23.0	30.8	0.68
Gorgonian corals	-2.5	26.6	0.72
Sponges	36.1	7.4	0.51
Sea pens	33.2	28.9	0.70
Reef-forming stony corals	1.0	11.7	0.73
Xenophyophores	21.5	12.8	0.83

4.5.4 Predicted distributions for modelled taxa

Stylasterid hydrocorals were predicted to show a distinct preference for the more complex relief around the channel systems emanating from the continental shelf in the northern half of the benthic AOI, especially towards its western border (Figure 4-2). The maximum abundance predicted for this group was 1,309 inds. 1,000 m⁻², but away from the channel areas abundance was mostly very low – well under 100 inds. 1,000 m⁻² – with the presence locations restricted to the southern channel system. Model precision (low CVs) was also greatest around the channel systems, and variable, but mostly higher, across the remaining areas of the benthic AOI. The KEA models produced separately for two stylasterid genera also indicate higher habitat suitability around the channel systems, but also indicate concentrations of these species along the western boundary of the benthic AOI as well as in shallower areas outside of it (Figure 3-49).

Abundance of bryozoans was also higher in the northern parts of the benthic AOI, especially offshore of Otago Peninsula where several hotspots of high abundance were predicted to occur (Figure 4-3). The maximum abundance predicted for bryozoans was 1,413 inds. 1,000 m⁻², but abundance was predicted to be relatively very low across much of the southern region of the benthic AOI – including the locations where much of the DTIS sample data was collected from. Model precision varied across the AOI but was generally highest in areas where abundance was also high. The KEA models produced separately for three genera of bryozoans showed generally very low habitat suitability for this taxon within the benthic AOI and higher suitability in shallower areas outside the area (Figure 3-30). Unlike the abundance models produced here, the KEA models likely lacked bryozoan presence data from within the benthic AOI to train the models.

Abundance of cup corals was predicted to be highest in the central part of the benthic AOI, in the vicinity of where numerous specimens were observed in the 2019 (TAN1902) baseline survey (Figure 4-4). It was within this area that the highest abundance of 479 inds. 1,000 m⁻² was predicted. A few areas to the south and east of this area also showed high abundance but for much of the remaining region abundances were below 50 inds. 1,000 m⁻². Precision was highly variable across the benthic AOI but was relatively high in areas of high abundance and in the north of the region and low across large areas of the southern AOI. The KEA models produced for

Flabellum spp. only cannot be easily compared with the abundance model for all cup coral species combined, the former showing the highest habitat suitability along the western fringes of the benthic AOI (Figure 3-47).

High predicted abundance of gorgonian corals was strongly correlated with the channel systems in the north of the benthic AOI but, in contrast to stylasterid hydrocorals, gorgonian abundance in the channels was greater further from the shelf, in deeper water (Figure 4-5). The highest abundance predicted for gorgonians was 431 inds. 1,000 m⁻². Gorgonians were absent at many of the sample sites used in the model, but there were a few relatively large observations in the vicinity of the southern channel area. Model precision was not so directly correlated with abundance for this taxon, with highest precision in western channel areas, away from regions of highest abundance where estimated precision was only moderate. The lowest precision was seen in large areas in the southeast. The KEA models produced separately for two genera of gorgonians show some agreement with the abundance models for all species, in that they indicate relatively high habitat suitability within the benthic AOI, but do not show the same focus on the channel systems (Figure 3-45).

The spatial pattern of predicted abundance for sponges was similar to that of gorgonian corals, with a strong association between high abundance and the channel systems in the centre and north of the benthic AOI (Figure 4-6). Sponges, however, were predicted to have high density throughout a larger spatial and depth range than gorgonians, with areas of high abundance extending further to the west. The highest abundance predicted for sponges was 545 inds. 1,000 m⁻². Several observations of high sponge abundance were made in the major southern channel, with sponges recorded as absent from only a very few sample sites. Precision was low through most of the channel areas where predicted abundance was high and also around some of the broader areas in the south and on the western edge of the benthic AOI in the north where abundance was moderate; lowest precision was in the southwest and the far north of the benthic AOI.

Predicted abundance of sea pens was greatest in the north of the benthic AOI, with a moderate association with the channels systems evident, and a few hotspots of particularly high values evident (Figure 4-7). The highest abundance predicted for sea pens was 204 inds. 1,000 m⁻². A few unusual roughly circular areas of moderate abundance in the centre and south of the benthic AOI are most likely related to the influence of the variable 'mud' in the model. This predictor had a strong influence in the regression model (selected second) compared with models for other taxa, and the spatial patterns of mud are based on considerable interpolation between sparse sediment sampling points – leading to spatial artefacts such as these. The same artefacts are evident in the maps of model precision around predicted sea pen abundance, but away from these precision was lowest in central and western areas, not strongly positively associated with abundance, and otherwise quite patchy elsewhere. The KEA models produced for *Anthoptilum* spp. predicted a distribution comparable with the abundance models for all species, with high habitat suitability also predicted in the north and channel systems of the benthic AOI (Figure 3-33).

High abundance of reef-forming scleractinian corals was predicted to be limited to the deeper northeastern parts of the channel system, with moderate abundance also mostly restricted to the northern sector of the benthic AOI (Figure 4-8). Abundance was uniformly low across much of the lower two thirds of the benthic AOI, with very few observations recorded in the area. The

highest abundance predicted for reef-forming scleractinian corals was 106 inds. 1,000 m⁻². Model precision was correlated with high abundance, with greater precision generally shown for the northern region of the benthic AOI and along the western fringes of the modelled area. Elsewhere precision was variable but was relatively low in several patches across the mid-south. The KEA models produced for the four main separate species of reef-forming scleractinian corals in the region reveal contrasting distributions of habitat suitability, with higher suitability predicted in the south for three of the species (see Figure 3-25). The KEA model distribution most similar to the abundance model for all species combined produced here is that for *Goniocorella dumosa*. It is difficult to draw conclusions from these variations, however, given the differing make up of the taxa modelled and the very different sample data used.

Predicted abundance of xenophyophores showed an unusual pattern compared with the other taxa modelled, with the highest values in a curved band following the contour of the Bounty Trough in that region across a depth range of approximately 900–1,100 m (Figure 4-9). Although depth itself is not a predictor in the models this result may be due to the strong influence of variables strongly correlated with depth, such as salinity and DO, in both the regression and binomial parts of the hurdle model. The highest abundance predicted for xenophyophores was 188 inds. 1,000 m⁻². Xenophyophores were present at many of the DTIS survey sites in the benthic AOI, but were absent at a number of sites also – with no obvious spatial pattern. Model precision was strongly positively correlated with predicted abundance, with the highest precision shown around the same depth contour of high abundance; elsewhere precision was variable with patches of very low precision limited to the very north and the central mid-west of the benthic AOI.

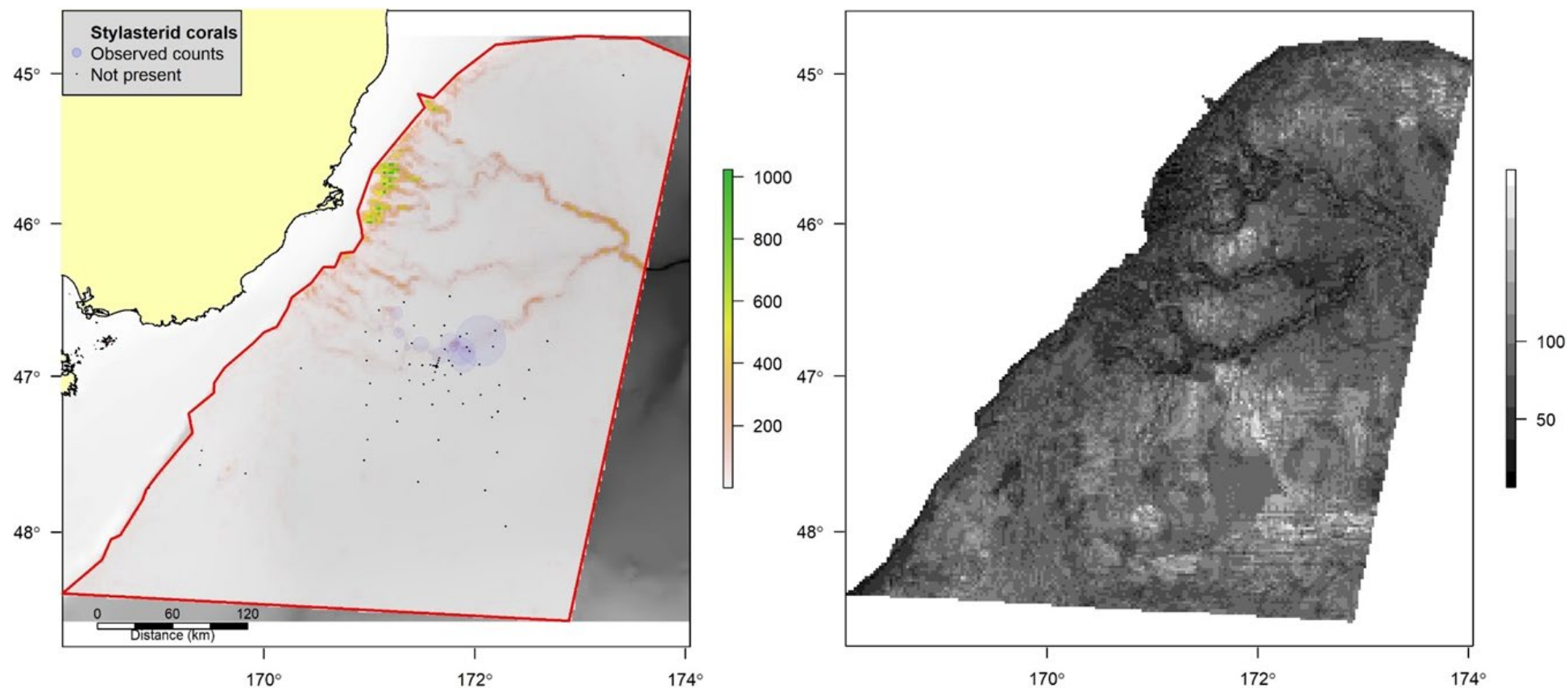


Figure 4-2: Stylasterid hydrocorals – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data. Left: predicted abundance (inds. 1,000 m⁻²), overlaid on bathymetry; blue circles indicate the location and relative counts of the raw data, sites where absent shown as black dots. Right: precision (CV), shown on a log scale to enhance variability

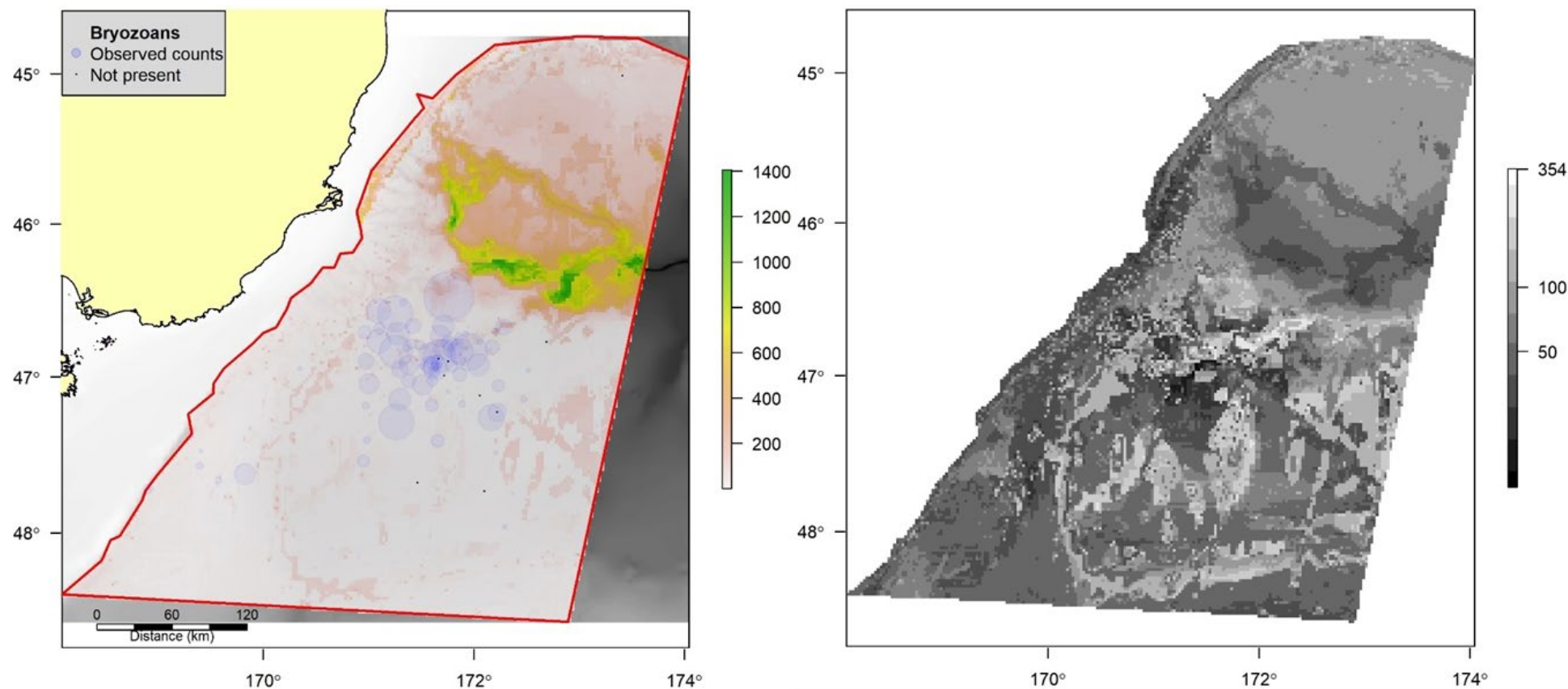


Figure 4-3: Bryozoans – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data. Left: predicted abundance (colonies 1,000 m⁻²), overlaid on bathymetry; blue circles indicate the location and relative counts of the raw data, sites where absent shown as black dots. Right: precision (CV), shown on a log scale to enhance variability.

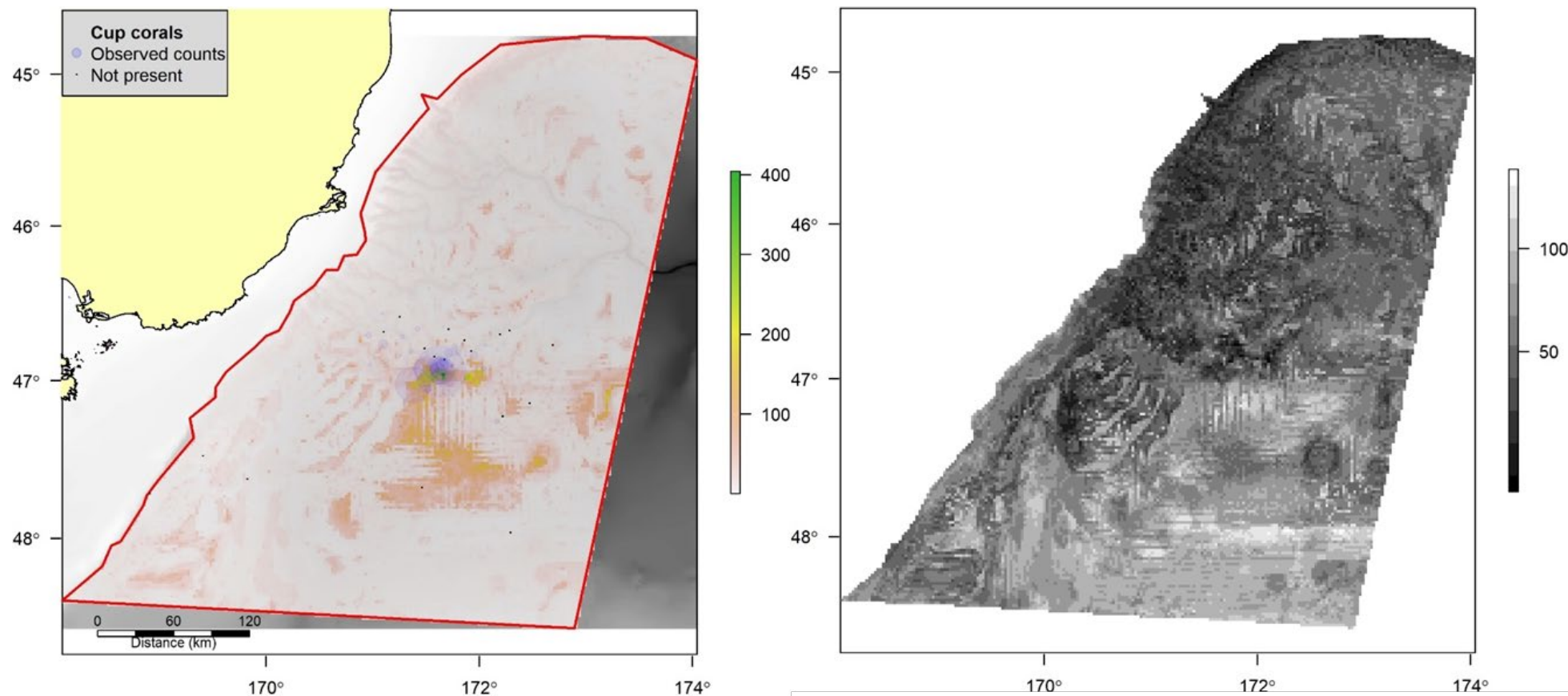


Figure 4-4: Cup corals – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data. Left: predicted abundance (inds. 1,000 m⁻²), overlaid on bathymetry; blue circles indicate the location and relative counts of the raw data, sites where absent shown as black dots. Right: precision (CV), shown on a log scale to enhance variability.

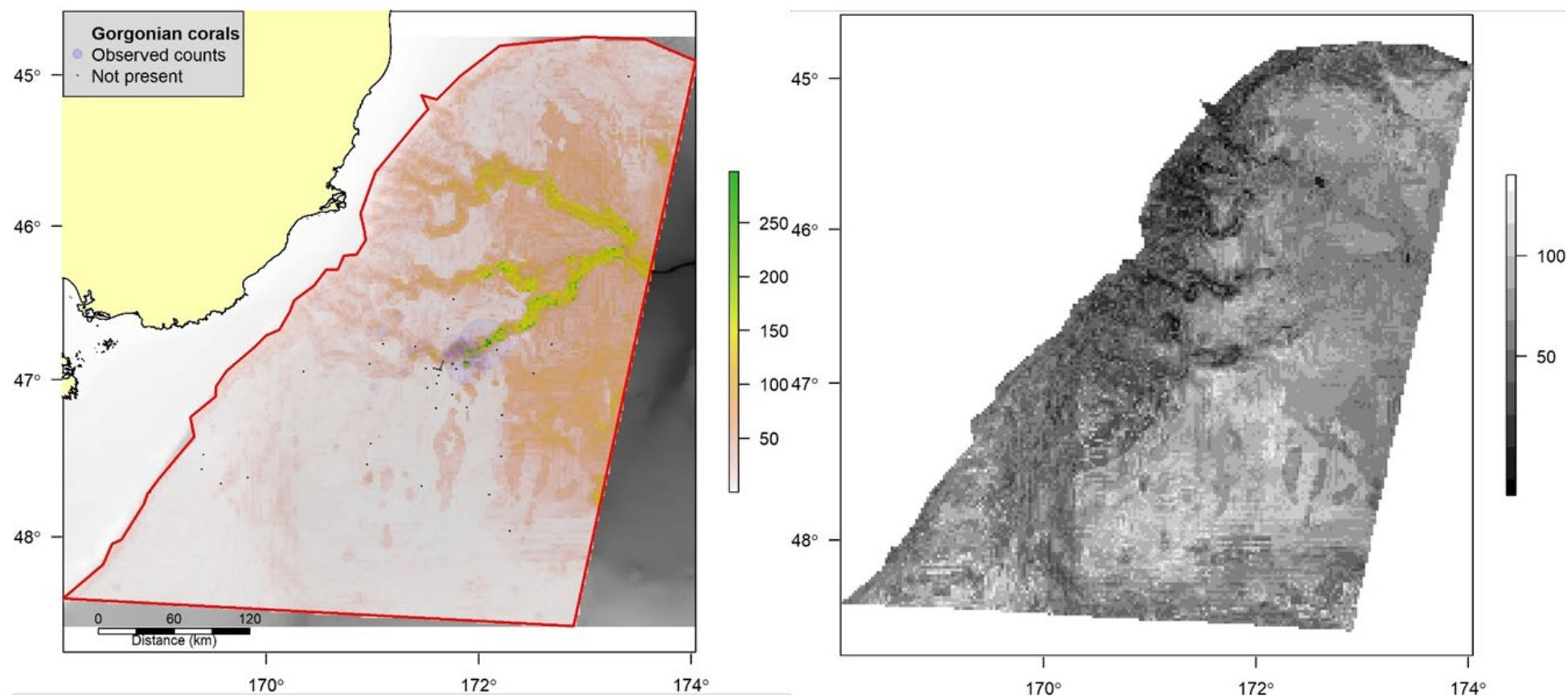


Figure 4-5: Gorgonian corals – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data. Left: predicted abundance (inds. 1,000 m⁻²), overlaid on bathymetry; blue circles indicate the location and relative counts of the raw data, sites where absent shown as black dots. Right: precision (CV), shown on a log scale to enhance variability.

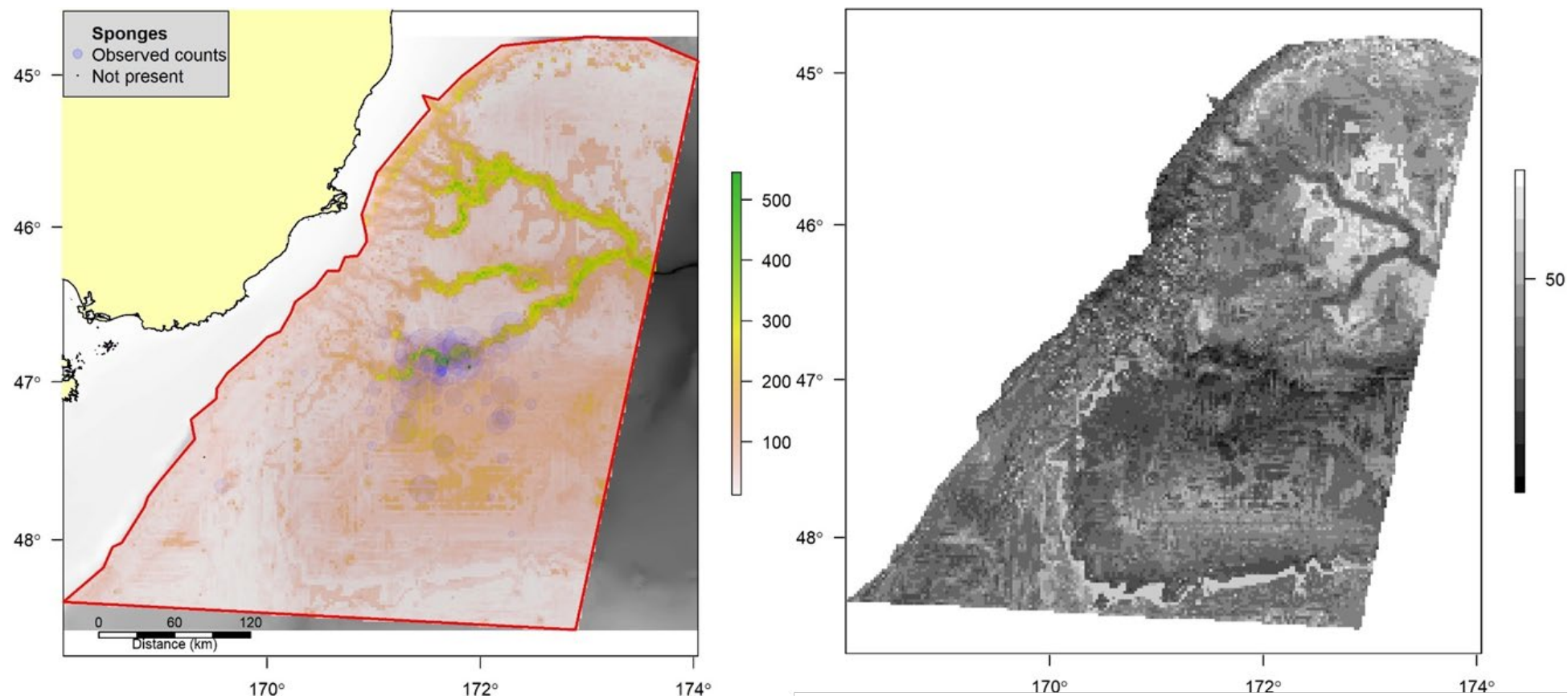


Figure 4-6: Porifera (sponges) – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data. Left: predicted abundance (inds. 1,000 m⁻²), overlaid on bathymetry; blue circles indicate the location and relative counts of the raw data, sites where absent shown as black dots. Right: precision (CV), shown on a log scale to enhance variability.

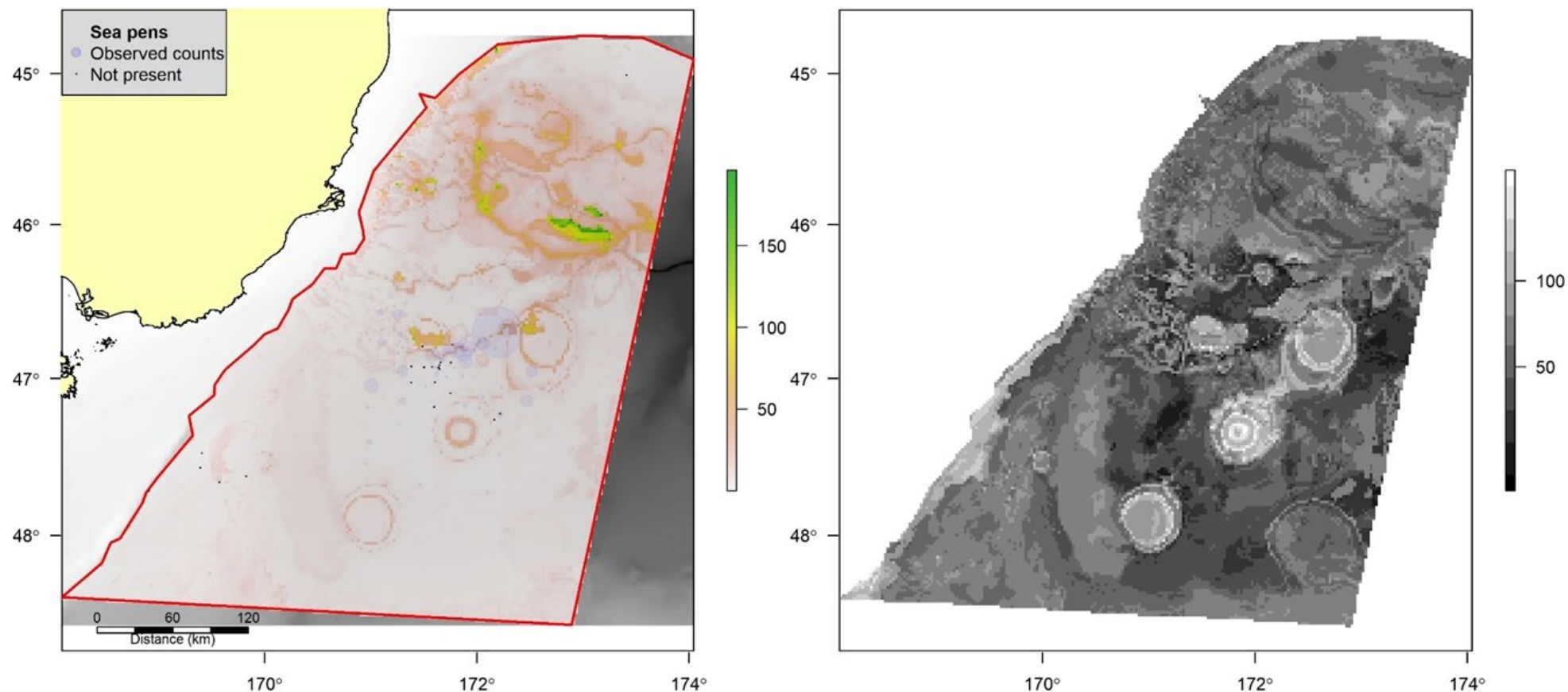


Figure 4-7: Pennatuloides (sea pens) – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data. Left: predicted abundance (inds. 1,000 m⁻²), overlaid on bathymetry; blue circles indicate the location and relative counts of the raw data, sites where absent shown as black dots. Right: precision (CV), shown on a log scale to enhance variability.

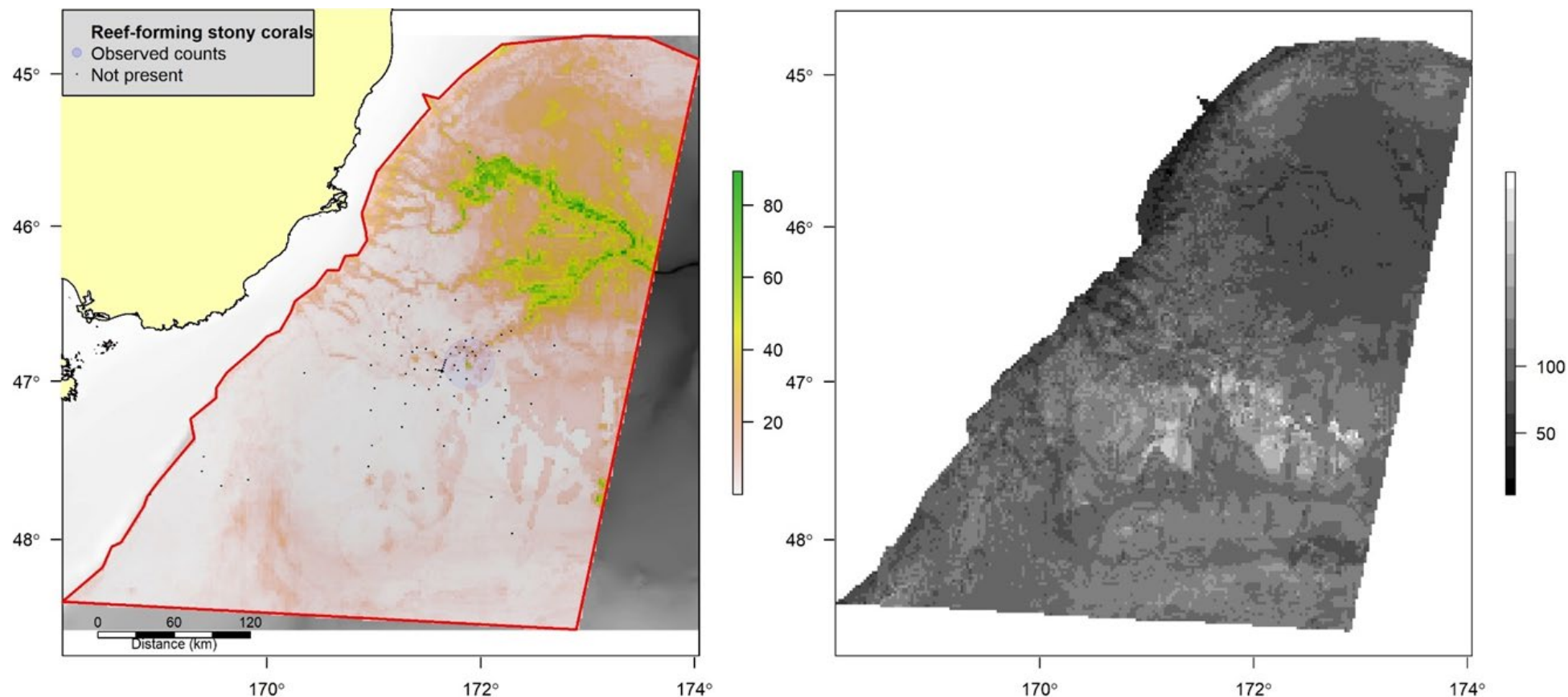


Figure 4-8: Reef-forming Scleractinia (stony corals) – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data. Left: predicted abundance (coral heads 1,000 m⁻²), overlaid on bathymetry; blue circles indicate the location and relative counts of the raw data, sites where absent shown as black dots. Right: precision (CV), shown on a log scale to enhance variability.

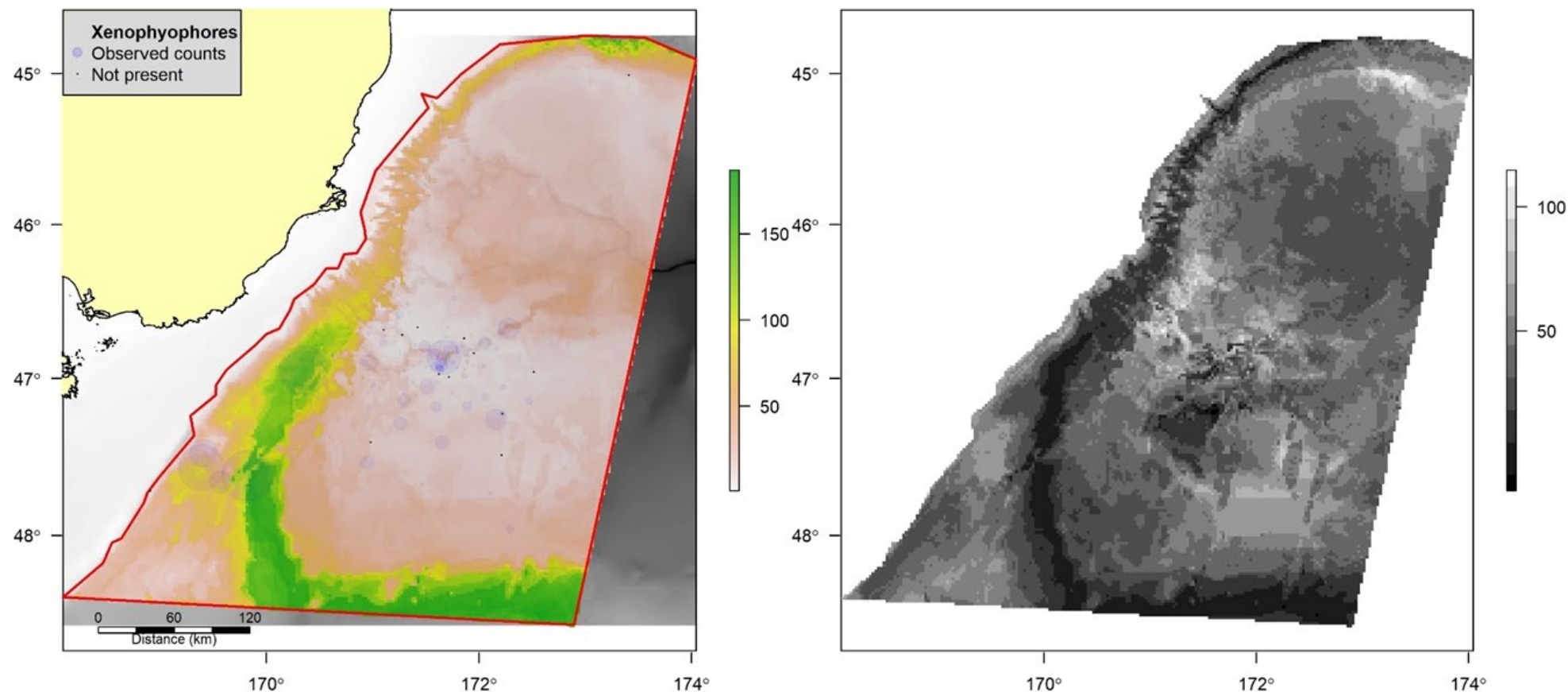


Figure 4-9: Xenophyophores – predicted abundance and associated uncertainty based on species distribution hurdle models from camera transect data. Left: predicted abundance (inds. 1,000 m⁻²), overlaid on bathymetry; blue circles indicate the location and relative counts of the raw data, sites where absent shown as black dots. Right: precision (CV), shown on a log scale to enhance variability.

4.5.5 Prediction of sensitive habitats and VMEs

Under the Exclusive Economic Zone and Continental Shelf (Environmental Effects – Permitted Activities) Regulations 2013, sensitive environments for the taxa modelled here that fall under this Act are defined in terms of percentage cover of the seabed rather than in density or abundance metrics. Exceptions to the use of the percentage cover metric are the definitions of sensitive environments for xenophyophores and sea pens.

Under the Act, a xenophyophore bed exists if “average densities of all species of xenophyophore found (including fragments) equal or exceed one specimen per m² sampled”. How “average densities” should be calculated (e.g., at what scale) is not specified but it could be argued that a statistical model (such as that used here) might be a suitable method. The maximum abundance of xenophyophores in the benthic AOI as estimated by the RF hurdle model was 188 per 1,000 m². This equates to about 0.19 individuals per m², substantially less than the threshold for a sensitive environment for this taxon under the Act.

The methodology required to define a sensitive environment for sea pens is stated in the Act but, as for xenophyophores, no scale of assessment is stipulated. A sea pen field exists if “a specimen of sea pen is found in successive point samples; or two or more specimens of sea pen per m² are found in a visual imaging survey or a survey collected using towed gear”. Of the 60 DTIS video survey transects within the benthic AOI that recorded sea pens, the greatest density observed was 142 individuals per 1,000 m², equal to about 0.14 per m². The maximum abundance of sea pens in the benthic AOI as estimated by the RF hurdle model was 204 per 1,000 m², equating to about 0.20 individuals per m². By either measure, as for xenophyophores, densities of sea pens in the benthic AOI are estimated to be substantially less than the threshold for a sensitive environment for this taxon under the Act.

VMEs are not formally recognized in domestic regulations but are an important consideration when assessing impacts from fishing on the high seas, as is done in SPRFMO and other RFMOs of the world’s oceans, based on definitions developed by the FAO (FAO 2009), and so it may be useful to consider these. Under these definitions, VME indicator taxa (benthic invertebrate taxa which indicate the likely presence of VME habitat) are represented by six of the eight taxa modelled here, excluding only xenophyophores and cup corals (see Table 4-1). Although the VME definitions are complex and difficult to operationalize for management of benthic impacts from fishing, for practical purposes SPRFMO sets bycatch weight thresholds for VME indicator taxa to indicate the likely presence of a VME. If the bycatch from a single fishing event exceeds any of the set thresholds, a ‘move-on’ rule is triggered to prevent continued fishing in the area. Those weight thresholds are as follows: sponges, 25 kg; reef-forming stony corals, 60 kg; gorgonian corals, 15 kg. For stylasterid corals, bryozoans, and sea pens the weight threshold is 1 kg, but these taxa are only included if forming part of a catch in which the threshold is exceeded for at least three different VME indicator taxa. Stylasterids (1,309 individuals per 1,000 m²) and bryozoans (1,413 individuals per 1,000m²) were the taxa with the greatest predicted densities in the abundance models and, notwithstanding their typically small size and weight, may therefore be the taxa most likely to exist in densities sufficient to exceed VME indicator taxa bycatch thresholds.

5 Summary

The benthic AOI covers a large area (approximately 106,996 km²) off the southeast coast of Aotearoa New Zealand's Te Waipounamu South Island, and includes seabed features such as shelf slope, broad slope basin, channel systems and seamounts. Available data have been summarised to highlight the known and predicted distribution of key faunal groups and habitats as well as to identify key knowledge gaps.

5.1 Data discovery

A total of 13,741 species location records were identified from within the benthic AOI. Data were most densely located along the north and west boundary of the benthic AOI and otherwise were sparsely distributed throughout the rest of the benthic AOI. The exception to this was a cluster of records generated from the 2019 benthic baseline survey area.

In total, 55% of the seafloor within the benthic AOI has been mapped by MBES. Habitat types identified within the benthic AOI include broad slope basin, shelf slope, channel systems, and seamount features.

No interstitial pore water data were available from within the benthic AOI that may have provided information on natural dissolved oxygen levels in the sediments of the AOI. Available data from historic CTD casts showed DO measurements in the 1,000–1,500 m depth range were between 150 and 200 µmol/kg (or approximately 4 mL/l), which is consistent with the oxygen minimum layer of the UCDW and NPDW intermediate depths (~1,200–1,500 m) south of the Chatham Rise (see Ingels 2025).

5.1.1 Sensitive environments, protected species, and vulnerable taxa

As discussed above, Schedule 6 of the EEZ Permitted Activities Regulations defines a number of sensitive environments within the Aotearoa New Zealand marine benthic environment.

Sensitive environments for stony coral thickets or reefs, xenophyophore beds, and brachiopod beds are known to be present within the benthic AOI. In addition, bryozoan thickets, and Chaetopteridae worm fields are likely to be present either within, or in close proximity to, the benthic AOI. It is also possible that sea pen fields, sponge gardens, and beds of large bivalve molluscs are present within the benthic AOI.

It is considered unlikely that calcareous tube worm thickets, macroalgal beds, Rhodolith beds, deep-sea hydrothermal vents or methane/cold seeps are present within the AOI.

With respect to protected species, as defined by the Wildlife Act, 1953, Antipatharia (black corals), gorgonian corals (sea whips and sea fans), Scleractinia (stony corals) and stylasterid hydrocorals are all known to be present within the benthic AOI.

Many of the sensitive environment and protected species taxa were particularly associated with the shelf slope, channel and seamount habitats within the benthic AOI. However, it is notable that xenophyophores (sensitive environment) and scleractinian cup corals (protected species) were present in high densities on the muddy sediments of the broad slope basin.

All of the identified taxa deemed from the available literature to be vulnerable to variability in DO and particulate smothering (see Ingels 2025) were found to be present within the benthic AOI.

5.2 Species distribution modelling

An extensive dataset of seabed imagery from within the benthic AOI and surrounding seas enabled the application of species distribution modelling to predict species abundance across all unsampled space within the area. These models were complemented for some taxa by existing habitat suitability models based on presence locations from physical sampling. Although model uncertainty was estimated in each case (for the current study), a potentially greater level of uncertainty in the predictions from all these models stems from uncertainty in the predictor variables used, which all rely on some level of interpolation of data points. Despite these limitations, the models constructed here provide the best available estimates of the presence and abundance of sensitive, protected, and VME species within the benthic AOI and can be used to highlight areas of potential concern.

High abundances of some taxa, especially stylasterid hydrocorals and bryozoans, were predicted for some isolated locations, particularly around the channels in the north of the benthic AOI.

5.3 Gaps in knowledge

There are large areas within the benthic AOI for which there are no empirical faunal data (either imagery and specimen data) and/or no detailed multibeam data to accurately represent seabed geography. Benthic species distribution modelling goes some way to overcome some of these gaps, however, these rely on spatial representations of predictor variables which themselves are based on sparse data, and ground truthing of modelled predictions are needed to reduce uncertainty on predictions.

In addition, while knowledge of deep-sea benthic communities increases year on year, there remains an overall lack of knowledge of the life histories of many deep-sea fauna.

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7 Glossary of abbreviations and terms

2019 baseline survey	Environmental baseline survey conducted for OMV New Zealand Ltd. in 2019
AOI	Area of Interest
Auckland Museum	Auckland War Memorial Museum Tāmaki Paenga Hira
BPI	Benthic Position Index
CBPM	Carbon-Based Productivity Model
COD	Centralised Observer Database
CTD	Conductivity, Temperature, Depth
CV	coefficient of variation
DAS	Data Acquisition System
DO	Dissolved oxygen
DTIS	NIWA’s Deep Towed Imaging System
Earth Sciences NZ	Earth Sciences New Zealand, a new Public Research Organisation (PRO) merging previous Crown Research Institutes (CRIs) NIWA and GNS
EEZ	Exclusive Economic Zone
EPGM	Eppeley-Vertically Generalised Production Model
FAO	United Nations Food and Agriculture Organization
FNZ	Fisheries New Zealand
GB	Gigablue
GEBCO	Nippon Foundation-General Bathymetric Chart of the Oceans
GIS	Geographic Information System
IHO	International Hydrographic Organisation
KEA	Key Ecological Area
MBES	Multibeam echosounder systems
NIWA	National Institute of Water and Atmospheric Research. NIWA merged with GNS on the 1st July 2025 to form the Earth Sciences New Zealand
OBIS	Ocean Biogeographic Information System (Southwestern Pacific Node)
OFOP	Ocean Floor Observation Protocol software
oob	out of bag
QMS	Quota Management System

RFMOs	Regional Fisheries Management Organisations
sd	Standard deviation
SPECIFY	NIWAInvert database held by NIWA Invertebrate Collection (data extracted using SPECIFY software)
SPRFMO	South Pacific Regional Fisheries Management Organisation
Te Papa	Museum of New Zealand Te Papa Tongarewa Natural Environment collection
TS	Territorial Sea
USBL	ultra-short baseline
VIF	Variance Inflation Factor
VME	Vulnerable Marine Ecosystems
VRM	Vector Ruggedness Measure

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