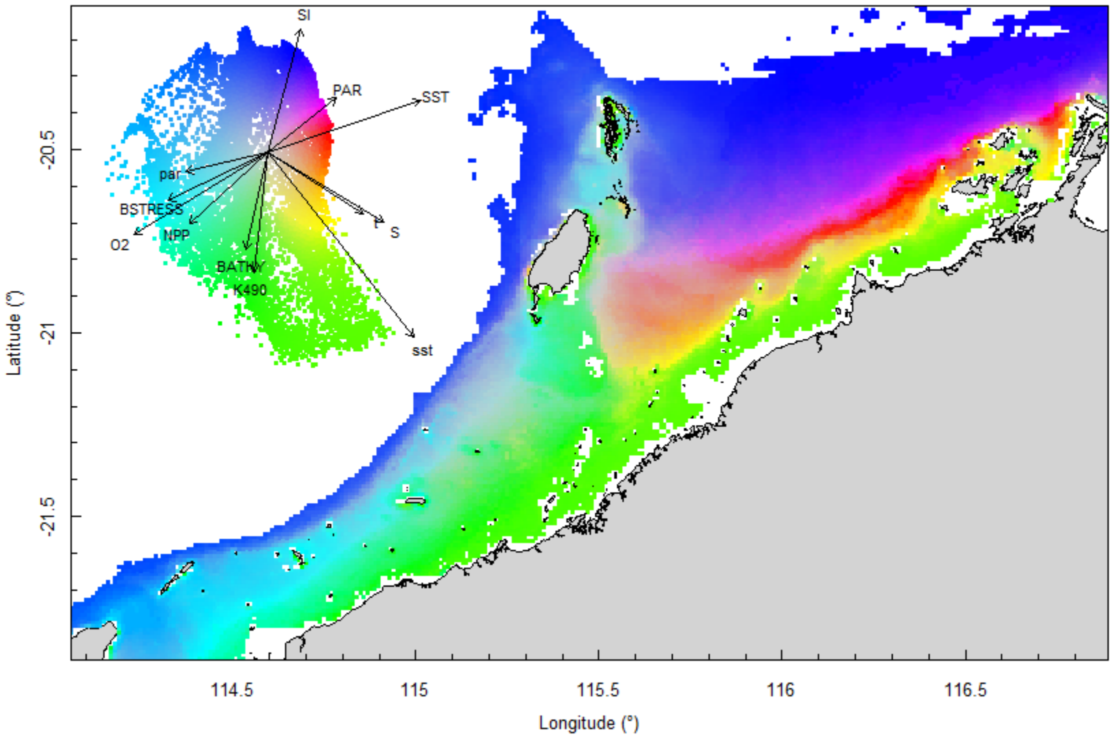
The Pilbara Marine Conservation Partnership

CSIRO & University of Western Australia

Environmental Pressures: Regional Biodiversity — Pilbara Seabed Biodiversity Mapping & Characterisation



Final report, January 2016

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Group	**People responsible**
Crustacea	Andrew Hosie & Ana Hara (WAM), Bee Morello (CSIRO)
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Soft coral	Monika Bryce (WAM), Damian Thomson and Joanna Strzelecki (CSIRO)
Sponges	Jane Fromont and Oliver Gomez (WAM), Joanna Strzelecki (CSIRO)
Plants	John Huisman (Murdoch University)
Echinoderms	John Keesing & Zoe Snedden (CSIRO), Loisette Marsh (WAM – Asteroids), Kate Naughton (Crinoids), Mark O'Loughlin (Holothurians), Tim O'Hara (Ophiuroids) (Museum Victoria); Ashley Miskelly (Australian Museum – Echinoids).

Pilbara Seabed Biodiversity Mapping & Characterisation

Summary

The Pilbara shelf is an important area of ecological and development significance. Activities such as offshore gas and petroleum extraction and processing, major port developments, and commercial and recreational fishing occur together with primary natural resource conservation areas. Managers need information on habitats and biodiversity distribution and risks to ensure these activities are conducted sustainably. However, while some demersal species information was available for the broader Pilbara region, this was mostly for fishes and some mobile invertebrates and did not include sessile invertebrates and habitats. Further, most existing information was for outside the specific shelf area of interest. Thus, there were significant gaps spatially and taxonomically, and for seabed habitats.

Between 2012 and 2015, the Pilbara Seabed Biodiversity Mapping & Characterisation Project, as part of the Pilbara Marine Conservation Program, mapped habitats and their associated biodiversity across the length and breadth of the west Pilbara shelf (0–50 m) to provide information that will help managers with regional planning and management, and to help ensure that human uses of the region are ecologically sustainable, as required by environmental protection legislation. Comprehensive information on the biodiversity of the seabed was acquired by visiting 125 sites, representing a wide range of known environments, during a ~month-long voyage on each of two vessels and deploying several types of sampling devices including: towed video and digital cameras, an epibenthic sled and a research trawl to collect samples for more detailed data about plants, invertebrates and fishes on the seabed. Data were collected and processed from ~63 km of towed video, and from sorting and identification of 1,469 benthic samples and 382 demersal fish samples. The project has analysed this information and produced all of the outputs as originally proposed; these included:

- Video transects of seabed habitat types, including 10 substratum, 22 biological habitat component types, and 12 benthos faunal types
- An inventory of 1326 species or taxa of invertebrates, fishes, and plants with catalogued museum voucher specimens, including new species, and a database of almost 6,880 records of species distribution and abundance on the seabed.
- Identification of the key environmental variables important for structuring seabed distributions, and predictive models of bio-physical relationships between seabed species, their assemblages and the physical environment.
- Maps of the distribution and abundance of 180 seabed species throughout the study region.

These data provide information on the current ecological status of the region, and strengthen understanding of linkages between ecological attributes and the processes that affect them. The outputs from this study can be used to support a range of spatial planning, assessment and management applications across the west Pilbara, including for conservation, assessments of current uses, and to provide information for evaluating future development proposals — thus providing lasting benefits.

1 Introduction

Planning, assessment and management of the marine environment requires an essential base level of understanding about the distribution of habitats and biodiversity. It is also critical for developing an effective sampling program for Key Performance Indicators (KPIs). Habitat is a key determinant of population structure and having a stratified sampling regime is vital to obtaining precise estimates of population parameters and properly identifying drivers of biological response. Consequently, the initial phase of the project included a component to compile all relevant existing available information relating to biodiversity and habitat variation in the region. Since the sea is a dynamic and three-dimensional environment, habitat descriptions included benthic mapping, and key water column properties related to fish and biotic health, linking to satellite data for ground-truthing. In order to plan the biodiversity sampling program we therefore capitalised on existing holdings of national scale environmental and biodiversity data sets, acquired additional regional datasets, and analysed these data to provide an initial regional characterisation and stratification prior to any fieldwork.

The regional seabed biodiversity study area spanned the region between Northern Ningaloo and the Dampier Archipelago encompassing Barrow Island and the Montebello Islands west to depths of approximately 50 m. In addition to video transects and photographs, extractive sampling using an epibenthic sled and a research trawl was planned in order to provide detailed biodiversity assessments rather than simple descriptions of coarse habitat types. The first year of the project collated and analysed existing available data to provide the preliminary characterisation of the region and stratification for the sampling design. Sampling was designed to representatively sample all known important environmental-driver gradients in the region and to ensure that areas for which there were low levels of data or poor ability to accurately predict habitat and biodiversity would be sampled. Field work was conducted at the end of the first year of the project in order to inform sampling in other PMCP programs, but detailed processing of samples, analysis and reporting continued into subsequent years.

2 Objectives

A primary determinant of the nature and complexity of ecological interactions is the composition and diversity of ecological communities. Accordingly we aimed to acquire information on regional biodiversity and habitat structure for the purposes of planning, assessment and management, as well as for use in the design of other ongoing sampling in the PMCP Coral Reef Health and Fish and Sharks projects. The Biodiversity and Habitat Project's goal was to provide a region wide characterisation of biodiversity and habitat patterns as its key objective.

The key specific objectives are:

1. Acquire available existing data, conduct an initial biophysical characterisation of the west Pilbara region, including initial identification of environmental drivers, and produce a preliminary bioregional map for survey design and for departmental purposes.

2. Survey and sample spatial patterns of biodiversity of benthic ecosystems across the entire west Pilbara region, using towed video transects, an epibenthic sled and a research trawl.

3. From survey data, characterise biodiversity of the west Pilbara region including identification of key environmental drivers of biodiversity patterns, and produce a final bioregional map to inform the design of future ecological sampling program and for departmental planning and management purposes.

3 Methods

3.1 Environmental Data Sets

The environmental data layers collated and used for the biophysical analysis and mapping of biodiversity included:

- Bathymetry DEM: depth, slope, aspect — the model bathymetry is based on several sources. The data set uses the Geoscience Australia (GA) GA2009 250m bathymetric product as a background. The WA state's official coastline (mean tide) was used to define 0 depth and islands. Commercial partners provided bathymetric data based upon LiDAR/LADS surveys and CSIRO and GA provided surveys based on acoustic systems. AHO and WA DPI provided historical soundings. These were integrated and processed in swath mapper processing software by Gordon Keith into a 0.01 degree gridded product.
- Sediment: gravel, sand, mud, carbonate — sediment properties where derived from dbSEABED (http://instaar.colorado.edu/~jenkinsc/dbseabed/, Chris Jenkins) gridded at 0.01°.
- Seabed current stress — Data sourced from the CSIRO RIBBON Model (http://www.emg.cmar.csiro.au/www/en/emg/projects/-Ribbon--Model.html).
- Bottom water attributes (annual average and seasonal range): temperature, salinity, oxygen, nitrate, phosphate, silicate — Data sourced from the CSIRO Atlas of Regional Seas (CARS) (http://www.marine.csiro.au/~dunn/cars2009/)
- NASA Ocean colour (SeaWiFS & MODIS): chlorophyll, light attenuation, SST, surface PAR — satellite derived datasets were processed by IMOS (Edward King), gridded at 0.01°.
- Derived variables: benthic irradiance, primary productivity, exported POC — calculated from ocean colour variables using published algorithms.
- Terrain morphology probabilities: ridge, channel, peak, depression, pass, plane — generated from bathymetric data by Vanessa Lucieer, University of Tasmania.
- Human use layers: fishing (e.g. trawl effort), mining, infrastructure, spatial management — datasets provided by WA DOF, DPI and DPaW

See Appendix 1 for descriptions of environmental variables used in project analyses, and see Appendix 2 for maps of each variable.

3.2 Initial characterisation & stratification

To achieve the initial regional scale characterisation, existing benthic biodiversity data from locations well distributed across the study area were acquired and used to integrate with environmental data and analyse relationships between species distributions and their environment. Additional biological data were collated from past CSIRO trawl surveys, WA Fisheries surveys and WA DEC reefs surveys with seven datasets available in total (see Appendix 3). An integrative analysis method, 'gradientForest' (Ellis et al 2012, Pitcher et al 2012), was used to obtain evidence-based relationships between species compositional change and multiple environmental gradients that were then used to transform all environmental layers to the same 'biological' scale. These transformed layer were mapped to provide an initial characterisation, which was also the basis for the most biologically relevant stratification for regional scale benthic sampling completed in mid–2013.

3.3 Field sampling

Previous studies have demonstrated that different sampling gears largely sample different species and different assemblage patterns, generating different species compositions & spatial patterns and confirming that data from multiple devices must be combined in order to comprehensively describe the biodiversity of an area (e.g. Pitcher et al. 2002 & 2007). For example the assemblage data generated from video alone is much less similar to benchmark datasets (all three gears combined) than either trawl or sled data alone. This stems from the different selectivity of sampling devices as well as the considerable difficulty in identifying and quantifying organisms from video as well as the limited observability resulting from variable visibility and camera movement in rough sea conditions.

To ensure the sampling of the benthic biodiversity of the Pilbara region was as comprehensive as possible, this study deployed a variety of sampling gears including towed underwater video, a 1.5 m epibenthic sled and an ~8-fathom research trawl. The biodiversity mapping voyages in the Pilbara were conducted in June 2013 on the research vessels *RV Naturaliste* (Western Australia Fisheries; trawl and sled sampling) and *RV Linneaus* (CSIRO Oceans & Atmosphere; video transects and some sled sampling).

3.4 Sorting & identification of samples

Initial Operational Taxonomic Unit (OTU) level sorting of the new samples collected by the June 2013 Pilbara seabed biodiversity sampling trip was carried out by CSIRO staff at Floreat (WA). Following this initial sorting, most specimens were sent to expert staff at the Western Australian Museum (WAM) with CSIRO staff providing assistance — or for some groups, to the Museum of Victoria, and marine plants to the WA Herbarium. At these laboratories, detailed identification of specimens was completed as well as collation and storage of voucher samples and description of new species. As previously advised, the sponges were particularly abundant and diverse, and completion of identifications for sponges required more time than expected, delaying final analyses. All data were transferred to a secure Oracle database at CSIRO and checked.

3.5 Analyses of new sample data

Data arising directly from the June 2013 field survey were mapped. These comprised (i) habitat data recorded during towed video camera transects, and (ii) biomass data of the major sorting groups of fishes and benthos derived from primary sorting of trawl and sled samples on vessels at sea.

After species sorting and identification of the new sled and trawl samples was completed, basic biodiversity indices were examined and species richness was modelled and mapped. Selected individual species (those sufficiently frequently occurring for analysis, and with successful prediction models) were also modelled and mapped. Univariate modelling was conducted using Random Forests (Breiman 2001), a bootstrapped tree-based method recognised for its prediction modelling power.

The initial regional scale characterisation was updated by integrating the new sled and trawl sample data in a combining analysis with the data previously collated from other sources. Relationships between species distributions and their environment were again analysed using ‘gradientForest’, to provide a final biophysical characterisation and map of patterns of biodiversity composition for the region.

4 Results

4.1 Initial characterisation & stratification

The relationships between species distributions in existing datasets and their environment, as determined by the gradientForest analysis are shown in Figure 1. These indicate the cumulative changes in biodiversity composition along multiple environmental gradients. After transforming all environmental layers to the same ‘biological’ scale, using the cumulative curves, the predicted biologically relevant stratification for regional scale benthic sampling is shown in Figure 2.

The sampling design provided for 125 video and sled sites and 64 trawl sites. This was planned so that invertebrate sampling sites would be about 12 km apart on average and fish sampling sites would be about 17 km apart on average, because previous analyses (e.g. Pitcher et al. 2002) had demonstrated that these sampling densities were appropriate given the change in invertebrate and fish composition with distance on the seabed. That is, samples taken much closer than these distances would likely be too similar and waste resources, whereas samples taken much further apart would likely sample biodiversity inadequately. In addition, given the estimated time required to deploy the different sampling gears on the two research vessels, this allocation would keep the vessels in proximity to each other and for similar amounts of time at sea, in order to provide assistance to each other. Finally, this allocation was appropriate given the resources available to the project.

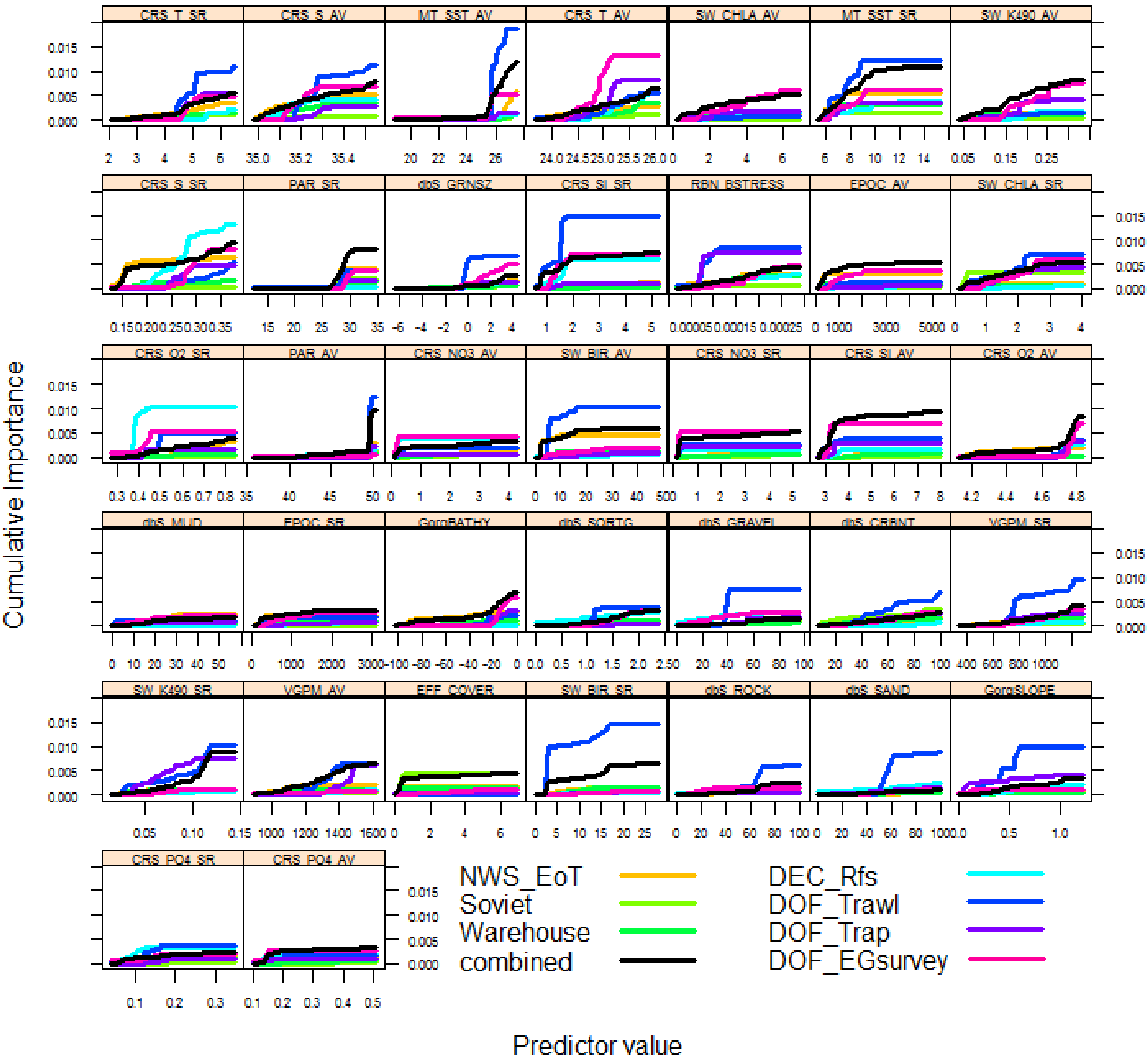

Figure 1 Relationships between change in species composition and 37 environmental variables (in order of importance) in the west Pilbara study region. The y-axis is the cumulative compositional change associated with increasing values of the x-axis (each environmental gradient). Seabed biological surveys include 3 existing CSIRO datasets and 4 acquired prior to fieldwork. Variables include parameters such as depth, SST, salinity, bottom irradiance, sediment composition, hydrodynamic shear stress, among others (see Appendix 1); 44 variables were assessed; 7 are excluded here due to unimportant response.

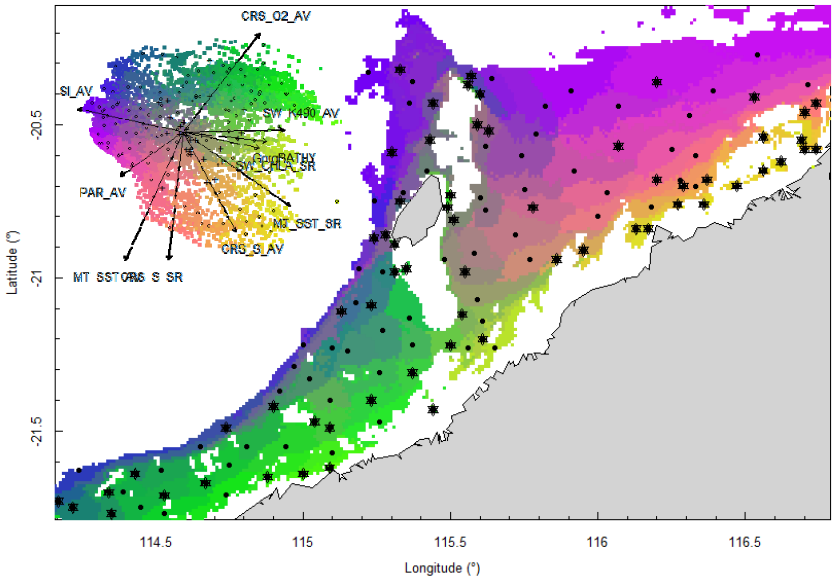

Figure 2. Stratification of the west Pilbara region (5-50m), based on analyses of previous biological surveys against 37 environmental layers including pre-existing datasets and those acquired by the project. The biplot shows the first 2 dimensions of the transformed biological space, which was sampled representatively (at points ◦), as well as vectors of the major environmental drivers. The geographic map shows the biologically informed stratification for regional sampling, with selected sample sites: •-tow-video & sled; ✸-trawl, video & sled. (Compare with Appendix 4 to see improvements due to data acquired by the project).

A key initial output from the project was a map of the initial characterisation. Preliminary analyses of the existing biological survey data suggested that approximately 11 clusters were statistically justifiable for management purposes. These represent predicted biological assemblages at ~1 km resolution (with ~1-10 km utility, at full regional extent ~18,700s sq kms, see Figure 3). The expectation is that assemblage composition would differ from cluster to cluster corresponding to distance apart in the biplot — some assemblages are more heterogeneous than others (e.g. in Figure 3, clusters 3 and 7 are each more heterogeneous than clusters 2 and 6 together).

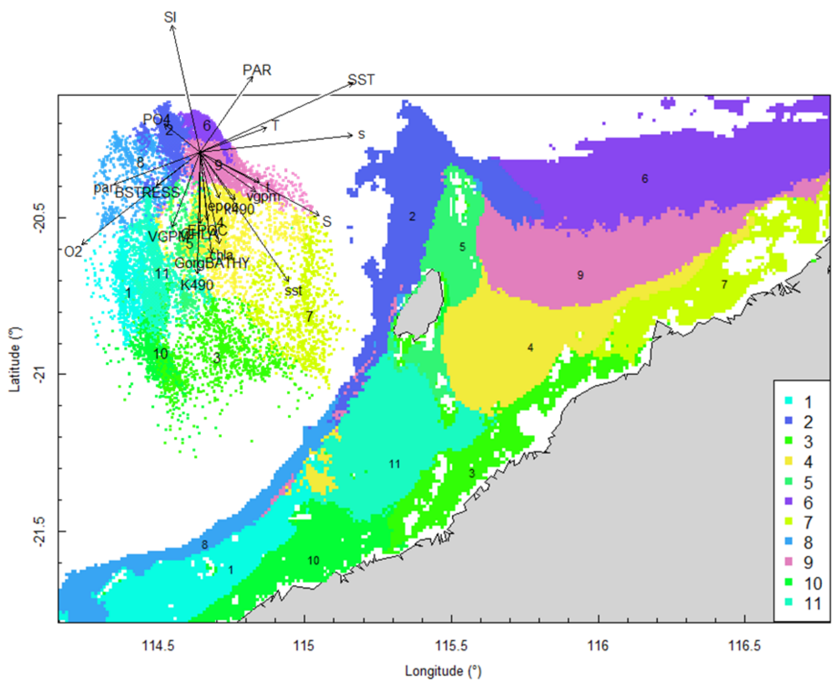

Figure 3. Initial seabed characterisation of the west Pilbara region (5-50m): 11 assemblage types were predicted based on analyses of previous biological survey data against multiple environmental layers including datasets and those acquired by the project. The biplot at top left shows the variables principally associated with each assemblage type.

4.2 Field sampling

The seabed biodiversity sampling voyages in the Pilbara were successfully completed in June 2013, using the research vessels *RV Naturaliste* (WA Fisheries) and *RV Linneaus* (CSIRO). In total, 125 sites were sampled with towed-video and digital stills for seabed habitat, 111 sites with an epibenthic sled for sessile and mobile invertebrates and 43 with a research trawl net for fishes and mobile invertebrates. A number of sites were unsuitable for sampling by sled and/or trawl. Many sled and trawl samples were dominated by a large abundance and diversity of sponges (e.g. see Figure 4).

Figure 4 Photograph illustrating an example of the abundance and diversity of sponges observed in the Pilbara study area.

The biomass, by taxonomic group, sampled during the voyages is shown in Figure 5 and Figure 6, for benthic sled and trawl respectively. Overall, sponges dominated the sled samples — and fish dominated the trawl samples. The substratum types observed during video transects are shown in Figure 7 indicating that sand dominates the sampled area and most seabed reef areas were found around Barrow Island and the Montebello Islands. The biological habitat types observed during video transects are shown in Figure 8 indicating macro-vegetated habitats in the vicinity of Barrow Island, and either gorgonian or sponge dominated habitats (or a mixture) scattered through much of the region; however, much of the seabed was bare of biological habitat, or bioturbated towards the NE.

4.3 Sorting & identification of samples

The samples collected showed high diversity of all groups examined in detail, noting that several groups (e.g. Annelida, Brachiopoda, Bryozoa, Ascidiacea, Hydrozoa) were not identified further in the laboratory due to resource constraints. Table 1 summarises the results of sorting of benthic sled and demersal trawl samples from the June 2013 trip. The diversity of the sponge communities was particularly high — and this required significantly more time for identifications. Data from sorting and identifications are stored in an Oracle database, as well as in the databases of the museums responsible for the final identification of specimens.

In total, 1326 taxa were recognized, of which 1157 occurred in sled samples, 427 in trawl samples, and 258 in both. The number of taxa at sled sites ranged from 2 to 140 (mean= 44.88; std dev= 33.27), and the number of taxa at trawl sites ranged from 0 to 140 (mean= 25.52; std dev= 21.27). Most taxa were sampled rarely or infrequently: 516 taxa (44.6%) were found at only one sled site, and 355 taxa (30.7%) were found at only 2–4 sled sites; 235 taxa (55%) were found at only one trawl site, and 138 taxa (32.3%) were found at only 2–4 trawl sites.

The numbers of species identified from each sled and trawl site are mapped in Figure 9. Random Forest models fitted to these richness data (log transformed) predicted richness across the region

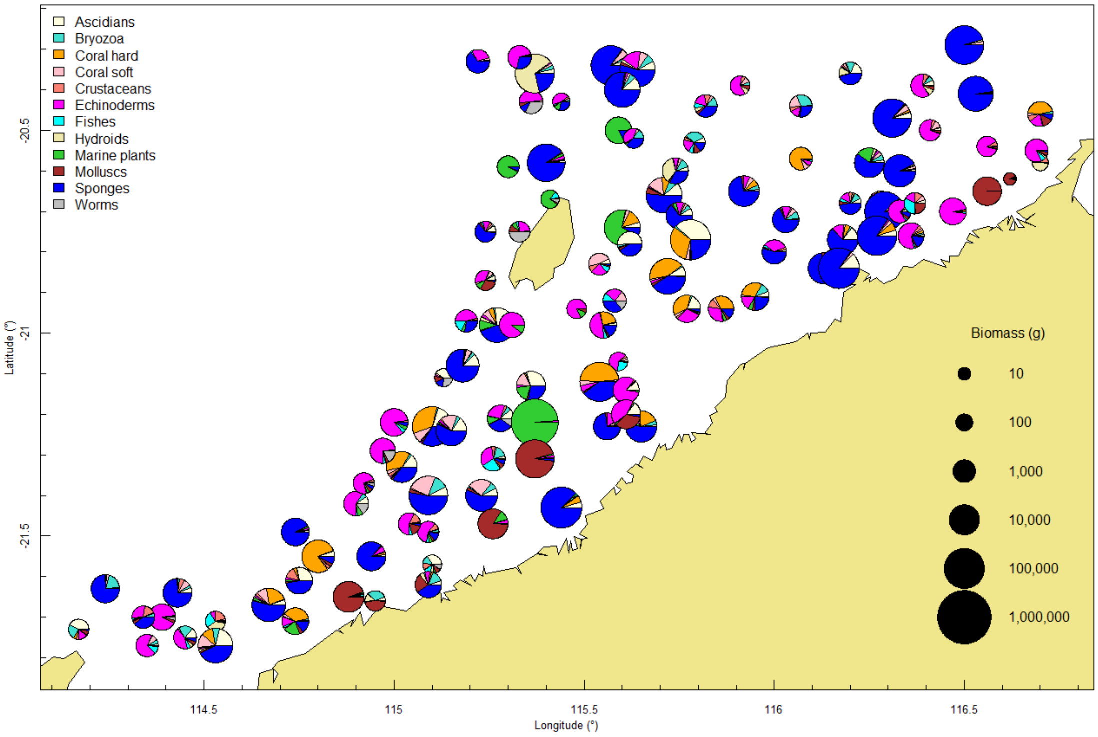

Figure 5 Biomass of benthic biodiversity and proportions by taxonomic group, sampled by epibenthic sled during the biodiversity mapping and characterisation cruise carried out in the Pilbara in June 2013.

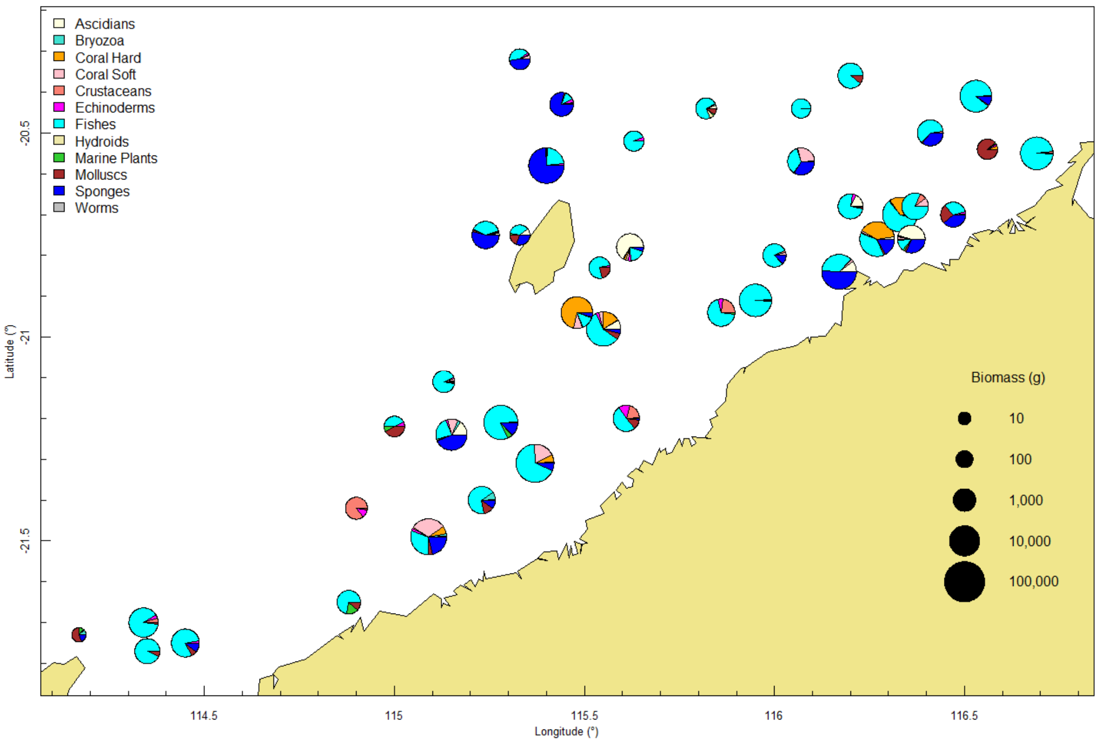

Figure 6 Biomass of demersal biodiversity and proportions by taxonomic group, sampled by trawl net during the biodiversity mapping and characterisation cruise carried out in the Pilbara in June 2013.

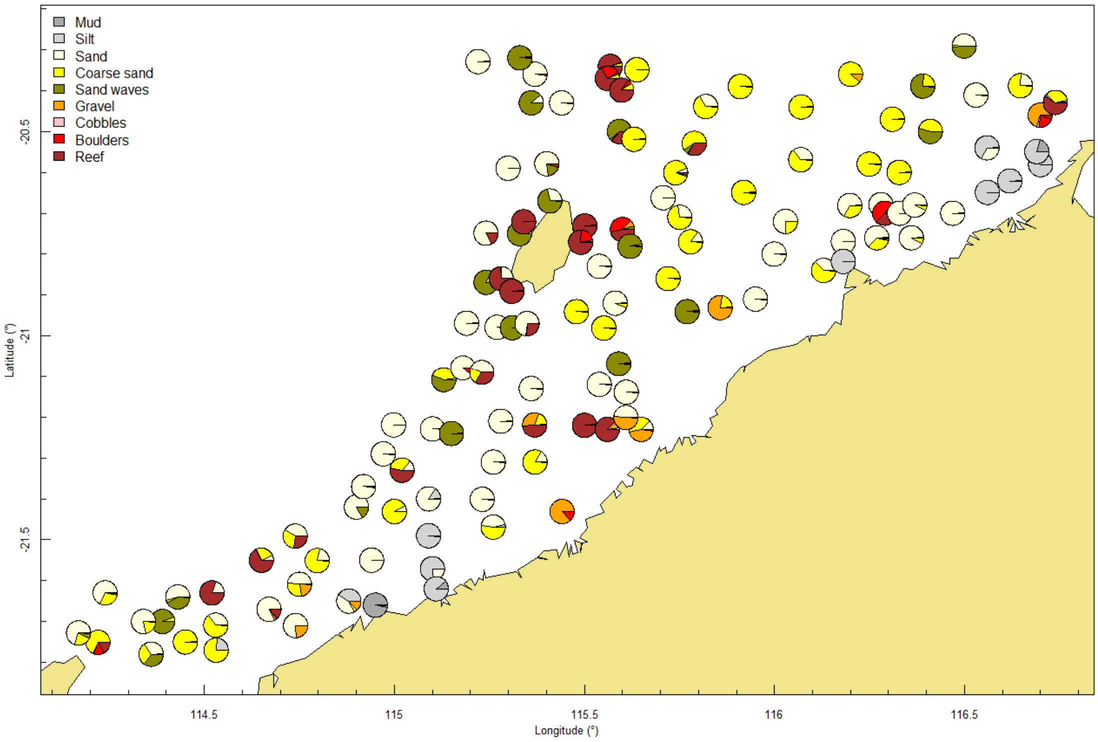

Figure 7 Substratum characterisation by proportions of the towed video transects completed during the biodiversity mapping and characterisation cruise carried out in the Pilbara in June 2013.

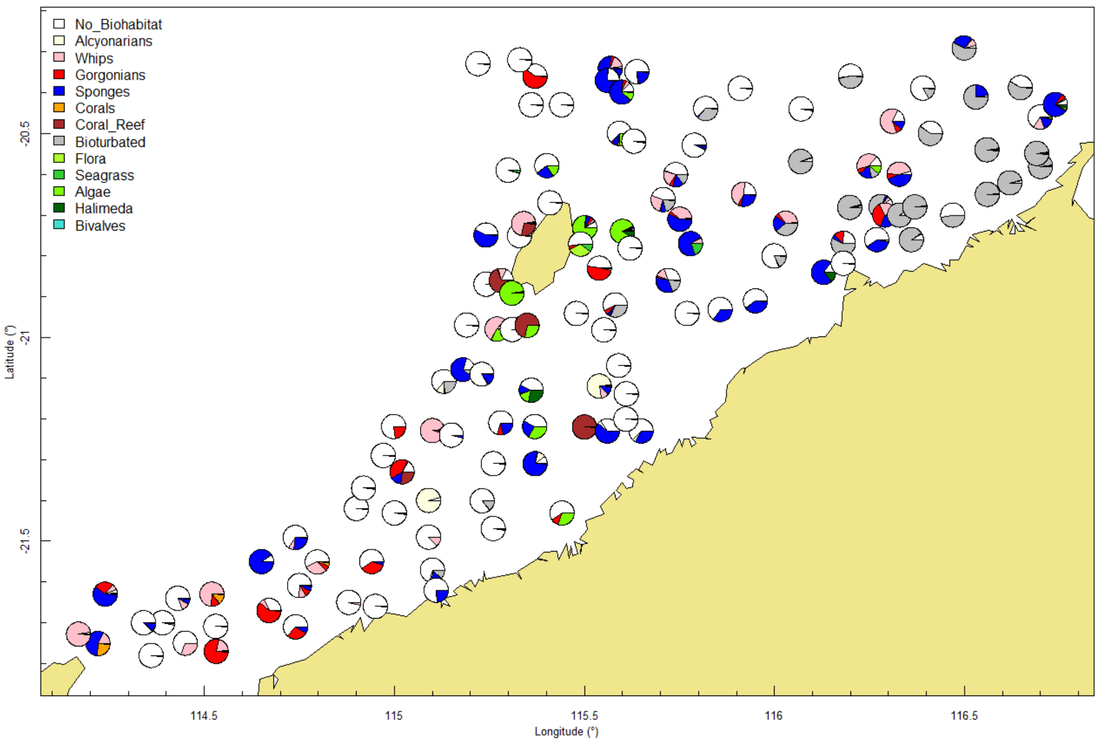

Figure 8 Biological habitat characterisation by proportions of the towed video transects completed during the biodiversity mapping and characterisation cruise carried out in the Pilbara in June 2013.

(background colour on maps). From 17% (Trawl) to 20% (Sled) of richness was predictable from environmental variables in cross-validated tests, although model fits to data were good ("explained variation" = 82% & 76% for Trawl & Sled respectively). Important variables for sled richness included: sediments, nutrients, bottom temperature, turbidity, productivity, sea surface temperature. Richness was notably lower in muddy areas in the vicinity of the Dampier Archipelago. Important variables for trawl richness included: sea surface temperature, oxygen, turbidity, productivity, light.

Table 1 Summary of sorting and identification of samples collected from the Pilbara in June 2013.

Phylum	Class	Number of taxa	Number of Sled sites	Number of Trawl sites
Annelida	Polychaeta	1	53	2
Arthropoda	unidentified	1	2	
Arthropoda	Malacostraca	196	99	21
Arthropoda	Maxillopoda	5	10	
Brachiopoda	unidentified	1	1	
Bryozoa	unidentified	1	86	16
Chordata	Actinopterygii	202	90	40
Chordata	Ascidiacea	2	86	16
Chordata	Chondrichthyes	3	2	2
Chordata	Reptilia	6	1	5
Cnidaria	Anthozoa	158	81	22
Cnidaria	Hydrozoa	1	65	5
Echinodermata	Asteroidea	32	87	14
Echinodermata	Crinoidea	49	84	20
Echinodermata	Echinoidea	30	80	9
Echinodermata	Holothuroidea	29	58	8
Echinodermata	Ophiuroidea	33	76	9
Mollusca	unidentified	1	1	
Mollusca	Bivalvia	90	73	11
Mollusca	Cephalopoda	11	24	27
Mollusca	Gastropoda	93	91	8
Mollusca	Polyplacophora	1	3	
Porifera	unidentified	2	45	11
Porifera	Calcarea	4	13	2
Porifera	Demospongiae	296	94	26
Porifera	Homoscleromorpha	1		1
Chlorophyta	Chlorophyceae	12	41	
Heterokontophyta	Phaeophyceae	23	70	22
Magnoliophyta	Liliopsida	4	15	5
Rhodophyta	unidentified	1	23	2
Rhodophyta	Florideophyceae	33	32	5
Rhodophyta	Rhodophyta	3	7	4

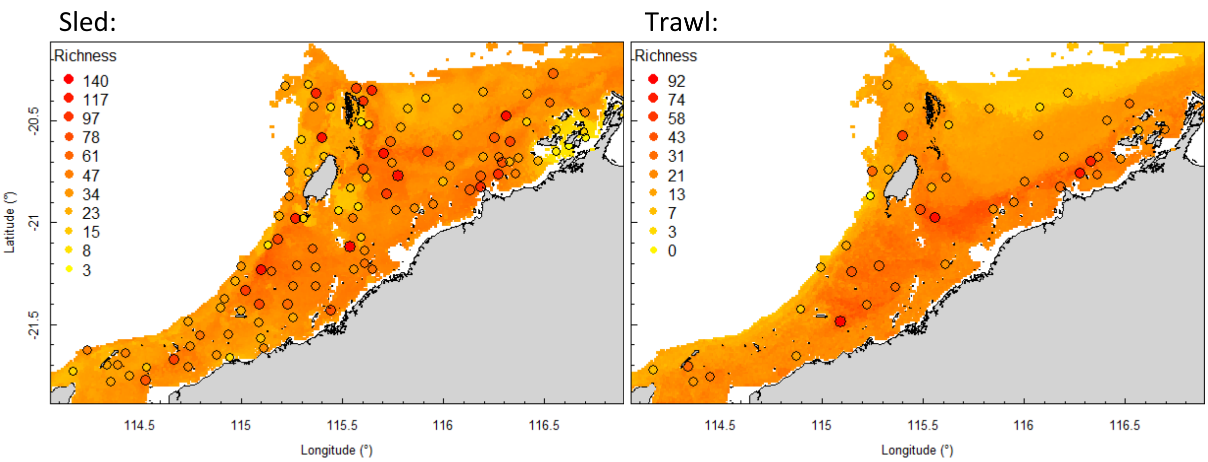

Figure 9 Maps of the number of species identified from Sled and Trawl sites sampled during the biodiversity survey.

A substantive number of potential, but unconfirmed, new species are likely to have been discovered. These include, among other possibilities, 12 unique sponge OTUs not found previously in any WAM collections; approximately 5 new species of Molluscs; a few Flabellid and one Rhizangid hard corals; 3–4 suspected new crinoid species; 5 undescribed species of symbiotic barnacles; and among the echinoderms, 3 new species of holothurians, one new *Goniodiscaster* sea star and 3 *Peronella* sand dollar species.

These taxa could not be confidently placed into known species. Determining whether these actually represent new, undescribed species and then describing them requires more careful work (both morphological and molecular) by taxonomic experts in Australia and overseas. Often this work involves revision of an entire genus or family and can take some time.

4.4 Analyses of new sample data

4.4.1 Regional characterisation

The updated regional scale biophysical characterisation, integrating the new sled and trawl sample data with the previous data (see Appendix 5), provided a final map of patterns of biodiversity composition for the region (Figure 10) that were broadly consistent with the initial characterisation. While composition naturally changes in a continuous — though non-uniform — manner, for the purposes of management a categorical characterisation is often preferred. The question then becomes how many categories. The results of multivariate analysis are shown in Figure 11 indicating that variation in trawl and sled data together is best explained by 6 clusters, or assemblages.

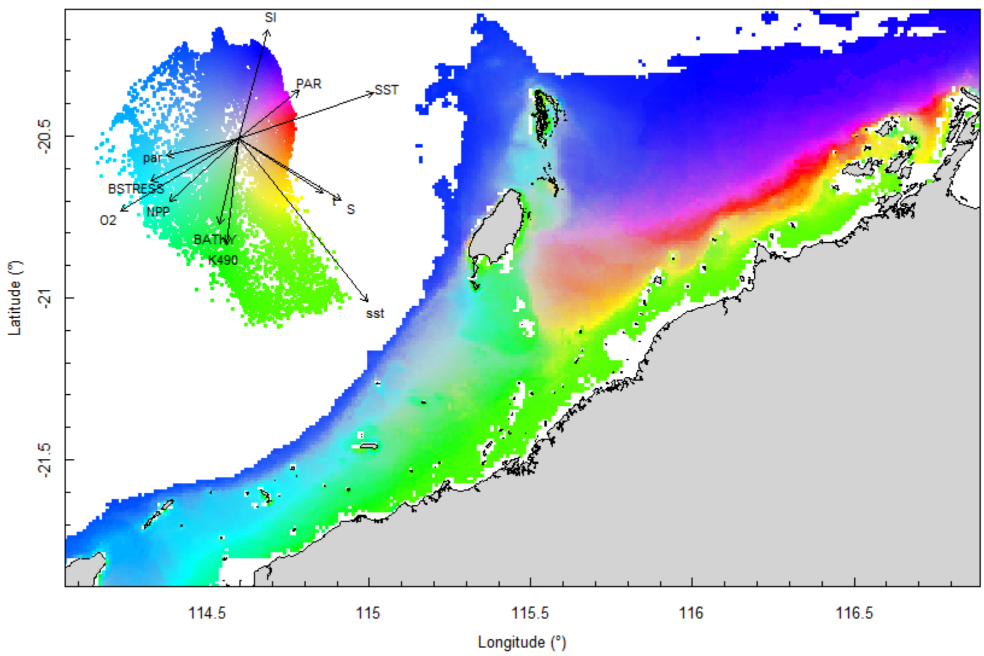

Figure 10. Final continuous seabed characterisation of the west Pilbara region (5-50m), showing expected changes in biodiversity composition associated multiple environmental gradients. The biplot at top left shows the first two dimensions of the transformed biological space and variables principally associated with changes in composition.

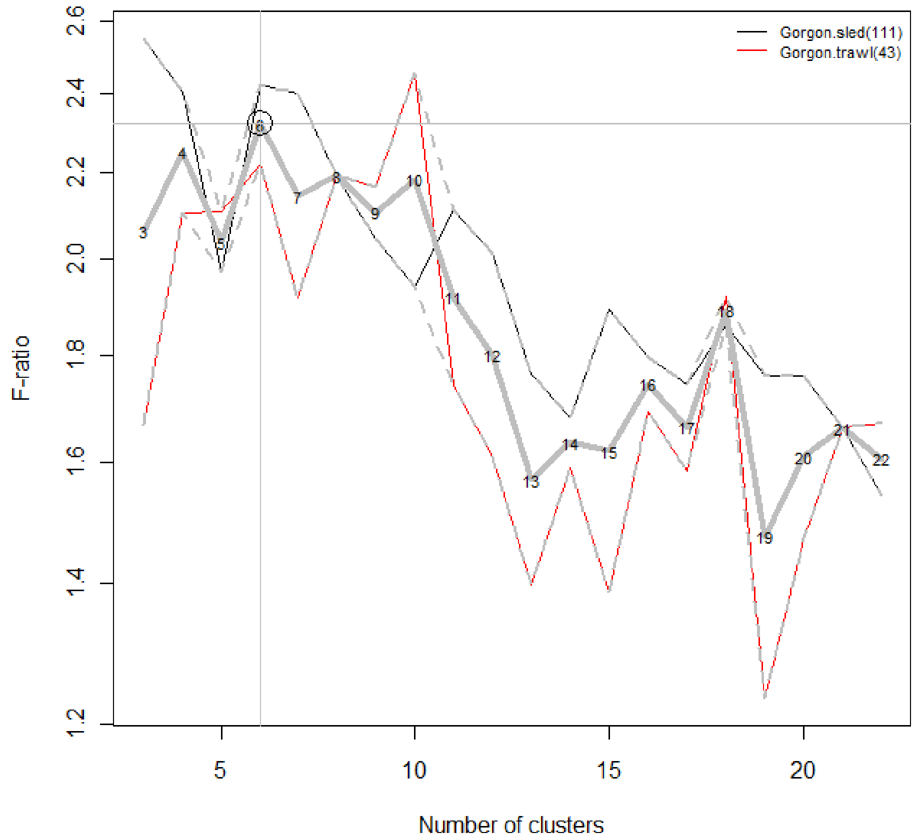

Figure 11. F-ratio results of multi-variate MANOVA illustrating variation in Sled and Trawl site data explained by a range of clusterings (3–22) of the regional biological space.

In this case, as is almost always so, there was not a clear optimum number of assemblages — because biodiversity composition changes continuously. The F-ratio is only a guide; other choices (e.g. 8, 10) are not significantly sub-optimal and there is also a coincident peak in F-ratio at 18 clusters for both trawl and sled (Figure 11). These choices provide different resolutions of biodiversity patterns — coarser to finer — and each may be applicable in different planning and/or management circumstances. Here we suggest that 6 assemblages may be too coarse and do not distinguish shallower reef areas around the Montebello Islands, or south of Barrow Island, from adjacent shelf seabed to the northeast, and southwest, respectively (Figure 12 left). On the other hand, 18 assemblages (Figure 12 right) may be too fine for some management applications. A suitable compromise may be 10 assemblages (Figure 13), which also retains a relatively high F-ratio.

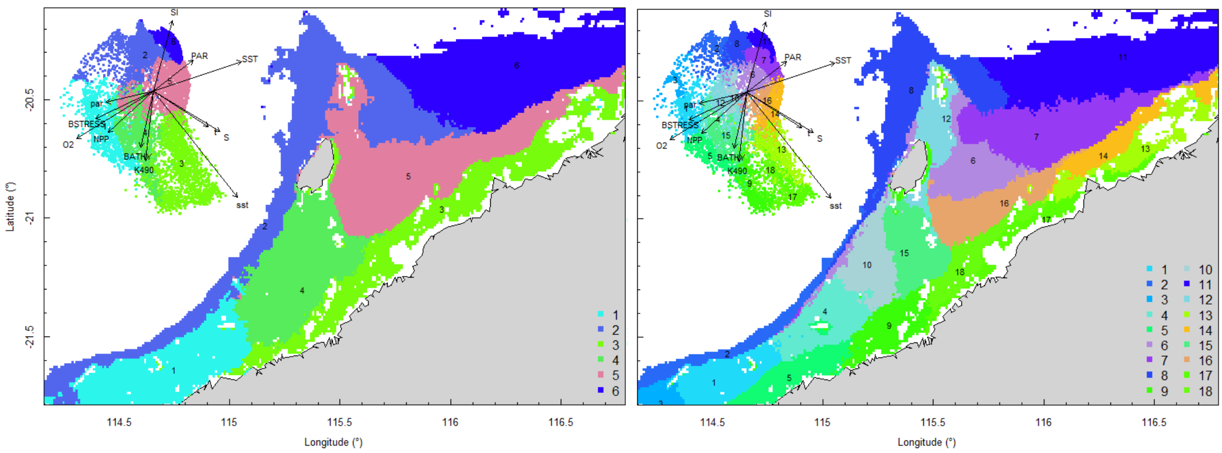

Figure 12. Clustering of the west Pilbara biological space into 6 and 18 assemblage types that each may be appropriate under different planning and/or management circumstances.

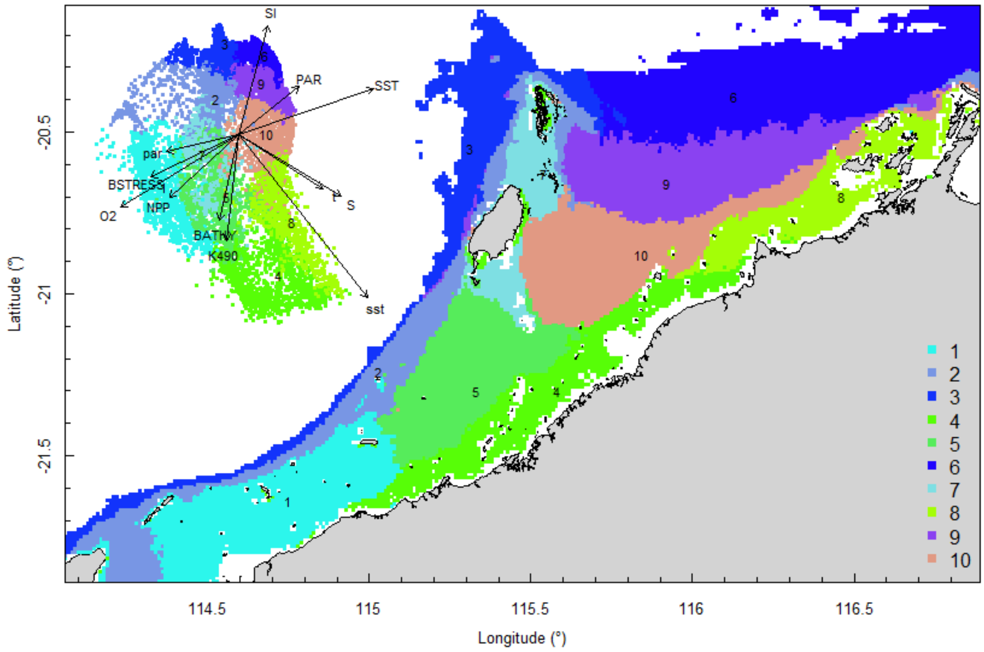

Figure 13. Final seabed characterisation of the west Pilbara region (5-50m): 10 assemblage types were defined based on analyses of new and existing biological survey data with multiple environmental layers. The biplot indicates the principal variables associated with the assemblages.

The important variables associated with compositional patterns in the combined trawl and sled data included: sea surface temperature, bottom temperature, nutrients, salinity, current stress, chlorophyll, oxygen, light, sediments, turbidity, and productivity.

The composition of each assemblage is described in relative terms as follows, with reference to Figure 13, Figure 14, Figure 15 and Appendix 6 (environmental variables, sled and trawl composition).

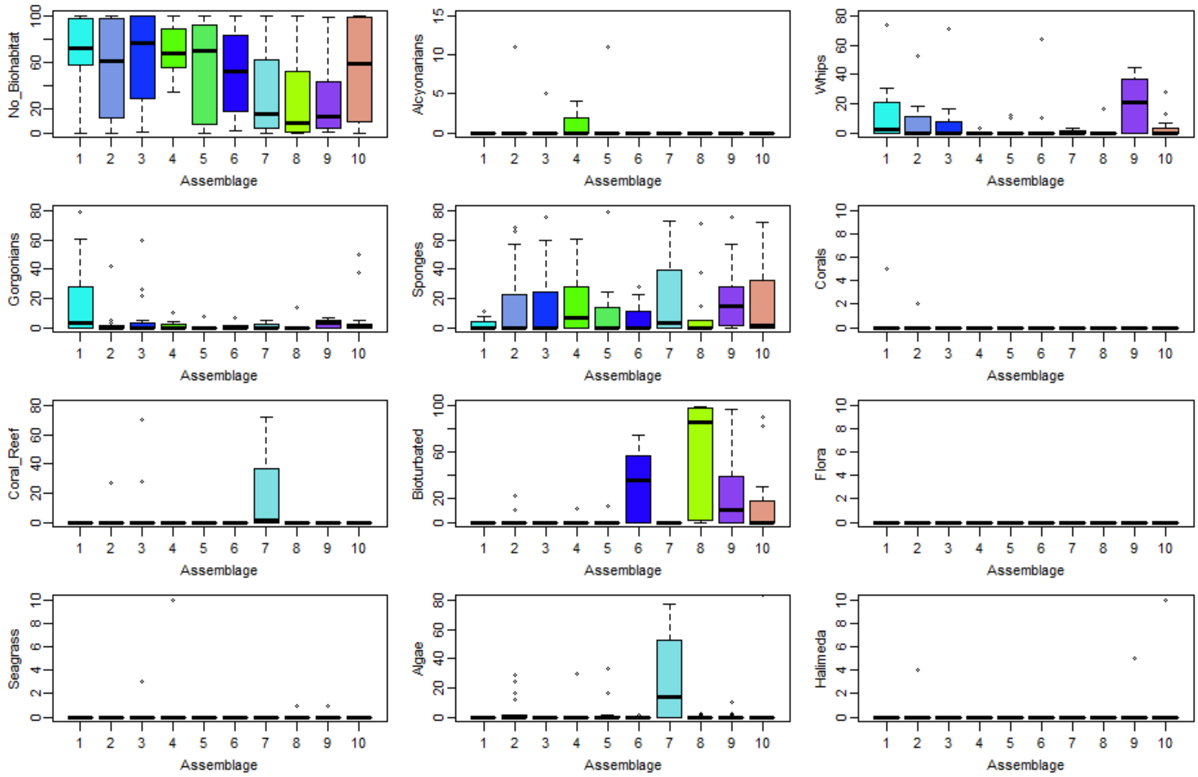

Figure 14. Boxplot summaries of biotic habitat components observed by towed-video, for each Assemblage in the west Pilbara study region. The box indicates the first and third quartiles and the horizontal bar indicates the median value; the whiskers indicate the 'normal' range of the data and small circles indicate outlying values.

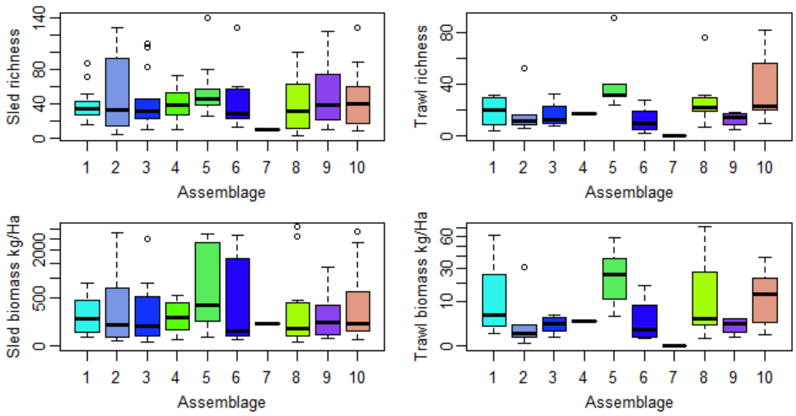

Figure 15. Boxplot summaries of richness and biomass, sampled by the sled and the trawl, for each Assemblage in the west Pilbara study region. The box indicates the first and third quartiles and the horizontal bar indicates the median value; the whiskers indicate the 'normal' range of the data and small circles indicate outlying values.

Assemblage 1: is moderately shallow (Depth: 3.9–16.2 m) with low average sea surface temperature (SST: 25.5–26.1°C), moderately low seabed temperature (24.1–25.3°C) with narrow seasonal range (4.6–5.7°C), moderately low salinity (35.1–35.4‰), high oxygen (4.77–4.82 mL L^{-1}) with moderately narrow seasonal range (0.4–0.48 mL L^{-1}), moderately high seabed stress (0.4–1.9e^{-4} Nm^{-2}), moderately low slope (0–0.4°), moderately high light attenuation (K490: 0.11–0.29 m^{-1}) with moderately wide seasonal range (0.03–0.1 m^{-1}), moderately high net primary production (NPP) (VGPM: 1249–1471 mg C m^{-2} d^{-1}), moderately high gravel (2.4–82.6 %), moderately low sand (5.7–96.5 %) and low mud (0–24.9 %). Other variables had about median range.

The habitat was typically bare seabed interspersed with moderately high cover of gorgonians (0–67.3%) and whips (0–46%), median cover of sponges (0–9%), low corals (0–8.1%) and ~no cover of other habitat forming biota.

The sled samples were of median richness (20.4–77.4 species) and biomass (22.2–842.1 kg Ha^{-1}), and comprised relatively high biomass of Polychaeta (0–9.2), Malacostraca (0.2–8.3), Cephalopoda (0–2.8), and Chlorophyceae (0–1.3); moderately high biomass of Bivalvia (0–183.8), Gastropoda (0–65.7), Crinoidea (0–17.6), Hydrozoa (0–10.6), Phaeophyceae (0–7.2), Ophiuroidea (0–2.5); Liliopsida (0–0.013) and Florideophyceae (0–0.025) were present whereas Calcarea sponges were ~absent and other groups had about median biomass.

Trawl samples had moderately low richness (5.3–31.2 species) but moderately high biomass (1.3–52.8 kg Ha^{-1}), and comprised relatively high biomass of Reptilia (0–50.9), Malacostraca (0–0.65), Echinoidea (0–0.25), Phaeophyceae (0–0.13), Gastropoda (0–0.011); moderately high biomass of Cephalopoda (0.03–0.2) and Crinoidea (0.006–0.08), whereas Holothuroidea, Hydrozoa, Ophiuroidea, Anthozoa, Asteroidea, Ascidiacea, Bivalvia were ~absent and other groups had about median biomass.

Assemblage 2: has median depth (12.0–36.6 m) and relative steep slope (0.04–0.73°), moderately low sea surface temperature (SST: 25.5–26.6°C) with narrow seasonal range (5.6–7.2°C) and median seabed temperature with moderately narrow seasonal range (4.35–6.25°C), moderately low salinity (35.02–35.28 ‰), moderately wide oxygen seasonal range (0.39–0.54 mL L^{-1}), moderately high seabed stress (0.6–4.2e^{-4} Nm^{-2}), moderately narrow K490 seasonal range (0.017–0.073 m^{-1}), moderately narrow NPP seasonal range (VGPM: 482.2–978.8 mg C m^{-2} d^{-1}), moderately high gravel (0–91.4 %), moderately low sand (0–99.4 %) and moderately high carbonate (28.4–99.75 %). Other variables had about median range.

The habitat was typically bare seabed interspersed with moderately high cover of whips (0–95.6%), median gorgonians (0–12.4%) and median sponges (0–73.4%), some cover of algae (0–25%), and low cover of alcyonarians (0–2.2%), corals (0–6.8%), coral reef (0–5.4%), bioturbation (0–13.4%) and halimeda (0–0.8%), and ~no cover of seagrass.

The sled samples were of median richness (5.4–125.9) and biomass (13.4–1568.2 kg Ha^{-1}), and comprised relatively high biomass of Phaeophyceae (0–48.01), Calcarea (0–13.25), Chlorophyceae (0–7.25), Polychaeta (0–6.3) and Florideophyceae (0–2.54), moderately high biomass of Ascidiacea (0–123.6), Crinoidea (0–26.7), Bivalvia (0–19.9), Hydrozoa (0–11.9), Holothuroidea (0–7.9) and Ophiuroidea (0–1.7). Liliopsida (0–0.07) and Cephalopoda (0–2.8) were sampled, and other groups had about median biomass.

The trawl samples were of moderately low richness (6.6–45.6) biomass (0.1–25.4 kg Ha^{-1}), and comprised relatively high biomass of Phaeophyceae (0–0.19), moderately high biomass of Demospongiae (0–18.01) and Ascidiacea (0–0.04), and low biomass of Holothuroidea (0–0.008). Ophiuroidea (0–0.014) and Crinoidea (0–0.25) were sampled, whereas Reptilia, Asteroidea, Bivalvia, Echinoidea, Gastropoda, Hydrozoa were ~absent and other groups had about median biomass.

Assemblage 3: is deep (27.3–48.9 m) with moderately steep slope (0.04–0.78 °), and has moderately high seabed temperature (24.98–25.89 °C) with narrow seasonal range (4.2–5.42 °C) and narrow SST seasonal range (5.68–6.31 °C), low salinity (34.98–35.15 ‰)with moderately narrow seasonal range (0.15–0.26 ‰), moderately low oxygen (4.54–4.65 mL L^{-1}) with narrow seasonal range (0.34–0.44 mL L^{-1}), moderately low light attenuation (K490: 0.048–0.079 m^{-1}) with narrow seasonal range (0.015–0.0415 m^{-1}), moderately low NPP (VGPM: 989.8–1237.4 mg C m^{-2} d^{-1}) with narrow seasonal range (378.3–724.1 mg C m^{-2} d^{-1}), moderately high gravel (0–74.02 %) and low mud (0–4.632 %). Other variables had about median range.

The habitat was typically bare seabed interspersed with moderately high cover of gorgonians (0–34.5%) and whips (0–29.8%); median cover of sponges (0–64%); moderately low coral reef (0–38.5%); low alcyonarians (0–1.2%) and seagrass (0–0.8%); and ~no cover of corals, bioturbation, algae and halimeda.

The sled samples were of median richness (10–107.4) and biomass (12.1–26580.8 kg Ha^{-1}), and comprised relatively high biomass of Crinoidea (0.24–747.7), Ophiuroidea (0–51.6), Polychaeta (0–21.9), Florideophyceae (0–1.02); moderately high biomass of Asteroidea (0–1512.7), Hydrozoa (0–872.1), Malacostraca (0.001–17.2) and Phaeophyceae (0–10.3). Liliopsida (0–0.023), Cephalopoda (0–0.61) and Calcarea (0–3.6) were sampled and other groups had about median biomass.

The trawl samples were of moderately low richness (8.6–30) and biomass (0.6–4.7 kg Ha^{-1}), and comprised relatively high biomass of Asteroidea (0–2.16), Ophiuroidea (0–0.038); moderately high biomass of Demospongiae (0.032–2.34), Ascidiacea (0–0.08), Phaeophyceae (0.001–0.04), Crinoidea (0.002–0.05), Actinopterygii (0.197–1.424), Reptilia (0–0.42), Echinoidea (0–0.004), Hydrozoa (0–0.002). Anthozoa (0.001–0.054) and Malacostraca (0–0.003) were sampled whereas Bivalvia, Holothuroidea, Gastropoda were ~absent and other groups had about median biomass.

Assemblage 4: is shallow (1.3–9.3 m) and flat (slope: 0–0.37 °) and has moderately low SST (24.701–26.705 °C) with relatively wide seasonal range (9.35–10.87 °C), low seabed temperature (24.11–25.36 °C) with wide seasonal range (5.74–6.82 °C), high salinity (35.12–35.61 ‰) with moderately narrow seasonal range (0.12–0.3 ‰), moderately high oxygen (4.69–4.81 mL L^{-1}), moderately high seabed stress (0.3–2.7e^{-4} Nm^{-2}), high light attenuation (K490: 0.184–0.374 m^{-1}) with wide seasonal range (0.05–0.11 m^{-1}), wide NPP seasonal range (VGPM: 787.3–1536.1 mg C m^{-2} d^{-1}), moderately low sand (3.8–95.6%), relatively high mud (0–33.9%) and moderately high carbonate (13.8–98.8 %). Other variables had about median range

The habitat was mostly bare seabed interspersed with median cover of sponges (0–50.8%) and gorgonians (0–7.9%); some cover of algae (0–19.5%), seagrass (0–6.5%), bioturbation (0–7.8%), alcyonarians (0–4%), whips (0–1.9%); and ~ no cover of coral reef, corals, halimeda.

The Sled samples were of median richness (11.4–66.7) and biomass (12–3931.6 kg Ha^{-1}), and comprised relatively high biomass of Cephalopoda (0–1.06); moderately high biomass of Anthozoa (0–234.3), Echinoidea (0–92.2), Ascidiacea (1.239–76.6), Bivalvia (0.484–60.7), Gastropoda (0.213–7.3), Hydrozoa (0–6.4), Actinopterygii (0.037–5.99), Holothuroidea (0–5.17), Florideophyceae (0–3.48), Ophiuroidea (0–1.31), Polychaeta (0–0.76), Chlorophyceae (0–0.57). Phaeophyceae were sampled (0–26.093) whereas Calcarea and Liliopsida were ~absent and other groups had about median biomass.

The Trawl sample was of median richness (17) and biomass (3.2 kg Ha^{-1}), and comprised relatively high biomass of Malacostraca (0.66), Cephalopoda (0.32), Echinoidea (0.42),Bivalvia (0.02), Ophiuroidea (0.01), whereas Asteroidea, Ascidiacea, Phaeophyceae, Crinoidea, Holothuroidea, Gastropoda, Hydrozoa, Reptilia, were ~absent and other groups had about median biomass.

Assemblage 5: is moderately shallow (4.5–18.3 m) and flat (slope 0–0.31 °) and has moderately low SST (25.89–26.414 °C) with wide seasonal range (7.48–9.46 °C), low seabed temperature (24.25–24.88 °C) with moderately wide seasonal range (5.76–6.71 °C), moderately high salinity (35.22–35.48 ‰) with narrow seasonal range (0.12–0.2 ‰), moderately high oxygen (4.74–4.79 mL L^{-1}) with moderately wide seasonal range (0.47–0.53 mL L^{-1}), high seabed stress (0.7–4.8e^{-4} Nm^{-2}), moderately high light attenuation (K490: 0.1203–0.212 m^{-1}) with wide seasonal range (0.0523–0.0985 m^{-1}), high NPP (VGPM: 1335.2–1488.4 mg C m^{-2} d^{-1}) with moderately wide seasonal range (801.7–1152.3 mg C m^{-2} d^{-1}), and low mud (0–0.38 %). Other variables had about median range.

The habitat was mostly bare seabed interspersed with median cover of sponges (0–40.5%) and algae (0–52.8%); moderately low cover of alcyonarians (0–82.7%) and whips (0–10.6%); low cover of coral_reef (0–30%), halimeda (0–8.7%), bioturbation (0–4.2%), gorgonians (0–2.4%), and ~ no cover of corals and seagrass.

The Sled samples were of moderately high richness (27.8–107) and biomass (44.1–7039.8 kg Ha^{-1}), and comprised relatively high biomass of Phaeophyceae (0–28.42), Polychaeta (0–8.53), Cephalopoda (0–2.31); moderately high biomass of Actinopterygii (0.32–11.48), Anthozoa (0.045–987.1), Ascidiacea (0–137.5), Bivalvia (0–1308.1), Echinoidea (0.091–99.56), Gastropoda (0.188–2.68), Holothuroidea (0.059–29.51), Hydrozoa (0–3.24), Malacostraca (0.359–2.42), Ophiuroidea (0–3.08). Chlorophyceae (0–2.84), Calcarea (0–1.17), Liliopsida (0–0.064), Florideophyceae (0–0.355) were sampled and other groups had about median biomass.

The Trawl samples were of high richness (25.4–81.6) and moderately high biomass (5.7–54.8 kg Ha^{-1}), and comprised relatively high biomass of Actinopterygii (3.01–38.82), Anthozoa (0.001–14.91), Demospongiae (0.91–7.51), Bivalvia (0–0.543), Phaeophyceae (0.006–0.76), Holothuroidea (0–0.59), Gastropoda (0–0.031); moderately high biomass of Echinoidea (0–0.032), Ascidiacea (0–0.174), Cephalopoda (0–0.477), Crinoidea (0–0.103). Asteroidea (0–0.015), Hydrozoa (0–0.175), Malacostraca (0–0.352) were sampled whereas Ophiuroidea and Reptilia were ~absent and other groups had about median biomass.

Assemblage 6: is deep (34.3–49.1 m) and flat (slope 0–0.2200392 °) and has high SST (26.65–27.11 °C) with moderately narrow seasonal range (6.195–7.164 °C), median seabed temperature with moderately narrow seasonal range (4.86–5.58 °C), low oxygen (4.54–4.58 mL L^{-1}) with narrow seasonal range (0.3–0.44 mL L^{-1}), low seabed stress (0.3–1.0e^{-4} Nm^{-2}), low light attenuation (K490: 0.043–0.064 m^{-1}) with moderately narrow seasonal range (0.0298–0.0432 m^{-1}), low NPP (VGPM: (936.6–1102.3 mg C m^{-2} d^{-1}) with narrow seasonal range (486.71–886.48 mg C m^{-2} d^{-1}), moderately high sand (67.4–99.3 %), low mud (0–1.9 %) and low carbonate (7.8–53.1 %). Other variables had about median range.

The habitat was mostly bare seabed with moderately high levels of bioturbation (0–68.6%), median cover of sponges (0–26%), moderately low cover of gorgonians (0–4.6%), low cover of algae (0–0.6%), presence of whips (0–42.4%) and no cover of corals, coral reef, flora, seagrass, alimeda, alcyonarians.

The Sled samples were of median richness (14.5–104.2) and biomass (9.5–2525.8 kg Ha^{-1}), and comprised relatively high biomass of Florideophyceae (0–1.614); moderately high biomass of Hydrozoa (0.332–6.591) and Malacostraca (0.082–0.671). Calcarea (0–1.134), Cephalopoda (0–0.552), Phaeophyceae (0–0.049) were sampled whereas Chlorophyceae and Liliopsida were ~absent and other groups had about median biomass.

The Trawl samples were of low richness (2.9–25.4) and moderately low biomass (0.3–15.9 kg Ha^{-1}), and comprised relatively high biomass of Cephalopoda (0.006–0.397), Gastropoda (0–0.014), Hydrozoa (0–0.029); moderate biomass of Malacostraca (0–0.041), Bivalvia (0–0.019), Crinoidea (0–0.071). Anthozoa, Echinoidea, Holothuroidea, Ophiuroidea and Reptilia were ~absent and other groups had about median biomass.

Assemblage 7: is shallow (1.174–11.522 m) with moderately low SST (25.57–26.76 °C) but high seabed temperature (24.89–25.94 °C) with moderately wide seasonal range (6.2–6.46 °C), low salinity (35.01–35.25 ‰) with moderately wide seasonal range (0.14–0.37 ‰), high seabed stress (0.8–4.3e^{-4} Nm^{-2}), high light attenuation (K490: 0.13–0.229 m^{-1}), high NPP (VGPM: 1239.9–1573.5 mg C m^{-2} d^{-1}), low gravel (0–29.3 %), moderately high sand (0–100 %), low mud (0–19.684 %) and high carbonate (80.26–100 %). Other variables had about median range.

The seabed had relatively less area of bare seabed and higher cover of algae (0–69.6%) and coral reef (0–61.5%); median cover of sponges (0–62.9%) and gorgonians (0–4.2%); moderately low cover of whips (0–2.5%) and no cover of alcyonarians, corals, bioturbation, flora, seagrass and Halimeda.

The single Sled sample was of low richness (10) and median biomass (109 kg Ha^{-1}), and comprised relatively high biomass of Echinoidea (102.813–102.813) and Phaeophyceae (5.484–5.484); moderately high biomass of Chlorophyceae (0.028–0.028) and median biomass of Gastropoda. All other groups were not sampled and no trawl samples were possible.

Assemblage 8: is shallow GorgBATHY (1.55–15.08 m) and flat (slope 0–0.275 °), and has moderately high SST (26.45–27.44 °C) with wide seasonal range (7.68–9.99 °C), high seabed temperature (25.32–26.32 °C) with moderately wide seasonal range (6.17–6.52 °C), high salinity (35.49–35.66 ‰) with wide seasonal range (0.3–0.46 ‰), moderately narrow oxygen seasonal range (0.44–0.47 mL L^{-1}), moderately high seabed stress (0.3–2.19e^{-4} Nm^{-2}), moderately high light attenuation (K490: 0.115–0.262 m^{-1}) with wide seasonal range (0.065–0.121 m^{-1}), moderately high NPP (VGPM: 1227.1–1505.2 mg C m^{-2} d^{-1}) with wide seasonal range (892.5–1395.6 mg C m^{-2} d^{-1}), moderately low gravel (0–34.5 %) and sand (0–97.8 %) sediments with high mud (0–99.3 %) and carbonate (29.5–100 %). Other variables had about median range.

The habitat was mostly bare seabed with large areas of bioturbation (0–98.4%); median cover of sponges (0–51.2%); low cover of whips (0–6.4%), gorgonians (0–5.6%), Halimeda (0–5.2%), algae (0–1.4%), seagrass (0–1%) and no cover of alcyonarians, corals, coral reef.

The sled samples were of moderately low richness (3.2–99.4) and median biomass (2.7–2856.2 kg Ha^{-1}), and comprised relatively high biomass of Cephalopoda (0–1.953); moderately high biomass of Bivalvia (0–105.403), Echinoidea (0–92.057), Holothuroidea (0–17.598), Asteroidea (0–13.686), Actinopterygii (0–9.612), Malacostraca (0–3.881), Ophiuroidea (0–2.783) and Polychaeta (0–1.024), whereas Calcarea (0–2.431), Florideophyceae (0–0.058), Liliopsida (0–0.016), Chlorophyceae (0–0.109) were sampled and other groups had about median biomass.

The trawl samples were of moderately high richness (10–63.5) and biomass (0.7–61.4 kg Ha^{-1}), and comprised relatively high biomass of Anthozoa (0–11.35), Malacostraca (0–1.34), Ascidiacea (0–0.86), Cephalopoda (0.001–0.34), Holothuroidea (0–0.035); moderately high biomass of

Actinopterygii (0.201–15.94), Demospongiae (0–3.79), Crinoidea (0–0.093), Phaeophyceae (0–0.052), Asteroidea (0–0.011), Ophiuroidea (0–0.003); moderately low biomass of Gastropoda (0–0.005). Bivalvia (0–0.128), Echinoidea (0–0.057), Reptilia (0–33.413) were sampled, whereas Hydrozoa were absent and other groups had about median biomass.

Assemblage 9: is moderately deep (21.16–33.14 m) and (0–0.261 °), and has moderately high SST (26.36–26.95 °C) and seabed temperature (25.15–25.6 °C), moderately wide salinity seasonal range (0.27–0.36 ‰), moderately low oxygen (4.58–4.65 mL L^{-1}) with moderately wide seasonal range (0.45–0.52 mL L^{-1}), low seabed stress (0.2–0.9e^{-4} Nm^{-2}), moderately low light attenuation (K490: 0.056–0.0821 m^{-1}) with moderately narrow seasonal range (0.0291–0.0633 m^{-1}), moderately low NPP (VGPM: 1033.2–1216.7 mg C m^{-2} d^{-1}), moderately low gravel (0.08–69.9 %) and carbonate (7.14–99.8 %) sediments with moderately high sand (28.1–99.6 %) and low mud (0–31.5 %). Other variables had about median range.

The habitat was mostly bare seabed with moderately large areas of bioturbation (0–94.6%); relatively high cover of whips (0–44.4%) and sponges (0.6–64.6%); moderately high cover of gorgonians (0–6.4%); moderately low cover of algae (0–5.2%); low cover of halimeda (0–2%) and seagrass (0–1%) and no cover of alcyonarians, corals, or coral reef.

The sled samples were of median richness (11.1–100.9) and biomass (17.1–1037.5 kg Ha^{-1}), and comprised relatively high biomass of Florideophyceae (0–16.515), Calcarea (0–1.36), Liliopsida (0–0.105); moderately high biomass of Hydrozoa (0–15.116), Holothuroidea (0–2.903), Cephalopoda (0–0.232), Chlorophyceae (0–0.258); and other groups had about median biomass.

The trawl samples were of moderately low richness (6–17.9) and biomass (0.6–3.7 kg Ha^{-1}), and comprised relatively high biomass of Echinoidea (0–0.069), Hydrozoa (0–0.042); moderately high biomass of Demospongiae (0.002–1.027), Anthozoa (0–0.886), Malacostraca (0–0.05), Crinoidea (0.001–0.044), Bivalvia (0–0.029); moderately low biomass of Reptilia (0–0.739), Cephalopoda (0–0.037), Gastropoda (0–0.003) and Asteroidea (0–0.001). Phaeophyceae, Holothuroidea, Ophiuroidea were absent and other groups had about median biomass.

Assemblage 10: is moderately shallow (7.1–20.1 m) and flat (slope: 0–0.283 °), and has moderately wide SST seasonal range (7.34–9.11 °C), moderately low seabed temperature (24.72–25.83 °C) with wide seasonal range (6.2–6.66 °C), moderately high salinity (35.14–35.51 ‰) with moderately wide seasonal range (0.23–0.43 ‰), moderately wide oxygen seasonal range (0.46–0.53 mL L^{-1}) and K490 seasonal range (0.041–0.089 m^{-1}), wide NPP seasonal range (VGPM: 955.52–1309.19 mg C m^{-2} d^{-1}) and low mud (0–30.5 %).

The habitat was mostly bare seabed with moderately large areas of bioturbation (0–84%); moderate cover of gorgonians (0–41%), whips (0–16.8%) and sponges (0–47.2%); low cover of seagrass (0–4.5%), algae (0–21%) and low Halimeda (0–2.5%); and ~no cover of alcyonarians, corals and coral reef.

The sled samples were of median richness (8.8–98.2) biomass (22.7–2476.5 kg Ha^{-1}), and comprised relatively high biomass of Anthozoa (0–798.75), Phaeophyceae (0–192.048), Asteroidea (0.013–38.464), Chlorophyceae (0–12.414), Holothuroidea (0–10.148), Liliopsida (0–0.087); moderately high biomass of Florideophyceae (0–3.345), Echinoidea (0–42.805), Gastropoda (0–3.533), Malacostraca (0–4.41), Polychaeta (0–4.337); and Cephalopoda (0–0.341) were sampled. Calcarea were absent and other groups had about median biomass.

The trawl samples were of moderately high richness (12.8–77.4) and biomass (1–36.8 kg Ha^{-1}), and comprised relatively high biomass of Anthozoa (0.002–10.487), Asteroidea (0–1.403), Bivalvia (0–1.007), Ascidiacea (0–0.741), Holothuroidea (0–0.243); moderately high biomass of Actinopterygii (0.642–24.909), Malacostraca (0–0.744), Gastropoda (0–0.289), Echinoidea (0–0.15), Crinoidea (0–0.111), Ophiuroidea (0–0.08), Phaeophyceae (0–0.058); and low biomass of Reptilia (0–0.517). Hydrozoa (0–0.018) were sampled and other groups had about median biomass.

4.4.2 Species distributions

Successful species distribution models and maps were generated for 183 species of 340 that met the minimum occurrence criterion of being sampled at ≥4 sites. Note that the majority of species (Sled: 75.3%; Trawl: 87.6%) were too rare for analyses (see section 4.3). A successful model is defined as being able to predict held-out data better than random in cross-validation tests. This is not the same as model fit to the data or "explained variation", which was generally around 80% for most models (even for some models with unsuccessful prediction performance) — nevertheless, a substantive number of models could not fit the data better than the overall mean. The prediction performance of the species distribution models is summarized in Figure 16. For sled, 143 of 286 models (50%) were successful and for trawl, 40 of 54 models (74%) were successful. While many successful models were relatively weak, prediction performance ranged up to 43% for sled and 56% for trawl. These differences between trawl and sled are not unusual as the larger sampled area of the trawl (~1.0 Ha) compared with the sled (~ 0.03 Ha) tends to produce less variable data. Further, fishes dominate the trawl samples and tend to be less heterogeneously distributed than invertebrates that are sampled better by the sled.

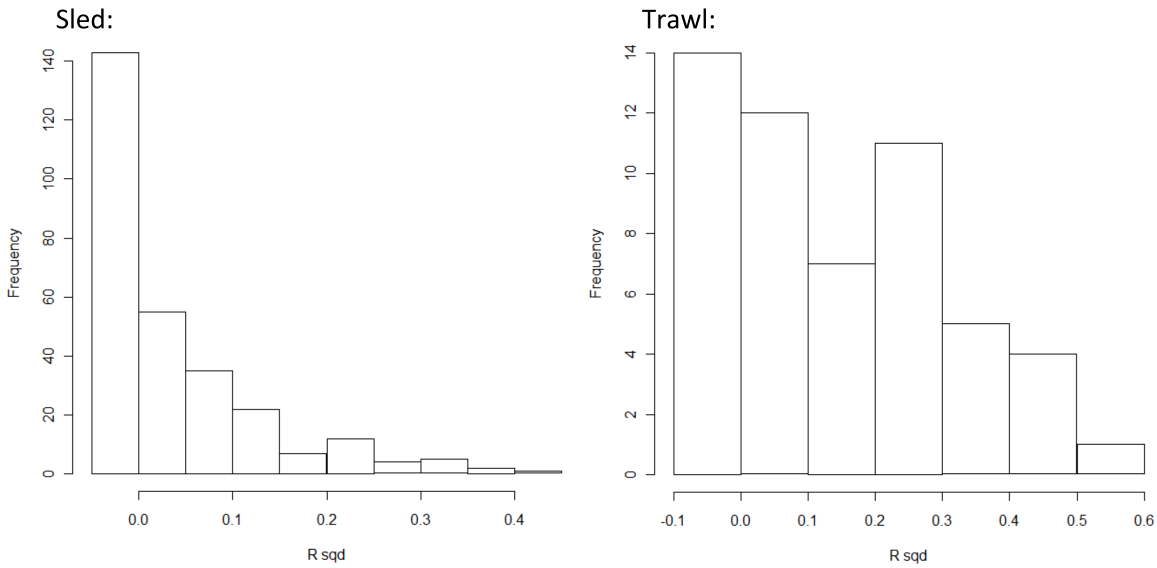

Figure 16. Histograms of species distribution model prediction performance (R squared) on held-out samples.

Of the 258 taxa sampled by both sled and trawl, 25 met the minimum occurrence criterion for both devices and were candidates for joint modelling. This was done by iteratively estimating, until convergence, a relative catchability between the two devices, using linear models, and fitting randomForest models to the joint data after adjusting for the differences. In this way, successful joint models were developed for 20 of the 25 taxa. In 5 cases, the joint model performed better than either the respective sled or the trawl models — and in 2 of those 5 cases, both the sled and trawl models were unsuccessful.

Distribution maps were ultimately predicted for 185 species (or taxa), based on a mix of either sled or trawl data, and a number of joint models. All maps are provided in Appendix 7; here a selection of contrasting species distributions from a range of taxa are presented (Figure 17, Figure 18, Figure 19). The maps indicate species names, frequency in sled, trawl or joint models, names of selected predictors, cross-validated model performance, and model complexity (as indicated by the number of predictors and number of terminal nodes [tree branches]). The maps demonstrate that different species are associated with different environmental variables and so have different distributions — even similar, congeneric species, thus emphasizing the importance of species level identifications where possible.

The distribution of *Lethrinus genivittatus* (Figure 17) is considered to be associated with marine

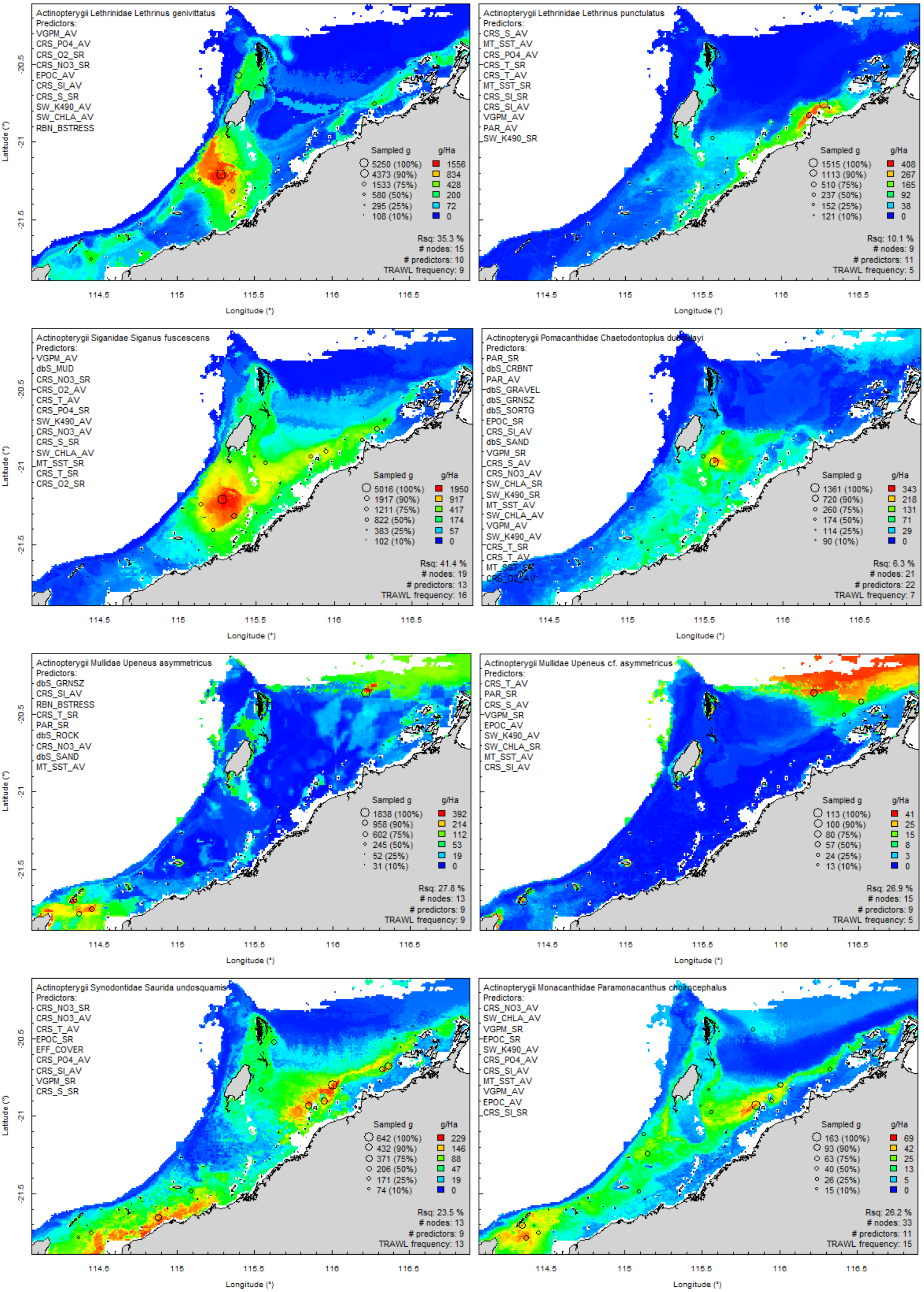

Figure 17. Maps of predicted distributions for selected species of fishes. Map annotations indicate species names, frequency in Trawl models, names of predictors, model performance (Rsq), and model complexity (number of predictors and nodes).

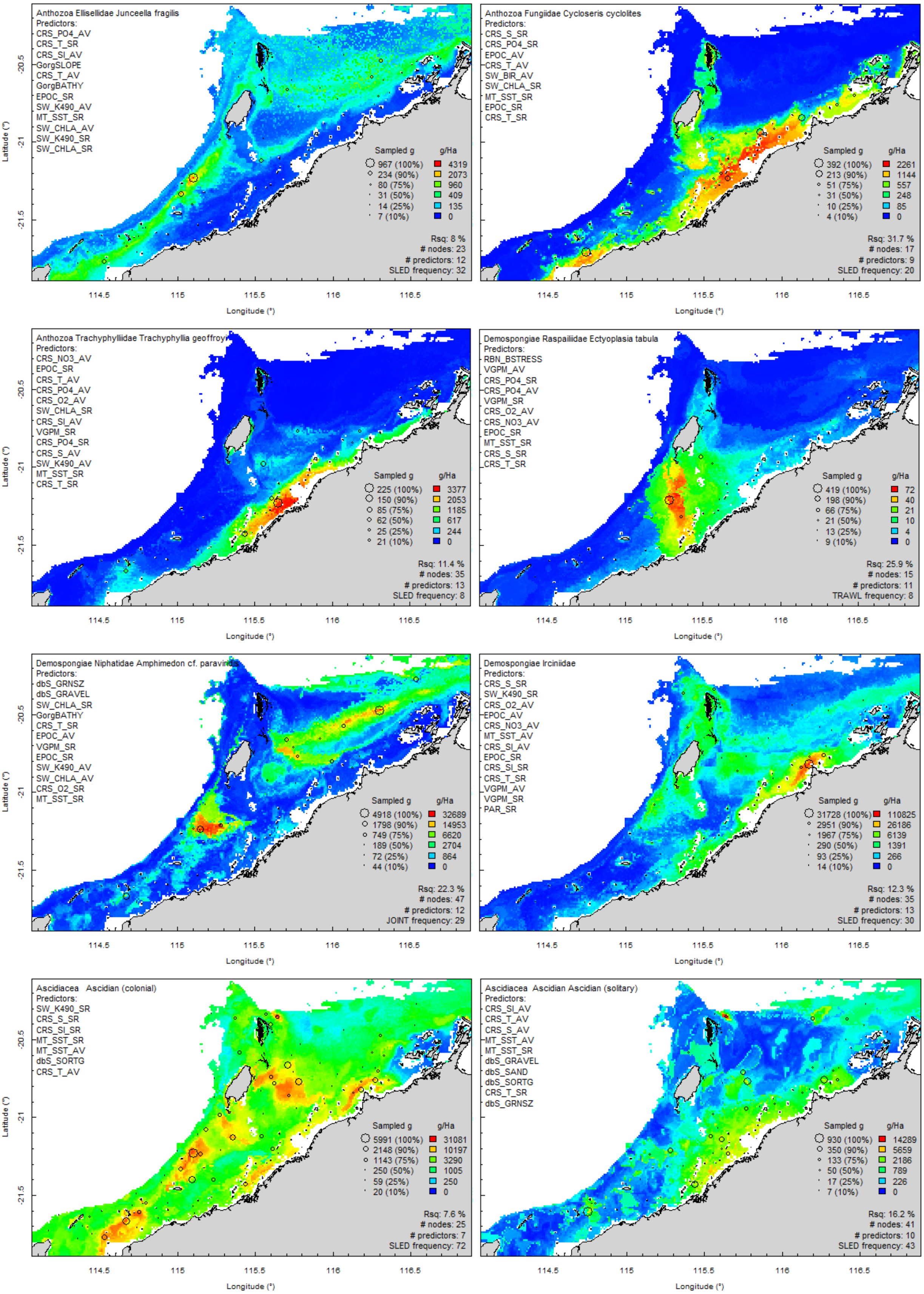

Figure 18. Maps of predicted distributions for selected species of corals, sponges and ascidians. Map annotations indicate species names, frequency in Sled, Trawl or Joint models, names of predictors, model performance (Rsq), and model complexity (number of predictors and nodes).

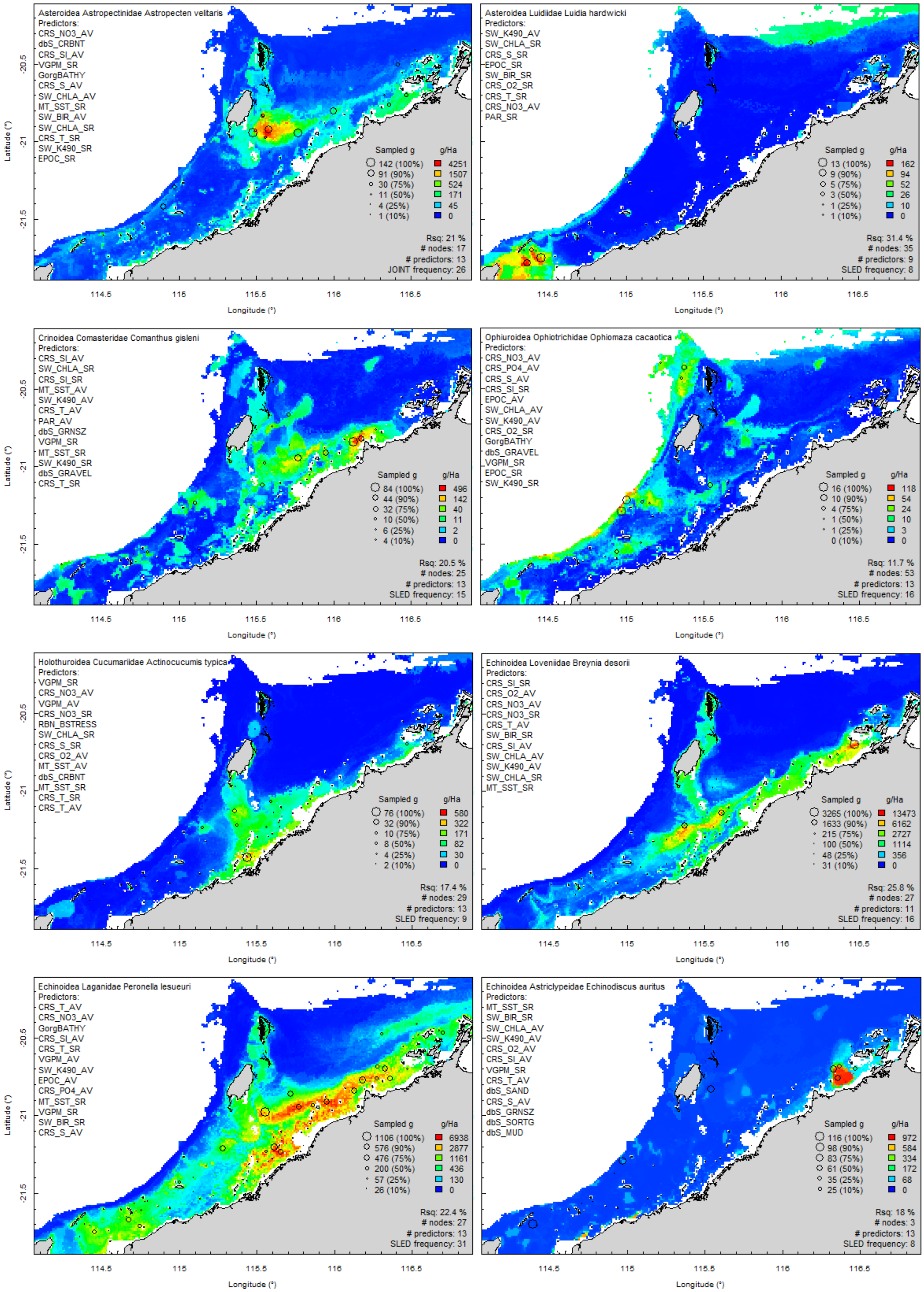

Figure 19. Maps of predicted distributions for selected species of echinoderms. Map annotations indicate species names, frequency in Sled or Joint models, names of predictors, model performance (Rsq), and model complexity (number of predictors and nodes).

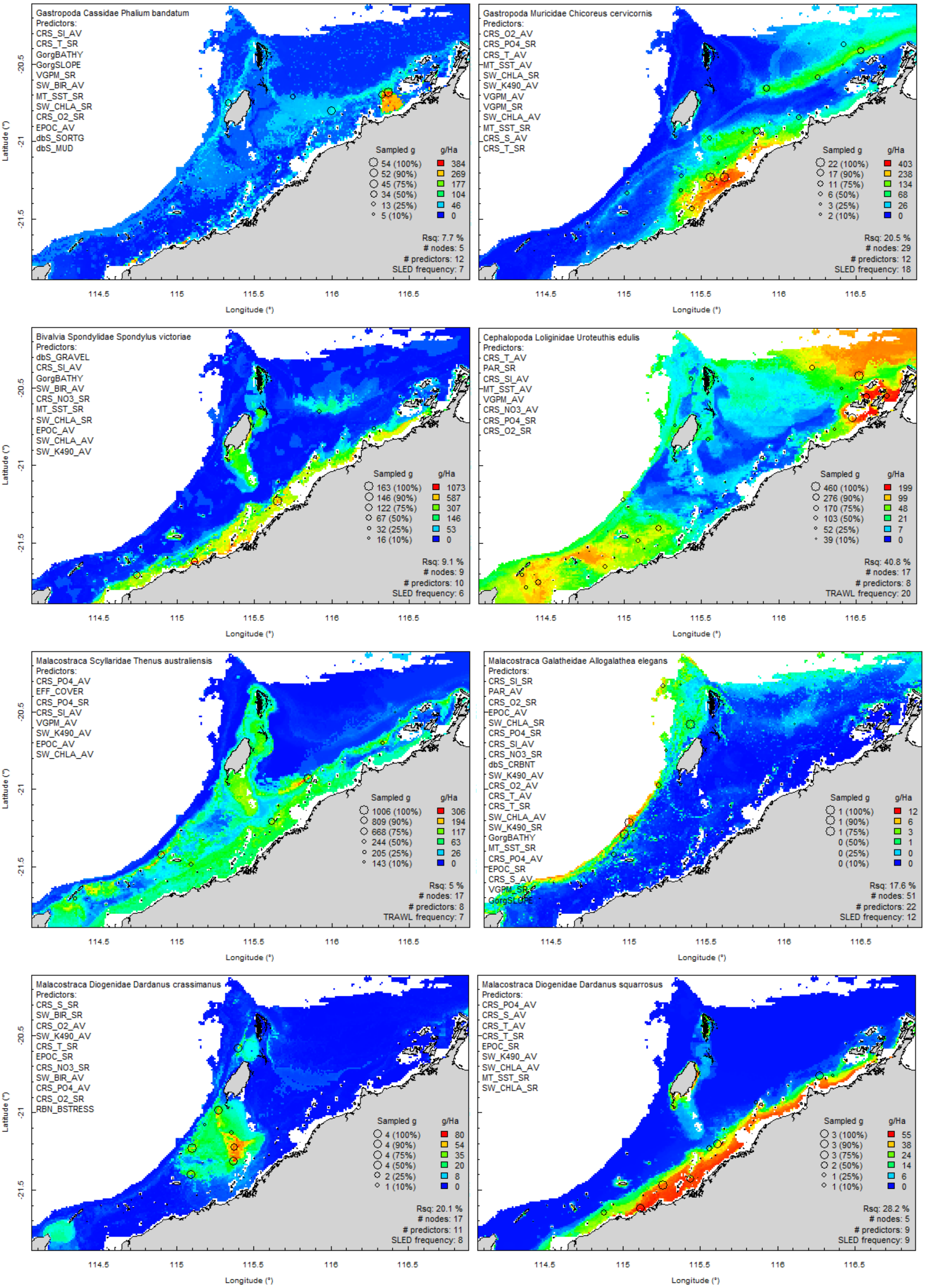

Figure 20. Maps of predicted distributions for selected species of molluscs and crustaceans. Map annotations indicate species names, frequency in Sled or Trawl models, names of predictors, model performance (Rsq), and model complexity (number of predictors and nodes).

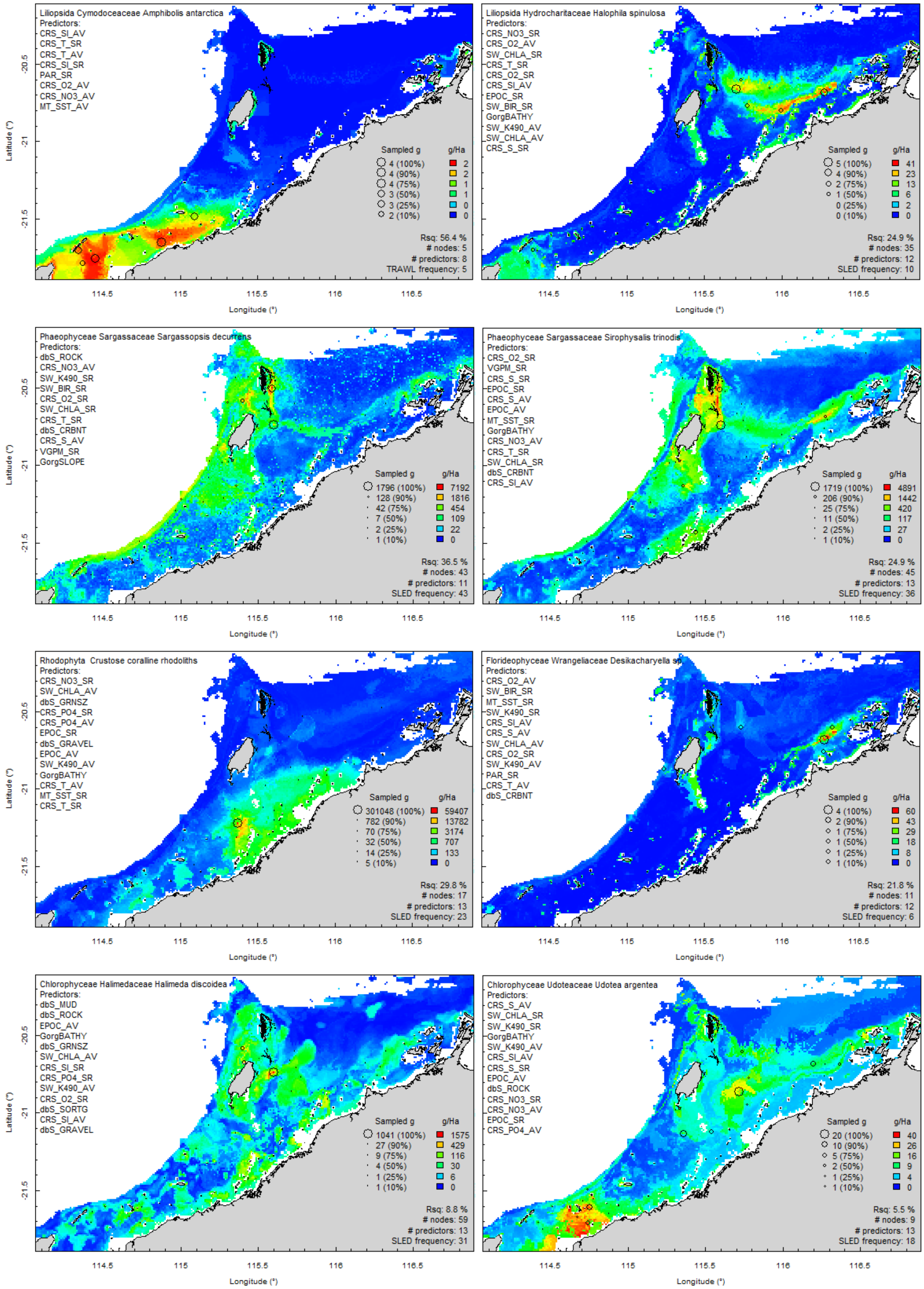

Figure 21. Maps of predicted distributions for selected species of sea grass and algae. Map annotations indicate species names, frequency in Sled or Trawl models, names of predictors, model performance (Rsq), and model complexity (number of predictors and nodes).

plants and has some correspondence with the distributions of some Sargassid species (Figure 21) and contrasts with congeneric *L. punctulatus* which corresponds with a number of sponges (e.g. Irciniidae), ascidians and some crinoids (Figure 18 and Figure 19). *Siganus* is a herbivore, and also corresponds with some Sargassid taxa. *Chaetodontoplus* is a popular aquarium species. The two goatfish (*Upeneus*, Figure 17) are very similar species with apparently contrasting distributions. The lizard fish (*Saurida*) and file fish (*Paramonocanthus*) are common on sandy seabeds.

Corals, sponges and ascidians (Figure 18) include some of the highest biomass taxa. *Trachyphyllia* and *Cycloseris* are likely to be species collected by the coral aquarium fishery. The seawhip, *Junceella*, along with many other gorgonians and sponges are potential habitat forming species.

Echinoderms (Figure 19) are a diverse group. *Astropecten* and *Luidia* are common sea-stars on sandy shelf seabeds, but with contrasting distributions. Crinoids (e.g. *Comanthus*) are often found attached in elevated positions on habitat forming benthos (e.g. at Cape Preston). Numerous other crinoids have a deeper offshore distribution similar to the brittle star *Ophiomaza*, which lives only on different kinds of crinoids. The sea cucumber (*Actinocucumis*) and heart urchin (*Breynia*) have inshore distributions and feed on sedimentary deposits. *Echinodiscus* and *Peronella* are both sand dollars but have very different distributions. The gastropod *Phalium* (Figure 21) is a known predator of *Echinodiscus* and their distributions appear to be clearly associated.

Chicoreus is a spectacular spiky gastropod with a central inshore distribution (Figure 21); the spiny bivalve *Spondylus* also has an inshore distribution and may be its prey. The common squid *Uroteuthis* and the bug lobster *Thenus* are both potential commercial by-product species. The squat lobster *Allogalathea* has a deeper offshore distribution. The congeneric hermit crabs *Dardanus* have strongly contrasting distributions.

The region may be a transition for seagrass species, with the temperate *Amphibolis antarctica* appearing at the edge of its range in the south of the study area, and the tropical *Halophila spinulosa* in the north of the study area (Figure 21). The biomass and cover of seagrass was low, but they are considered important food sources for turtles and dugongs. Most algal taxa were distribution towards the central part of the region and are considered important habitat (e.g. Sargassid species) for fishes and other species, and have been implicated in lethrinid recruitment. Algae are diverse and include browns (e.g. Sargassaceae sps.), coraline rhodoliths, reds (e.g. *Desikacharyella*), calcified greens (e.g. *Halimeda*), and other greens (e.g. Udotea).

5 Discussion

The project has demonstrated substantial biodiversity on seabed of the Pilbara region, and has filled in data gaps for the majority of the ~18,700 km² study area, much of which had no pre-existing data. Most of the prior biological knowledge about the region comes from fisheries surveys largely outside the immediate vicinity of the study area. The completed sorting and identification of samples has revealed new species and provided valuable specimens accessioned into the WA Museum that comprise an important biodiversity and genetic resource for WA. These new data and analyses have also documented the important relationships between sampled species distributions and environmental gradients that have been used to predict patterns of seabed assemblages and if species distributions at regional scale. These maps of regional biodiversity are more comprehensive and more detailed than available previously.

The Pilbara shelf seabed is a complex mix of physical environments. The biological assemblages were observed to respond significantly to the multiple interacting physical gradients and few of these gradients have simple trends in geographic space. Some of the environmental gradients most associated with driving patterns of biodiversity composition include: seasonal range in sea surface temperature, which is greater in shallower and inshore areas; average annual sea surface temperature, which is higher in the NE of the region cf. the SW; seasonal range in salinity, which is greater in the NE coastal areas and lowest in central areas; seasonal range in bottom temperature, which is greater in central and NE inshore areas and lowest in deeper offshore area; seabed current stress, which is higher in central areas and around North West Cape; bottom water oxygen, which is higher on SW shelf areas and decreasing to the NE and with depth; and turbidity, which is higher in inshore areas. Other variables also are associated with biodiversity patterns but are increasingly less important overall, including those related to light, productivity, nutrients, and sediment types. These gradients in the Pilbara are perhaps not as strong as in some other areas such as the Torres Strait and parts of the Great Barrier Reef region, where sediment types and seabed current stress are strong drivers.

The epibenthic sled and research trawl both sampled a diverse seabed biota of about 12 phyla and 1326 species, of which almost 20% were sampled by both devices; 899 (78%) were unique to the sled and 169 (40%) to the trawl. The sled samples were rich with more than ~45 taxa per site on average, whereas the trawl samples averaged about 25 taxa per site. This site richness is somewhat lower than other similar tropical demersal/benthic surveys in the Torres Strait and the Great Barrier Reef regions (e.g. Pitcher et al. 2007ab: TS: sled: ~49, trawl: ~76; GBR: sled: ~41, trawl: ~76 — excluding Bryozoans), particularly for the trawl samples. Nevertheless, the trawl sampled fishes more consistently and representatively, whereas the Sled sampled all other biota better, though with greater variability due to its much smaller swept area. These devices provided specimens that could be properly identified, showed that otherwise inseparable taxa could have strikingly different distribution patterns, and revealed the biodiversity of the region (even at sites where no biota were observed in video). The level of relative rarity of species in the samples was also high: ~76% of sled species were found at <5 sled sites, and >87% of trawl species were found <5 trawl sites. This rarity was somewhat higher than other similar tropical demersal/benthic surveys (e.g. Pitcher et al. 2007ab: TS: sled: ~76%, trawl: ~75%; GBR: sled: ~62%, trawl: ~65%), particularly for the trawl samples. This suggests that more species, possibly many more, remain to be discovered by further sampling in the region.

As is typical of biological sampling, a large proportion of taxa were sampled at only one or a very few sites. This suggests that many more seabed species remain to be discovered in the shelf seabed of the region. Compared with the total number of species sampled, relatively fewer species were considered frequent enough for analyses (at ≥5 sites). Nevertheless, there were about 315 species that meet this criterion, including 25 that were sampled by both devices. The randomForest method provided a robust and flexible approach for modelling statistical relationships between the biological data and environmental gradients, and for identifying the important variables and predicting distributions. Ultimately, accounting for species modelled from both devices and joint modelling, 180 taxa had 'successful' models. Species with unsuccessful models had no statistically predictable relationship with the environmental variables. For the majority of species, i.e. those occurring at <5 sites, no individual analyses or modelling was possible, although the sample data are available. While the environmental variables have demonstrable utility for predicting the regional distribution of many species with adequate frequency of occurrence, not all the successful models could predict well even if they fitted the site data well. That is, they do not often account for the majority of observed variation in local biomass — other factors, including stochastic processes such as recruitment and mortality, biological interactions, and random sampling effects typically outweigh deterministic environmental relationships, or habitat preferences, at the local site biomass scale. Nevertheless, the regional scale patterns of distribution are representative.

The multitude of species sampled, modelled and mapped respond in different, overlapping and varying ways to the multiple interacting environmental variables, which as noted above do not have simple trends in geographic space. Different species were associated with different variables, and some positively and others negatively to the same variables. Overall, the important variables for species were largely in line with the environmental variables associated with assemblage patterns.

5.1 Integration with other PMCP projects and sub-projects

The datasets collated by this project have been used by the Hydrodynamic Model & Connectivity Project of the PMCP, and the characterisation of benthic habitats and assemblages in the Pilbara region, have been used to inform the sampling locations for the broad-scale sampling that is being carried out within the scope of the Coral Health and Reef and Sharks projects of the PMCP.

5.2 Planning and management implications

The outputs from this study are intended to support a range of spatial planning, assessment and management applications across the west Pilbara, including for conservation, assessments of current uses, and to provide information for evaluating future development proposals. Such applications of the project's outputs will be developed in an ongoing fashion as part of continuing dialogue with government stakeholders.

The outputs from the project can support important management questions:

- Is the current positioning and scale of MPA networks and no-take zones providing comprehensive, adequate and representative protection for marine benthic species, assemblages and habitats?
- What is the CAR performance of spatial management at multiple levels, including habitats, assemblages and for hundreds of species?
- What should be the size and location of spatial management zones in the region?
- What is the appropriate design for spatial management plans for activities such as recreational fishing, industrial and tourism development, infrastructure planning relevant to DEC but also to DOF, EPA, DPI
- Are proposed development areas unique in terms of their biodiversity and habitat values, or for any key threatened species?
- How can biodiversity be taken into account in assessments of development plans in relation to relevant marine management units in a quantitative and objective manner?
- How do anthropogenic risk factors map across various habitats and biodiversity values in the region, including marine parks?

The project's outputs will enable spatial analyses of the overlap of human uses with multiple levels of biodiversity, permitting ecological risk assessments and, for some types of uses, fully quantitative assessments of their sustainability. The outputs will also support design of spatial aspects of monitoring in relationship to biodiversity attributes and human use factors.

As an example, we quantified the representation of the 10 assemblages defined for the west Pilbara shelf (Figure 13) in the region's Marine Park areas (both State and Commonwealth, Figure 22) and their exposure to regional trawl fisheries (Table 2). Highly protected areas (IUCN IA) ranged from 0−19% of each Assemblage, and trawl footprints ranged from 0−10.3%. Analogous quantification is possible for fishery closure areas and major marine infrastructure development, among others. Further, the representation of habitats, commercial species, species of conservation concern and other species in Marine Park zoning or other closure areas, and their exposure to major uses such as fishing pressure and infrastructure development can be similarly quantified.

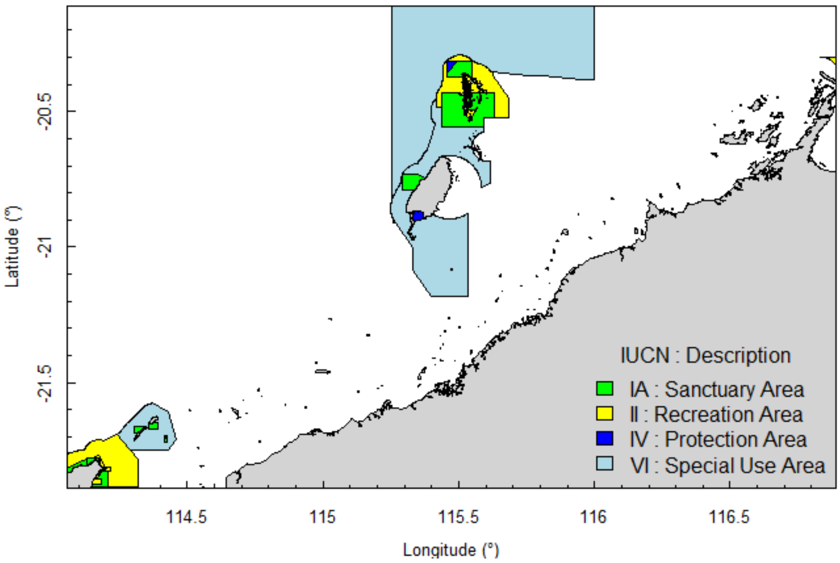

Figure 22. Map of State and Commonwealth Marine Park areas (IUCN Categories) on the west Pilbara shelf.

Table 2. Overlap, by percentage area, of Marine Park areas (IUCN Categories) and trawl fishery footprints with 10 Assemblages defined on the west Pilbara shelf.

Assemblage	IUCN IA	IUCN II	IUCN IV	IUCN VI	Footprint
1	1.1	1.1	0.0	6.4	10.3
2	6.7	22.0	0.4	13.5	6.5
3	0.6	5.7	0.2	56.5	0.0
4	1.0	0.7	0.5	1.3	4.7
5	0.0	0.0	0.0	15.3	0.8
6	0.0	0.3	0.0	8.0	0.3
7	19.0	5.5	0.0	57.5	0.0
8	0.0	0.0	0.0	0.0	0.1
9	0.6	1.2	0.0	1.0	0.0
10	0.0	0.2	0.0	6.1	0.6

6 References

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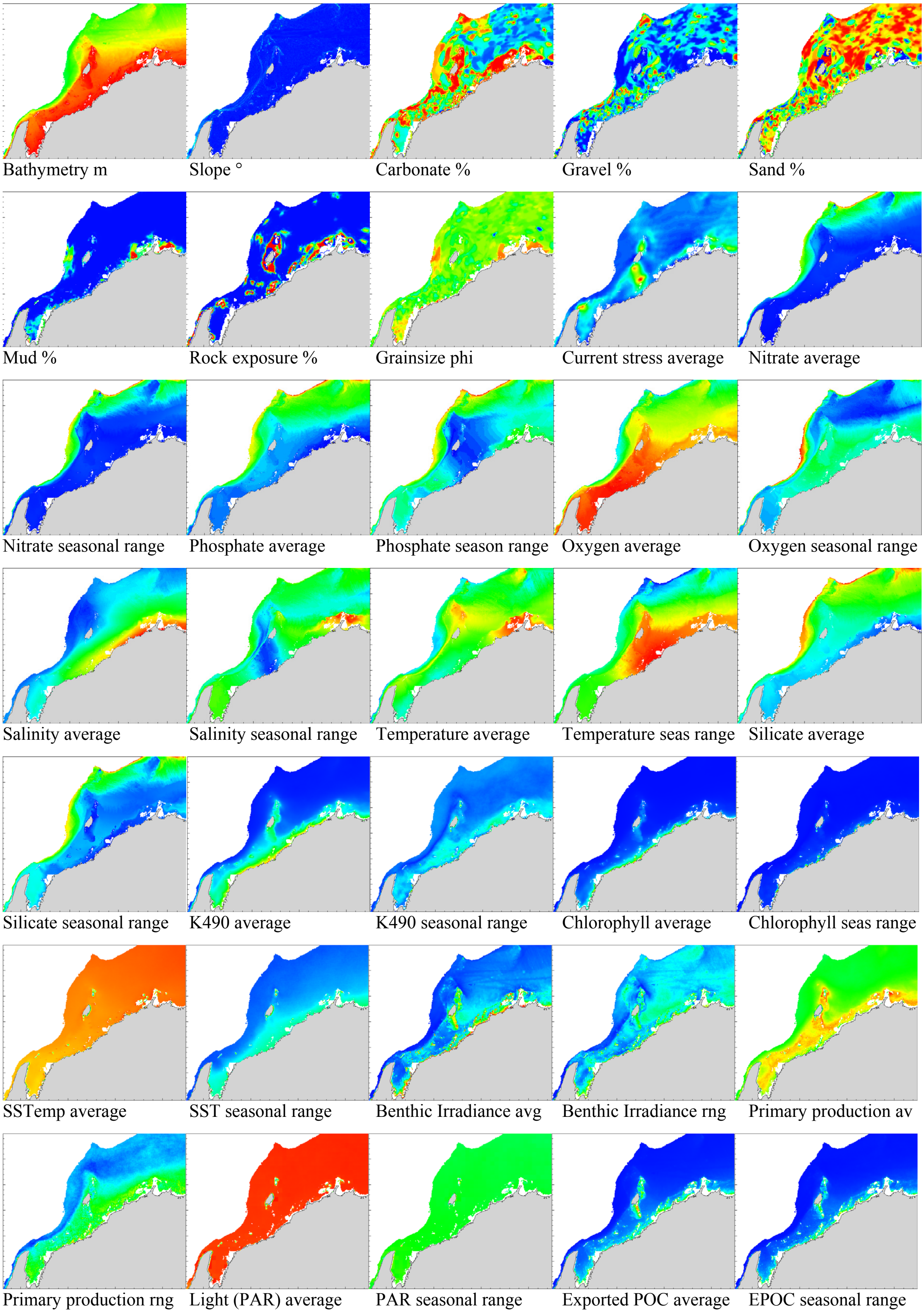
7 Appendices

Appendix 1. List of mapped environmental variables

Table A-1 Descriptions of mapped environmental variables used in project analyses

Variable	Abbreviation	Description
GorgBATHY	BATHY	Depth from bathymetry DEM – metres
GorgSLOPE	SLOPE	Slope derived from bathymetry DEM – degrees
GorgASPECT	ASPECT	Aspect of slope derived from bathymetry DEM – degrees T
RBN_BSTRESS	BSTRESS	Seabed tidal current stress, RMS mean – Nm^{-2}
dbS_CRBNT	CRBNT	Sediment % carbonate ($CaCO_3$) composition, percent
dbS_GRAVEL	GRAVEL	Sediment % gravel grainsize fraction, (Ø > 2 mm)
dbS_SAND	SAND	Sediment % sand grainsize fraction, (63 µm < Ø < 2 mm)
dbS_MUD	MUD	Sediment % mud grainsize fraction, (Ø < 63 µm)
dbS_ROCK	ROCK	Rock exposure (%) at the sediment surface
dbS_GRNSZ	GRNSZ	Sediment characteristic grainsize, log(mean) Phi
dbS_SORTG	SORTG	Sediment grainsize dispersion, Phi standard deviation
CRS_NO3_AV	NO3	Nitrate bottom water annual average NO_3 – µM
CRS_NO3_SR	no3	Nitrate Seasonal Range
CRS_PO4_AV	PO4	Phosphate bottom water annual average PO_4 – µM
CRS_PO4_SR	po4	Phosphate Seasonal Range
CRS_O2_AV	O2	Oxygen bottom water annual average O_2 – mL L^{-1}
CRS_O2_SR	o2	Oxygen Seasonal Range
CRS_S_AV	S	Salinity bottom water annual average S – ‰ (ppt)
CRS_S_SR	s	Salinity Seasonal Range
CRS_T_AV	T	Temperature bottom water annual average T – °C
CRS_T_SR	t	Temperature Seasonal Range
CRS_SI_AV	SI	Silicate bottom water annual average Si – µM
CRS_SI_SR	si	Silicate Seasonal Range
SW_CHLA_AV	CHLA	Chlorophyll annual average from SeaWiFS – mg m^{-3}
SW_CHLA_SR	chla	Chlorophyll Seasonal Range
SW_K490_AV	K490	Attenuation coefficient at wavelength 490nm annual average from SeaWiFS – m^{-1}
SW_K490_SR	k490	Attenuation coefficient Seasonal Range
MT_SST_AV	SST	Sea Surface Temperature annual average from Modis – °C
MT_SST_SR	sst	Sea Surface Temperature Seasonal Range
VGPM_AV	NPP	Net Primary Production annual average from SeaWiFS – mg C m^{-2} d^{-1}
VGPM_SR	npp	Net Primary Production seasonal range
EPOC_AV	EPOC	Export Particulate Organic Carbon flux annual average from SeaWiFS – mg C m^{-2} d^{-1}
EPOC_SR	epoc	Export Particulate Organic Carbon seasonal range
PAR_AV	PAR	Photosynthetically Active Radiation (PAR) from MODIS – Einsteins $m^{-2}day^{-1}$
PAR_SR	par	Photosynthetically Active Radiation seasonal range
SW_BIR_AV	BIR	Benthic Irradiance annual average, BIR = PAR × exp(-K490 * Depth)
SW_BIR_SR	bir	Benthic Irradiance Seasonal Range
TERAN_CHAN	CHAN	Terrain channel, probability of membership of topographic shape "channel"
TERAN_PASS	PASS	Terrain pass, probability of membership of topographic shape "pass"
TERAN_PEAK	PEAK	Terrain peak, probability of membership of topographic shape "peak"
TERAN_PIT	PIT	Terrain pit, probability of membership of topographic shape "pit"
TERAN_PLAN	PLAN	Terrain plane, probability of membership of topographic shape "plane"
TERAN_RIDG	RIDG	Terrain ridge, probability of membership of topographic shape "ridge"

Appendix 2. Maps of regional environmental variables



Appendix 3. Map of previous biological survey sites

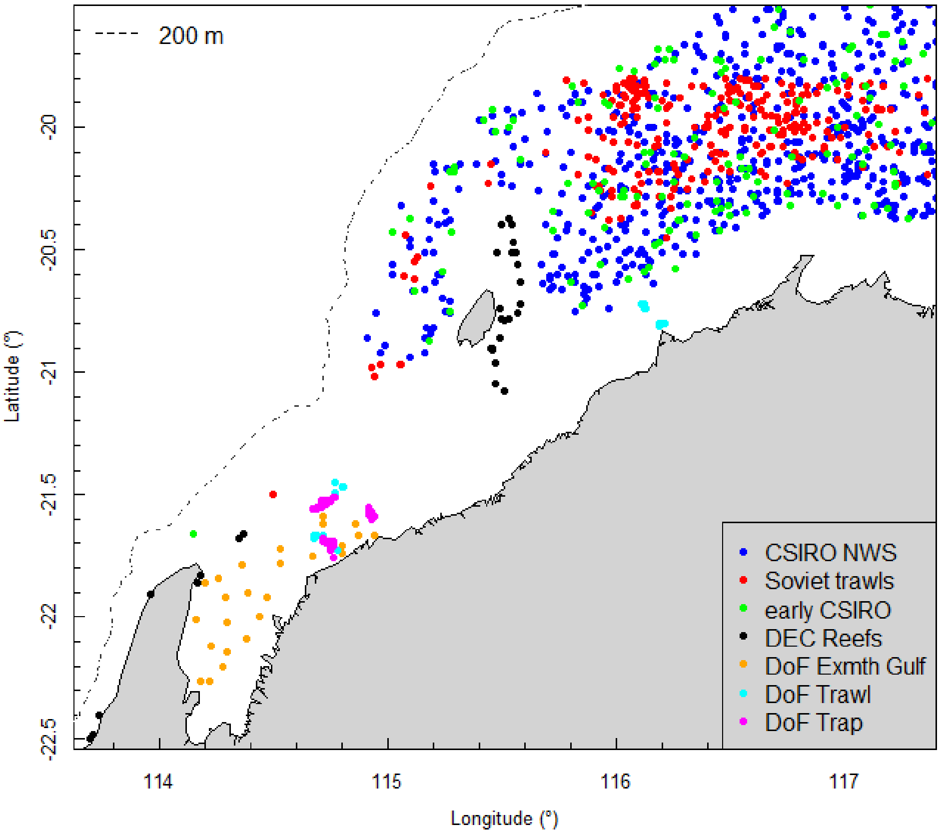


Fig. A3-1. Map of greater Pilbara vicinity, showing location of previous biological survey sites used in the initial characterisation and stratification of the study area.

Appendix 4. Map of preliminary regional characterisation

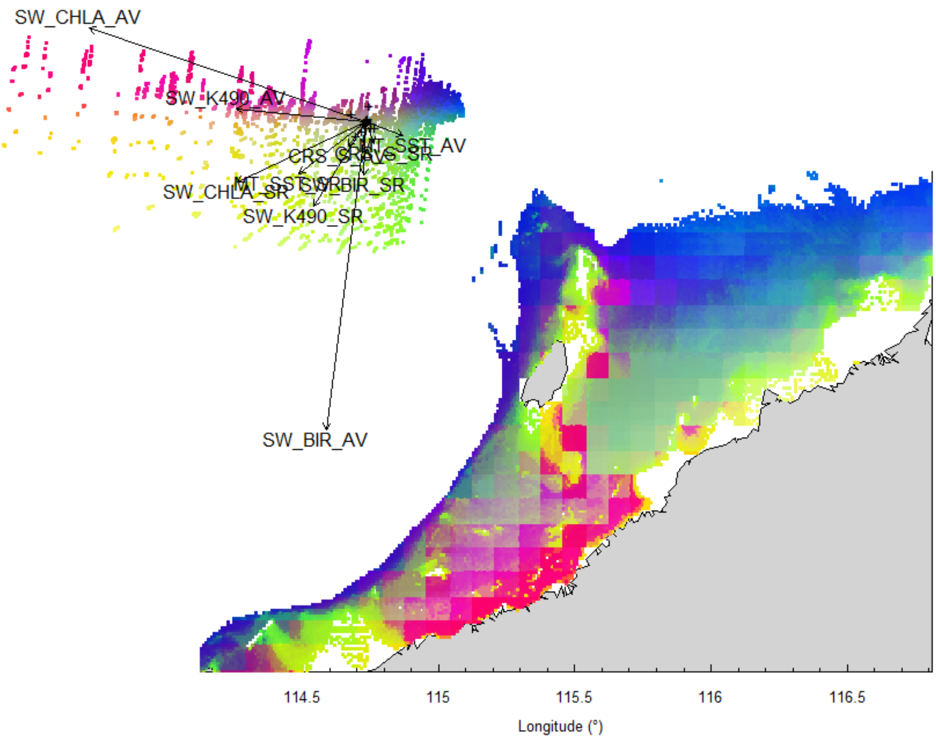


Fig. A4-1. Results of preliminary analyses of pre-existing CSIRO fish survey data on multiple environmental data coverages, prior to acquisition by the project of additional biological and environmental datasets and finer resolution ocean-colour derived datasets.

Appendix 5. Relationships between change in species composition and environmental variables.

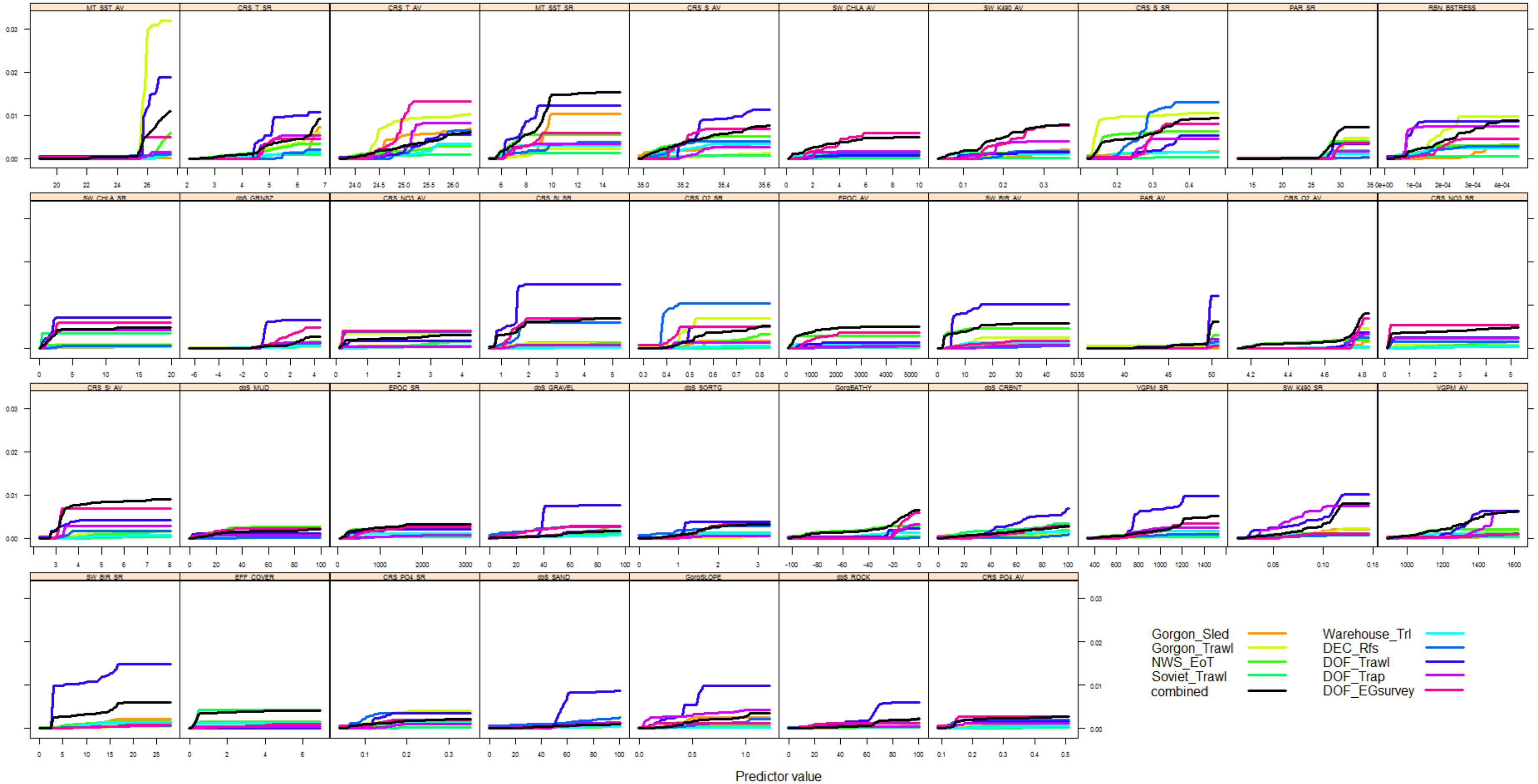


Fig. A5-1. Relationships between change in species composition and 37 environmental variables (in order of importance) in the west Pilbara study region. Seabed biological datasets include the new sled and trawl samples as well as the 7 previous surveys. Variables include parameters such as depth, SST, salinity, bottom irradiance, sediment composition, hydrodynamic shear stress, among others. 44 variables were assessed; 7 are excluded here due to unimportant response.

Appendix 6. Graphical summaries of composition of Assemblages.

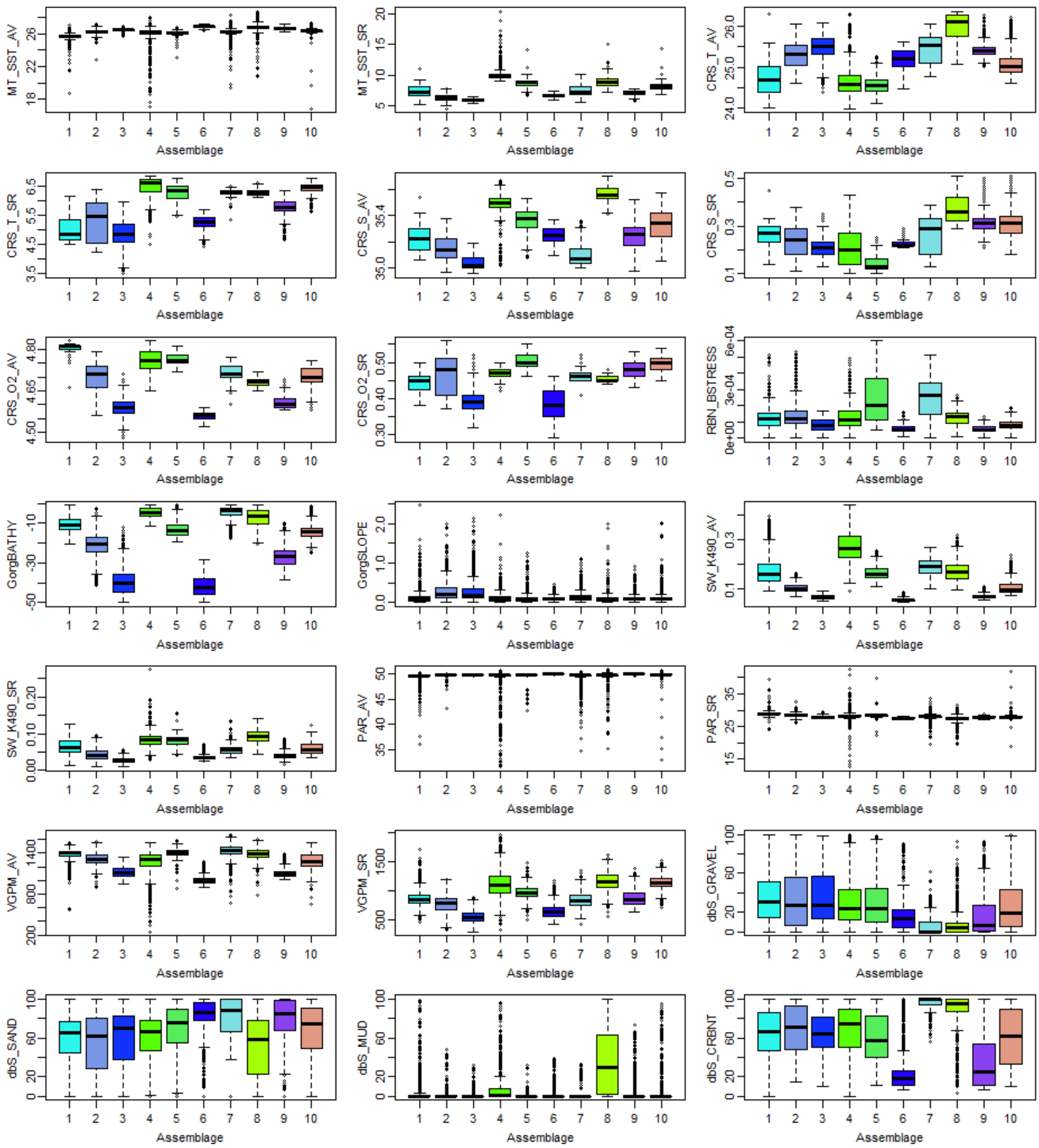


Fig. A6-1. Boxplot summaries of environmental variables for each Assemblage in the west Pilbara study region. Variables include parameters such as depth, SST, salinity, bottom irradiance, sediment composition, hydrodynamic shear stress and others; 21 variables are summarized in order of importance were assessed (See Appendix 1 for definitions of variables). The box indicates the first and third quartiles and the horizontal bar indicates the median value; the whiskers indicate the ‘normal’ range of the data and small circles indicate outlying values.

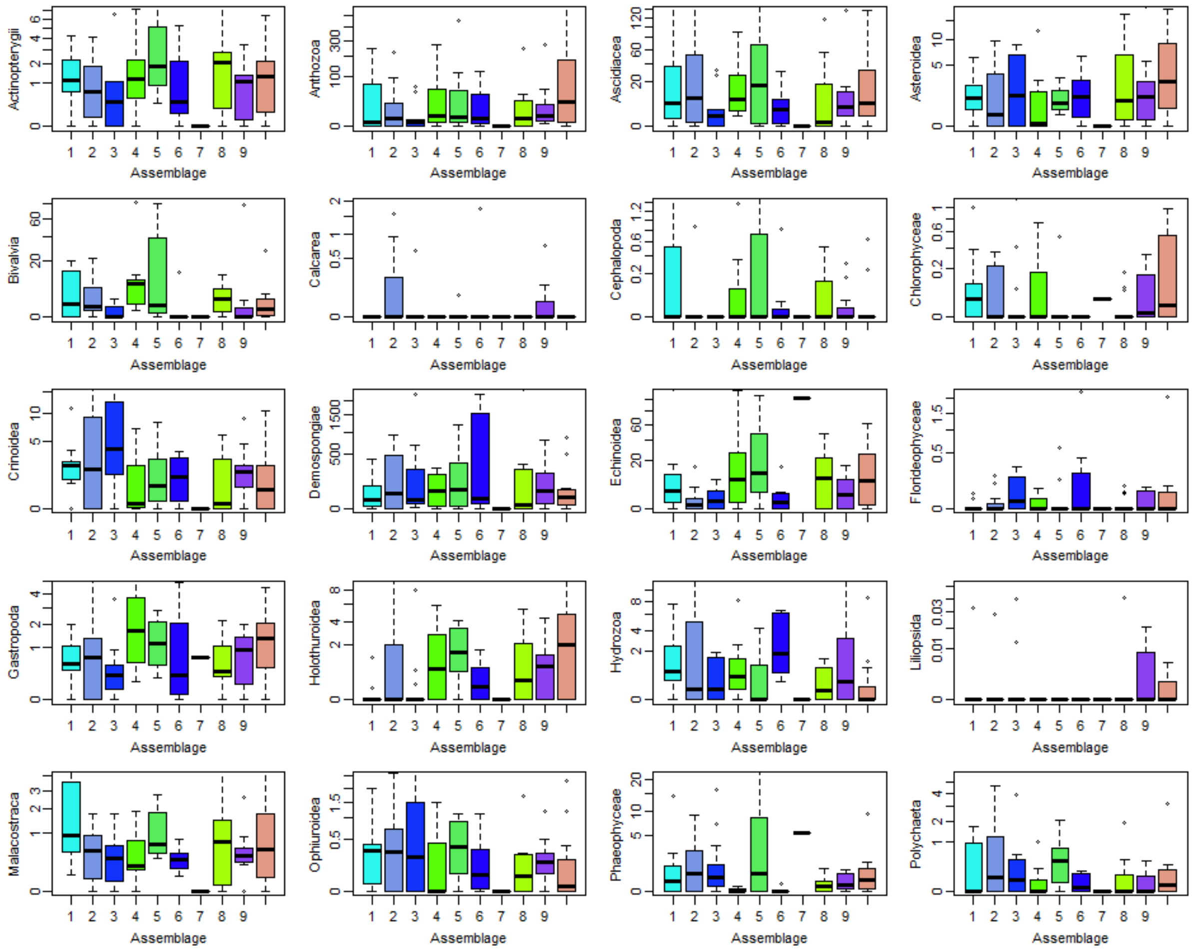


Fig. A6-2. Boxplot summaries of sled biota composition, at taxonomic class level, for each Assemblage in the west Pilbara study region. The box indicates the first and third quartiles and the horizontal bar indicates the median value.

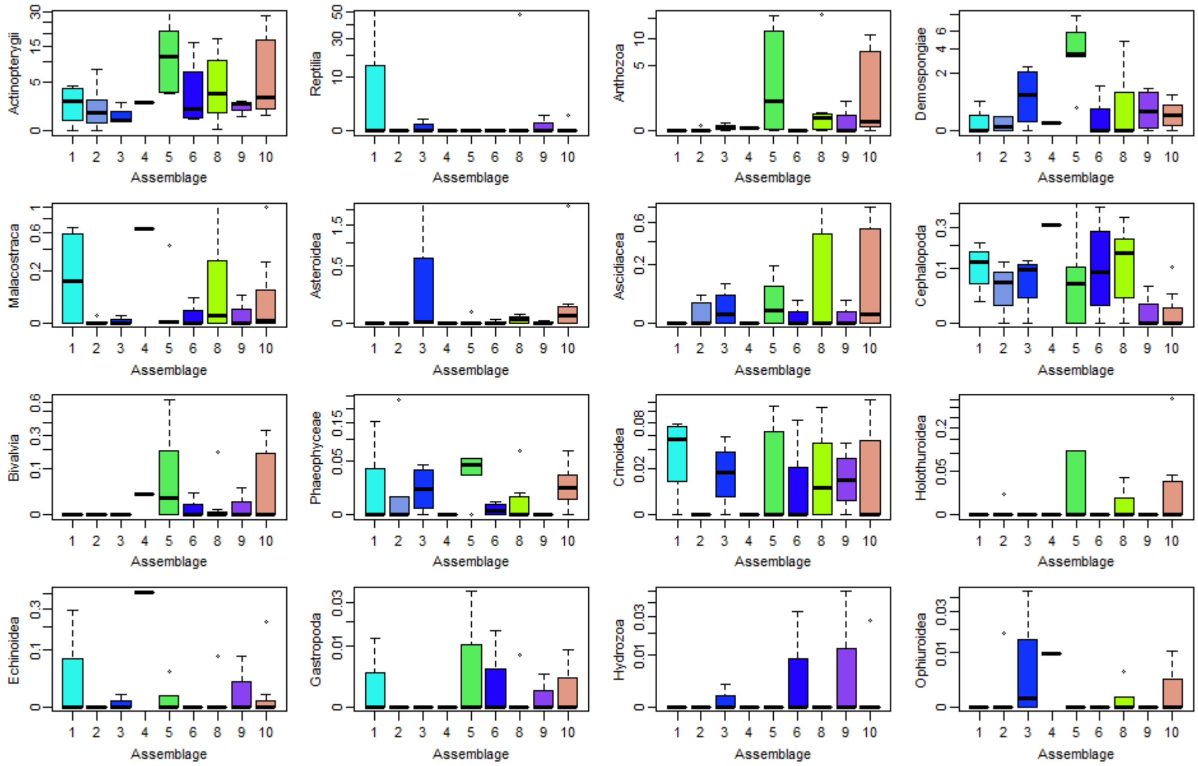
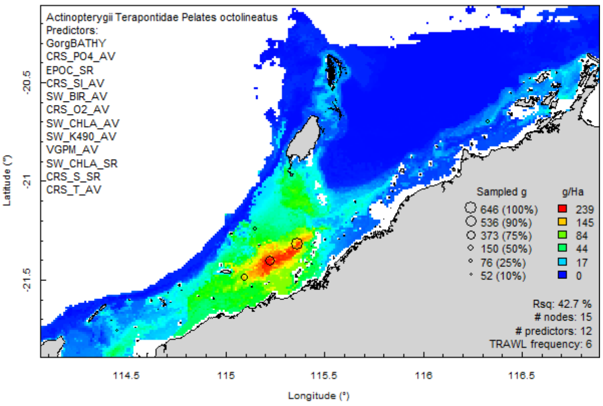
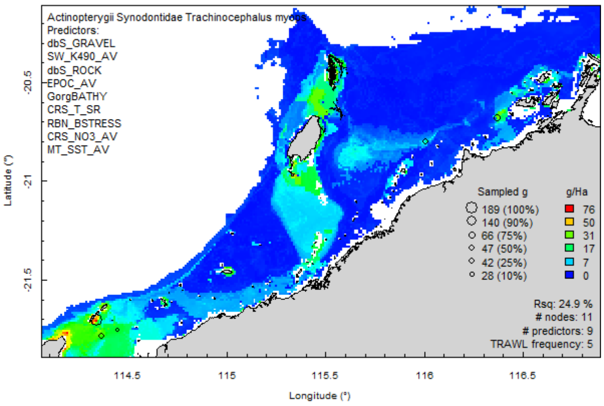


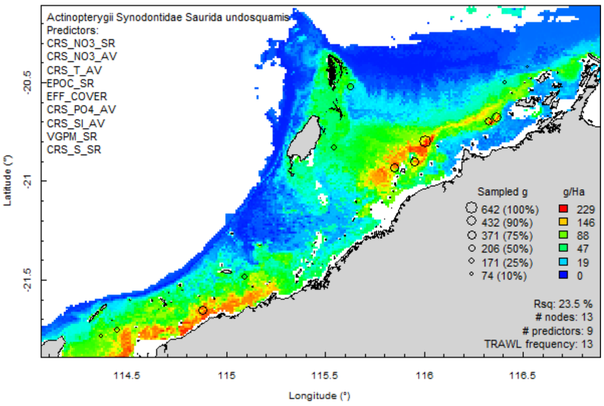
Fig. A6-3. Boxplot summaries of trawl biota composition, at taxonomic class level, for each Assemblage in the west Pilbara study region. The box indicates the first and third quartiles and the horizontal bar indicates the median value.

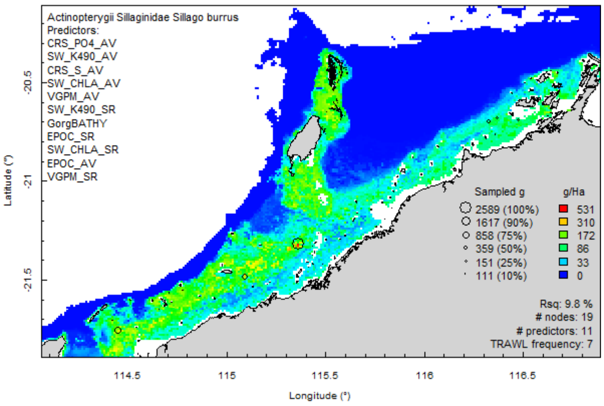
Appendix 7. Predicted species distribution maps.

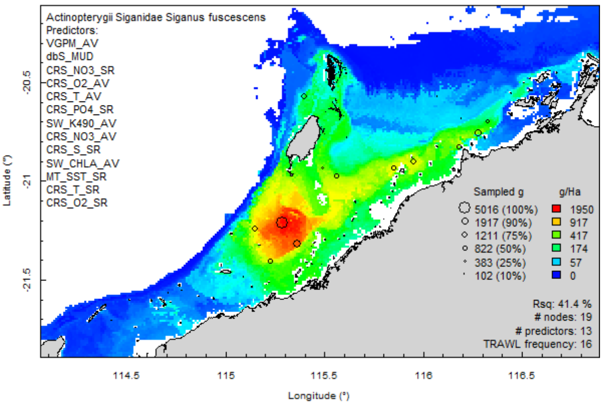
Actinopterygii (fishes):

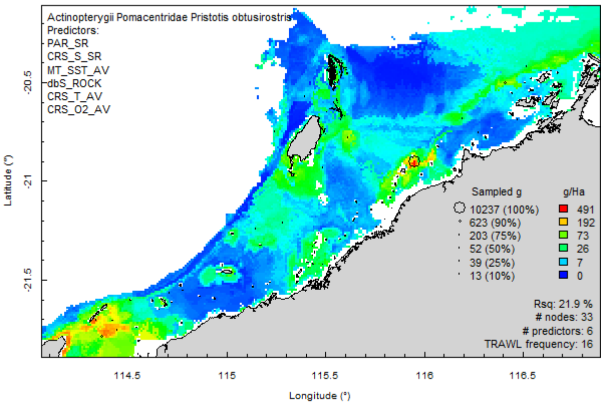


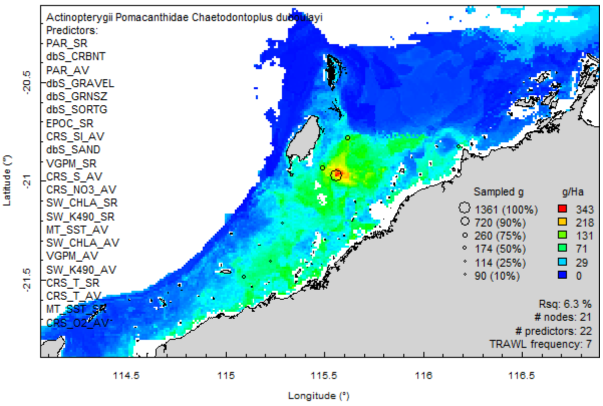


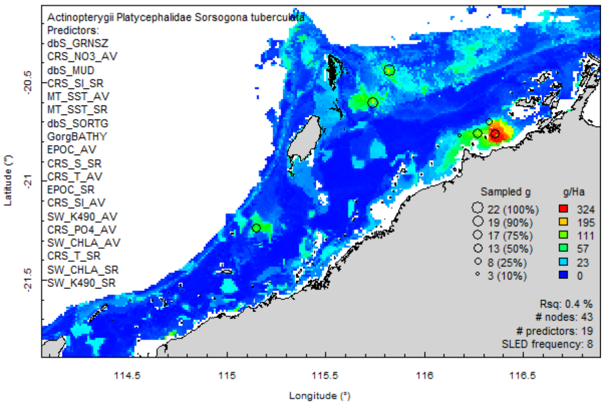


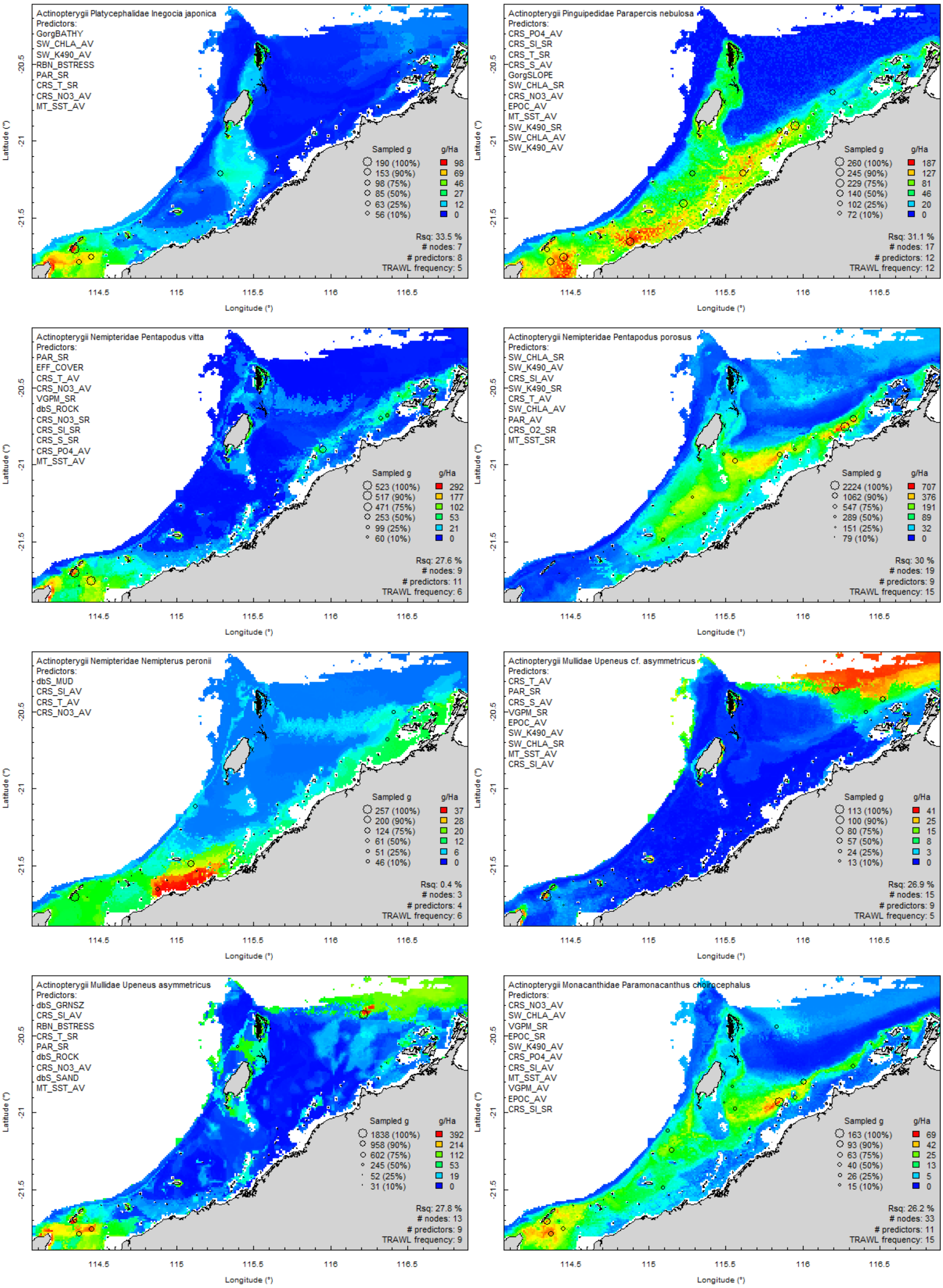


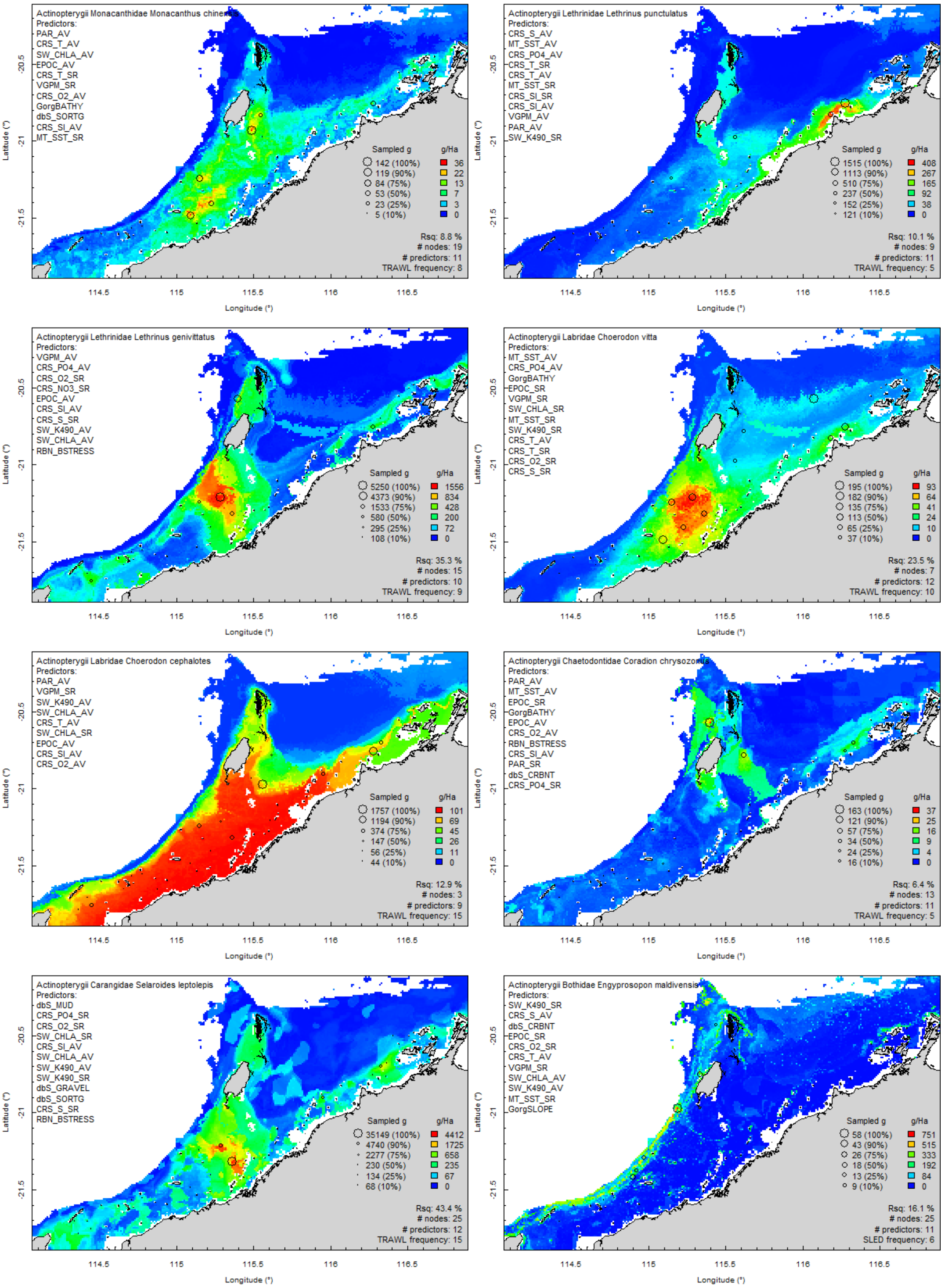




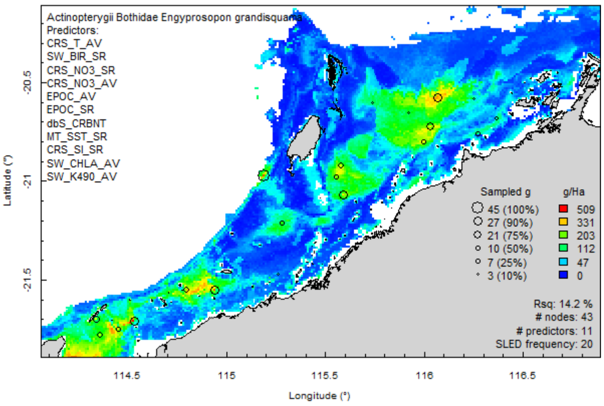


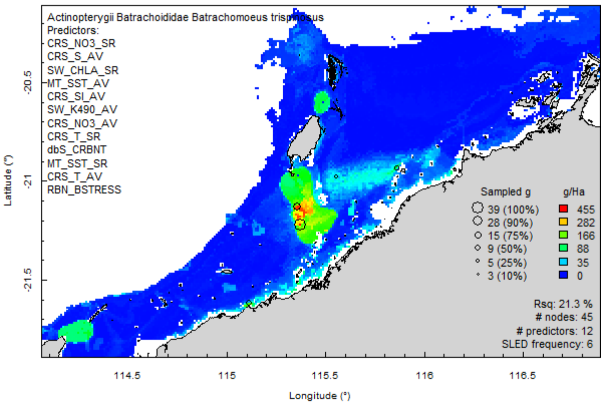


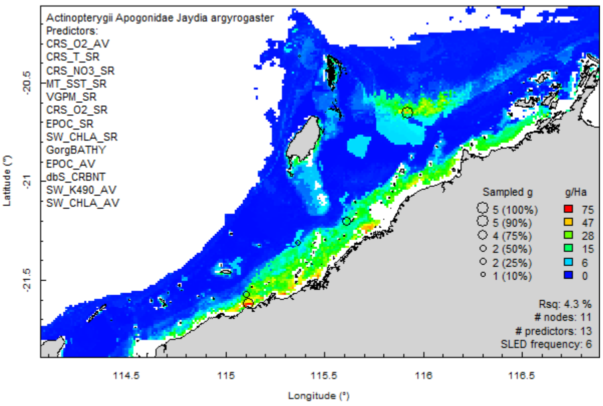

Actinopterygii Platycephalidae Inegocia japonica
Predictors:
GorgBATHY
SW_CHLA_AV
SW_K490_AV
RBN_BSTRESS
PAR_SR
CRS_T_SR
CRS_NO3_AV
MT_SST_AV
Sampled g
190 (100%)
153 (90%)
98 (75%)
85 (50%)
63 (25%)
56 (10%)
g/Ha
98
69
46
27
12
0
Rsq: 33.5 %
nodes: 7
predictors: 8
TRAWL frequency: 5
Actinopterygii Pinguipedidae Parapercis nebulosa
Predictors:
CRS_PO4_AV
CRS_SI_SR
CRS_T_SR
CRS_S_AV
GorgSLOPE
SW_CHLA_SR
CRS_NO3_AV
EPOC_AV
MT_SST_AV
SW_K490_SR
SW_CHLA_AV
SW_K490_AV
Sampled g
260 (100%)
245 (90%)
229 (75%)
140 (50%)
102 (25%)
72 (10%)
g/Ha
187
127
81
46
20
0
Rsq: 31.1 %
nodes: 17
predictors: 12
TRAWL frequency: 12
Actinopterygii Nemipteridae Pentapodus vitta
Predictors:
PAR_SR
EFF_COVER
CRS_T_AV
CRS_NO3_AV
VGPM_SR
dbS_ROCK
CRS_NO3_SR
CRS_SI_SR
CRS_S_SR
CRS_PO4_AV
MT_SST_AV
Sampled g
523 (100%)
517 (90%)
471 (75%)
253 (50%)
99 (25%)
60 (10%)
g/Ha
292
177
102
53
21
0
Rsq: 27.6 %
nodes: 9
predictors: 11
TRAWL frequency: 6
Actinopterygii Nemipteridae Pentapodus porosus
Predictors:
SW_CHLA_SR
SW_K490_AV
CRS_SI_AV
SW_K490_SR
CRS_T_AV
SW_CHLA_AV
PAR_AV
CRS_O2_SR
MT_SST_SR
Sampled g
2224 (100%)
1062 (90%)
547 (75%)
289 (50%)
151 (25%)
79 (10%)
g/Ha
707
376
191
89
32
0
Rsq: 30 %
nodes: 19
predictors: 9
TRAWL frequency: 15
Actinopterygii Nemipteridae Nemipterus peronii
Predictors:
dbS_MUD
CRS_SI_AV
CRS_T_AV
CRS_NO3_AV
Sampled g
257 (100%)
200 (90%)
124 (75%)
61 (50%)
51 (25%)
46 (10%)
g/Ha
37
28
20
12
6
0
Rsq: 0.4 %
nodes: 3
predictors: 4
TRAWL frequency: 6
Actinopterygii Mullidae Upeneus cf. asymmetricus
Predictors:
CRS_T_AV
PAR_SR
CRS_S_AV
VGPM_SR
EPOC_AV
SW_K490_AV
SW_CHLA_SR
MT_SST_AV
CRS_SI_AV
Sampled g
113 (100%)
100 (90%)
80 (75%)
57 (50%)
24 (25%)
13 (10%)
g/Ha
41
25
15
8
3
0
Rsq: 26.9 %
nodes: 15
predictors: 9
TRAWL frequency: 5
Actinopterygii Mullidae Upeneus asymmetricus
Predictors:
dbS_GRNSZ
CRS_SI_AV
RBN_BSTRESS
CRS_T_SR
PAR_SR
dbS_ROCK
CRS_NO3_AV
dbS_SAND
MT_SST_AV
Sampled g
1838 (100%)
958 (90%)
602 (75%)
245 (50%)
52 (25%)
31 (10%)
g/Ha
392
214
112
53
19
0
Rsq: 27.8 %
nodes: 13
predictors: 9
TRAWL frequency: 9
Actinopterygii Monacanthidae Paramonacanthus choirocephalus
Predictors:
CRS_NO3_AV
SW_CHLA_AV
VGPM_SR
EPOC_SR
SW_K490_AV
CRS_PO4_AV
CRS_SI_AV
MT_SST_AV
VGPM_AV
EPOC_AV
CRS_SI_SR
Sampled g
163 (100%)
93 (90%)
63 (75%)
40 (50%)
26 (25%)
15 (10%)
g/Ha
69
42
25
13
5
0
Rsq: 26.2 %
nodes: 33
predictors: 11
TRAWL frequency: 15
Latitude (°)
-20.5
-21
-21.5
Longitude (°)
114.5
115
115.5
116
116.5

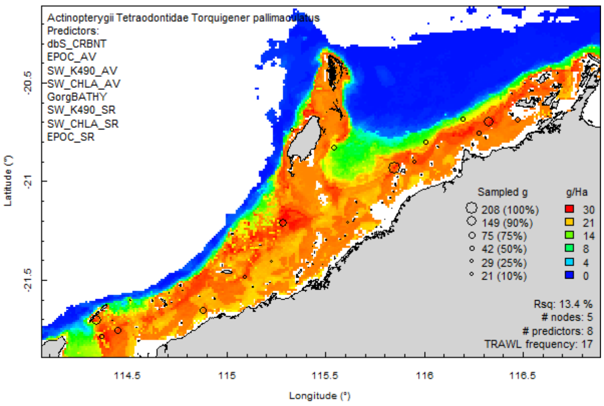


Actinopterygii Monacanthidae Monacanthus chinensis
Predictors:
PAR_AV
CRS_T_AV
SW_CHLA_AV
EPOC_AV
CRS_T_SR
VGPM_SR
CRS_O2_AV
GorgBATHY
dbS_SORTG
CRS_SI_AV
MT_SST_SR
Sampled g
142 (100%)
119 (90%)
84 (75%)
53 (50%)
23 (25%)
5 (10%)
g/Ha
36
22
13
7
3
0
Rsq: 8.8 %
nodes: 19
predictors: 11
TRAWL frequency: 8
Actinopterygii Lethrinidae Lethrinus punctulatus
Predictors:
CRS_S_AV
MT_SST_AV
CRS_PO4_AV
CRS_T_SR
CRS_T_AV
MT_SST_SR
CRS_SI_SR
CRS_SI_AV
VGPM_AV
PAR_AV
SW_K490_SR
Sampled g
1515 (100%)
1113 (90%)
510 (75%)
237 (50%)
152 (25%)
121 (10%)
g/Ha
408
267
165
92
38
0
Rsq: 10.1 %
nodes: 9
predictors: 11
TRAWL frequency: 5
Actinopterygii Lethrinidae Lethrinus genivittatus
Predictors:
VGPM_AV
CRS_PO4_AV
CRS_O2_SR
CRS_NO3_SR
EPOC_AV
CRS_SI_AV
CRS_S_SR
SW_K490_AV
SW_CHLA_AV
RBN_BSTRESS
Sampled g
5250 (100%)
4373 (90%)
1533 (75%)
580 (50%)
295 (25%)
108 (10%)
g/Ha
1556
834
428
200
72
0
Rsq: 35.3 %
nodes: 15
predictors: 10
TRAWL frequency: 9
Actinopterygii Labridae Choerodon vitta
Predictors:
MT_SST_AV
CRS_PO4_AV
GorgBATHY
EPOC_SR
VGPM_SR
SW_CHLA_SR
MT_SST_SR
SW_K490_SR
CRS_T_AV
CRS_T_SR
CRS_O2_SR
CRS_S_SR
Sampled g
195 (100%)
182 (90%)
135 (75%)
113 (50%)
65 (25%)
37 (10%)
g/Ha
93
64
41
24
10
0
Rsq: 23.5 %
nodes: 7
predictors: 12
TRAWL frequency: 10
Actinopterygii Labridae Choerodon cephalotes
Predictors:
PAR_AV
VGPM_SR
SW_K490_AV
SW_CHLA_AV
CRS_T_AV
SW_CHLA_SR
EPOC_AV
CRS_SI_AV
CRS_O2_AV
Sampled g
1757 (100%)
1194 (90%)
374 (75%)
147 (50%)
56 (25%)
44 (10%)
g/Ha
101
69
45
26
11
0
Rsq: 12.9 %
nodes: 3
predictors: 9
TRAWL frequency: 15
Actinopterygii Chaetodontidae Coradion chrysozonus
Predictors:
PAR_AV
MT_SST_AV
EPOC_SR
GorgBATHY
EPOC_AV
CRS_O2_AV
RBN_BSTRESS
CRS_SI_AV
PAR_SR
dbS_CRBNT
CRS_PO4_SR
Sampled g
163 (100%)
121 (90%)
57 (75%)
34 (50%)
24 (25%)
16 (10%)
g/Ha
37
25
16
9
4
0
Rsq: 6.4 %
nodes: 13
predictors: 11
TRAWL frequency: 5
Actinopterygii Carangidae Selaroides leptolepis
Predictors:
dbS_MUD
CRS_PO4_SR
CRS_O2_SR
SW_CHLA_SR
CRS_SI_AV
SW_CHLA_AV
SW_K490_AV
SW_K490_SR
dbS_GRAVEL
dbS_SORTG
CRS_S_SR
RBN_BSTRESS
Sampled g
35149 (100%)
4740 (90%)
2277 (75%)
230 (50%)
134 (25%)
68 (10%)
g/Ha
4412
1725
658
235
67
0
Rsq: 43.4 %
nodes: 25
predictors: 12
TRAWL frequency: 15
Actinopterygii Bothidae Engyprosopon maldivensis
Predictors:
SW_K490_SR
CRS_S_AV
dbS_CRBNT
EPOC_SR
CRS_O2_SR
CRS_T_AV
VGPM_SR
SW_CHLA_AV
SW_K490_AV
MT_SST_SR
GorgSLOPE
Sampled g
58 (100%)
43 (90%)
26 (75%)
18 (50%)
13 (25%)
9 (10%)
g/Ha
751
515
333
192
84
0
Rsq: 16.1 %
nodes: 25
predictors: 11
SLED frequency: 6
Latitude (°)
-20.5
-21
-21.5
Longitude (°)
114.5
115
115.5
116
116.5

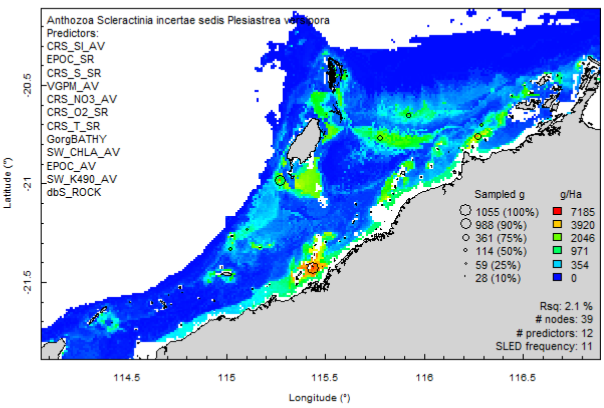


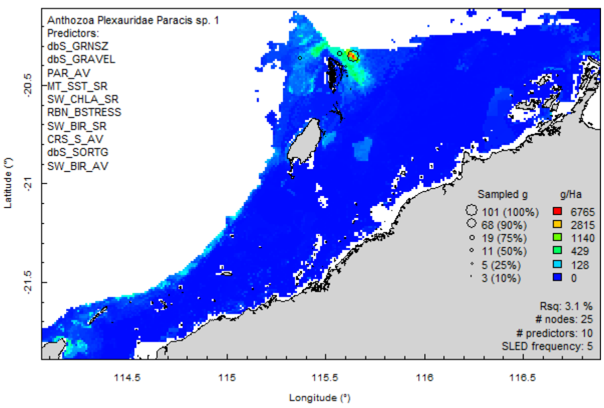


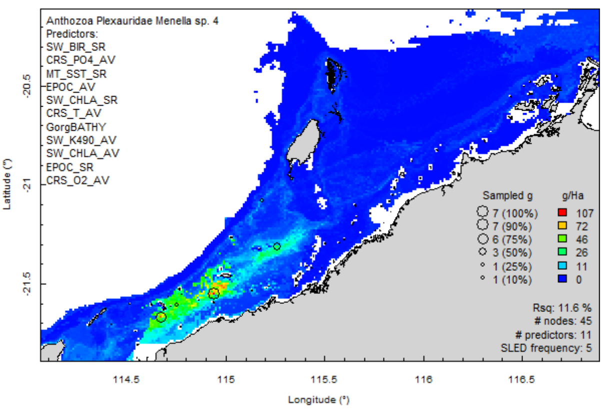


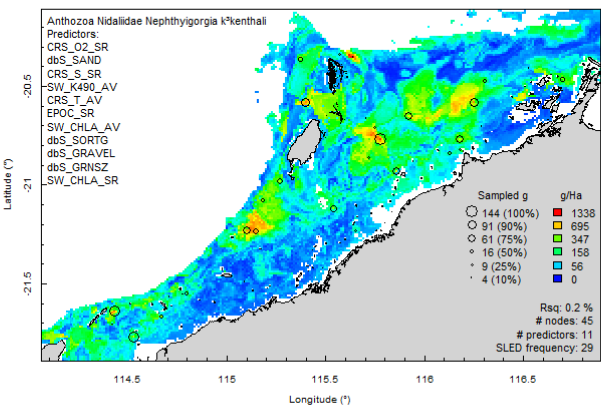


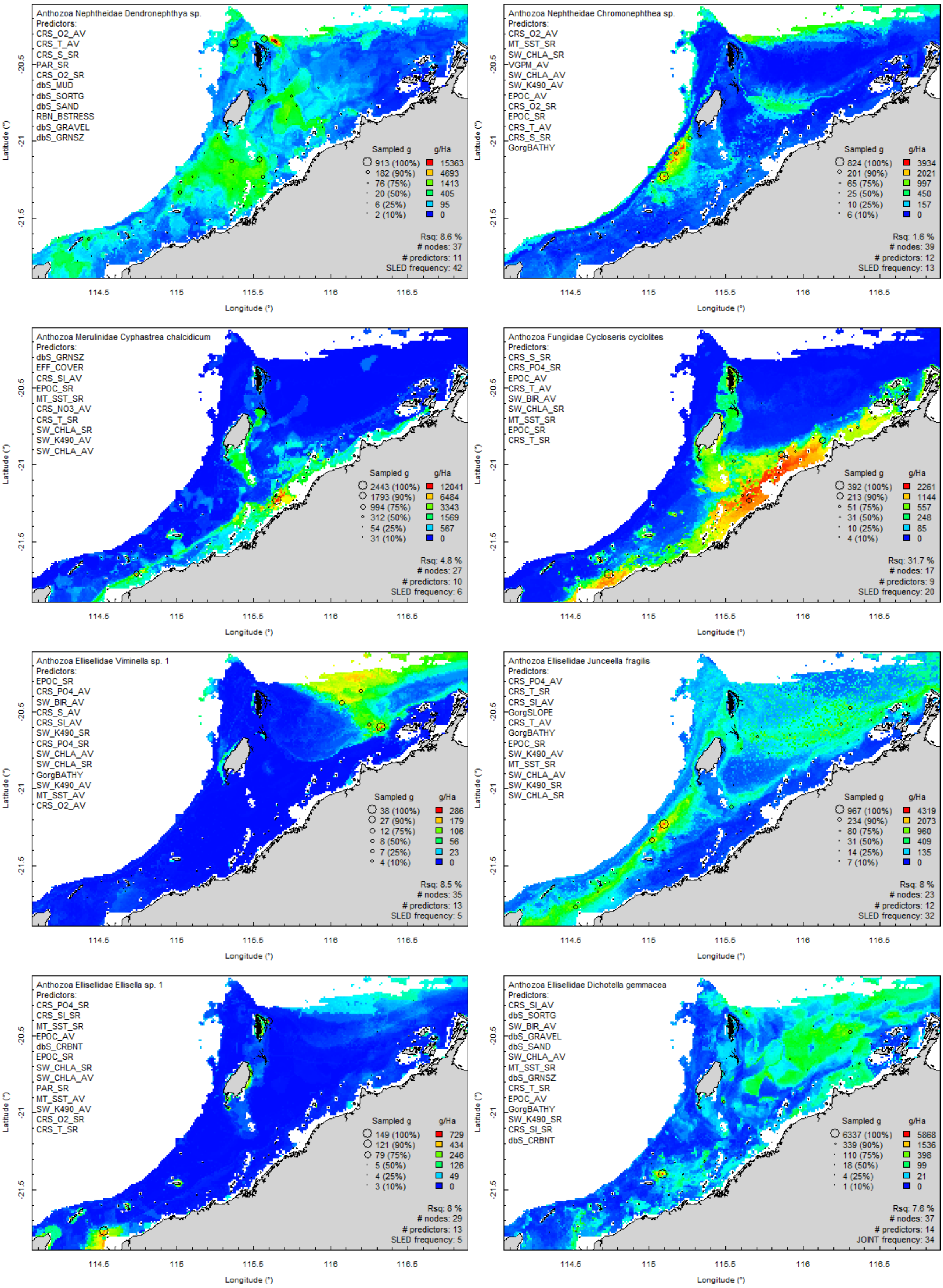
Anthozoa (corals & gorgonians):

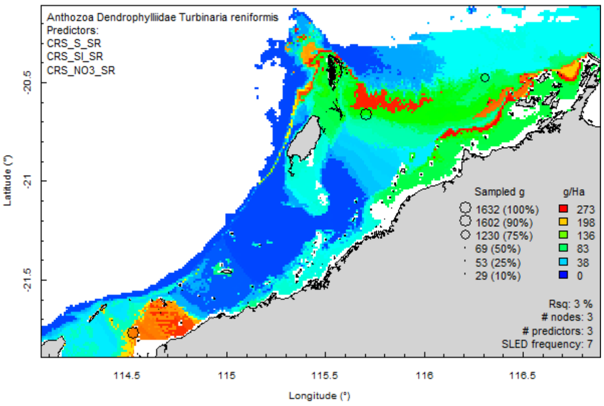


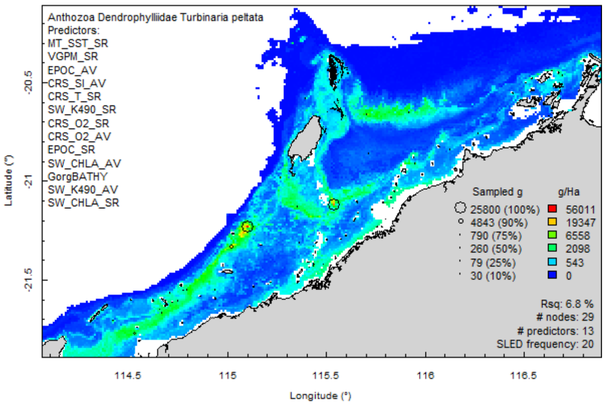


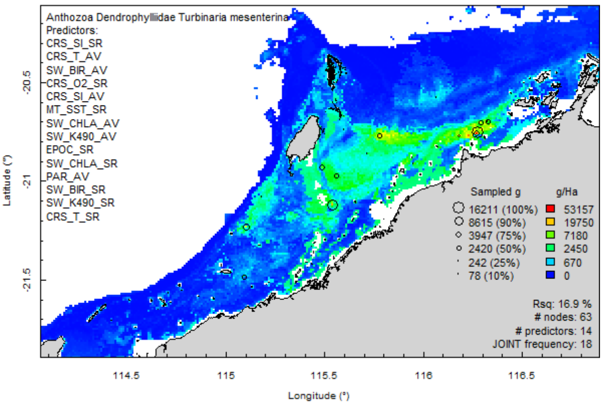


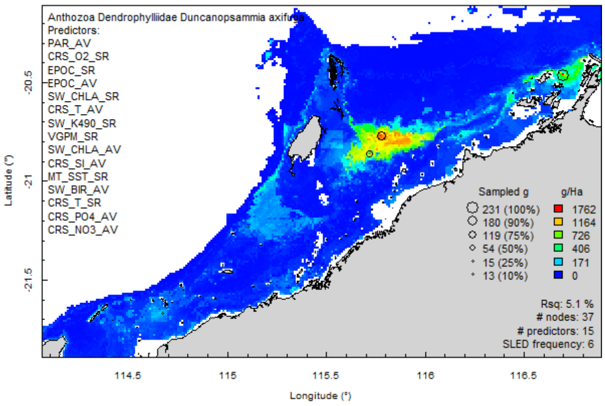


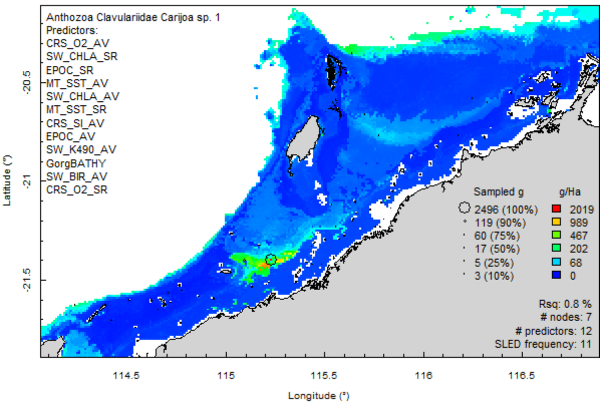

Anthozoa Nephtheidae Dendronephthya sp.
Predictors:
CRS_O2_AV
CRS_T_AV
CRS_S_SR
PAR_SR
CRS_O2_SR
dbS_MUD
dbS_SORTG
dbS_SAND
RBN_BSTRESS
dbS_GRAVEL
dbS_GRNSZ
Sampled g
913 (100%)
182 (90%)
76 (75%)
20 (50%)
6 (25%)
2 (10%)
g/Ha
15363
4693
1413
405
95
0
Rsq: 8.6 %
nodes: 37
predictors: 11
SLED frequency: 42
Anthozoa Nephtheidae Chromonephthea sp.
Predictors:
CRS_O2_AV
MT_SST_SR
SW_CHLA_SR
VGPM_AV
SW_CHLA_AV
SW_K490_AV
EPOC_AV
CRS_O2_SR
EPOC_SR
CRS_T_AV
CRS_S_SR
GorgBATHY
Sampled g
824 (100%)
201 (90%)
65 (75%)
25 (50%)
10 (25%)
6 (10%)
g/Ha
3934
2021
997
450
157
0
Rsq: 1.6 %
nodes: 39
predictors: 12
SLED frequency: 13
Anthozoa Merulinidae Cyphastrea chalcidicum
Predictors:
dbS_GRNSZ
EFF_COVER
CRS_SI_AV
EPOC_SR
MT_SST_SR
CRS_NO3_AV
CRS_T_SR
SW_CHLA_SR
SW_K490_AV
SW_CHLA_AV
Sampled g
2443 (100%)
1793 (90%)
994 (75%)
312 (50%)
54 (25%)
31 (10%)
g/Ha
12041
6484
3343
1569
567
0
Rsq: 4.8 %
nodes: 27
predictors: 10
SLED frequency: 6
Anthozoa Fungiidae Cycloseris cyclolites
Predictors:
CRS_S_SR
CRS_PO4_SR
EPOC_AV
CRS_T_AV
SW_BIR_AV
SW_CHLA_SR
MT_SST_SR
EPOC_SR
CRS_T_SR
Sampled g
392 (100%)
213 (90%)
51 (75%)
31 (50%)
10 (25%)
4 (10%)
g/Ha
2261
1144
557
248
85
0
Rsq: 31.7 %
nodes: 17
predictors: 9
SLED frequency: 20
Anthozoa Ellisellidae Viminella sp. 1
Predictors:
EPOC_SR
CRS_PO4_AV
SW_BIR_AV
CRS_S_AV
CRS_SI_AV
SW_K490_SR
CRS_PO4_SR
SW_CHLA_AV
SW_CHLA_SR
GorgBATHY
SW_K490_AV
MT_SST_AV
CRS_O2_AV
Sampled g
38 (100%)
27 (90%)
12 (75%)
8 (50%)
7 (25%)
4 (10%)
g/Ha
286
179
106
56
23
0
Rsq: 8.5 %
nodes: 35
predictors: 13
SLED frequency: 5
Anthozoa Ellisellidae Junceella fragilis
Predictors:
CRS_PO4_AV
CRS_T_SR
CRS_SI_AV
GorgSLOPE
CRS_T_AV
GorgBATHY
EPOC_SR
SW_K490_AV
MT_SST_SR
SW_CHLA_AV
SW_K490_SR
SW_CHLA_SR
Sampled g
967 (100%)
234 (90%)
80 (75%)
31 (50%)
14 (25%)
7 (10%)
g/Ha
4319
2073
960
409
135
0
Rsq: 8 %
nodes: 23
predictors: 12
SLED frequency: 32
Anthozoa Ellisellidae Ellisella sp. 1
Predictors:
CRS_PO4_SR
CRS_SI_SR
MT_SST_SR
EPOC_AV
dbS_CRBNT
EPOC_SR
SW_CHLA_SR
SW_CHLA_AV
PAR_SR
MT_SST_AV
SW_K490_AV
CRS_O2_SR
CRS_T_SR
Sampled g
149 (100%)
121 (90%)
79 (75%)
5 (50%)
4 (25%)
3 (10%)
g/Ha
729
434
246
126
49
0
Rsq: 8 %
nodes: 29
predictors: 13
SLED frequency: 5
Anthozoa Ellisellidae Dichotella gemmacea
Predictors:
CRS_SI_AV
dbS_SORTG
SW_BIR_AV
dbS_GRAVEL
dbS_SAND
SW_CHLA_AV
MT_SST_SR
dbS_GRNSZ
CRS_T_SR
EPOC_AV
GorgBATHY
SW_K490_SR
CRS_SI_SR
dbS_CRBNT
Sampled g
6337 (100%)
339 (90%)
110 (75%)
18 (50%)
4 (25%)
1 (10%)
g/Ha
5868
1536
398
99
21
0
Rsq: 7.6 %
nodes: 37
predictors: 14
JOINT frequency: 34
Latitude (°)
-20.5
-21
-21.5
Longitude (°)
114.5
115
115.5
116
116.5

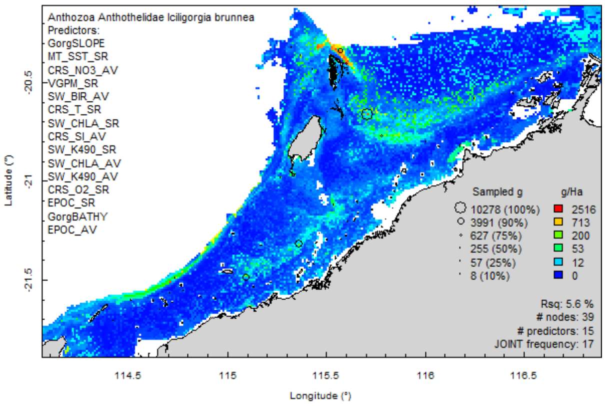

Anthozoa Dendrophylliidae Turbinaria reniformis
Predictors:
CRS_S_SR
CRS_SI_SR
CRS_NO3_SR
Sampled g
1632 (100%)
1602 (90%)
1230 (75%)
69 (50%)
53 (25%)
29 (10%)
g/Ha
273
198
136
83
38
0
Rsq: 3 %
nodes: 3
predictors: 3
SLED frequency: 7
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)

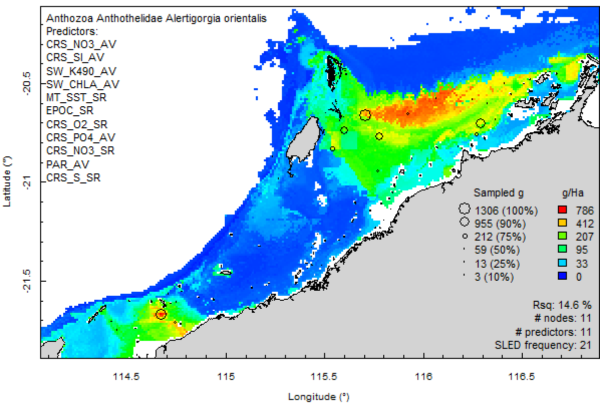

Anthozoa Dendrophylliidae Turbinaria peltata
Predictors:
MT_SST_SR
VGPM_SR
EPOC_AV
CRS_SI_AV
CRS_T_SR
SW_K490_SR
CRS_O2_SR
CRS_O2_AV
EPOC_SR
SW_CHLA_AV
GorgBATHY
SW_K490_AV
SW_CHLA_SR
Sampled g
25800 (100%)
4843 (90%)
790 (75%)
260 (50%)
79 (25%)
30 (10%)
g/Ha
56011
19347
6558
2098
543
0
Rsq: 6.8 %
nodes: 29
predictors: 13
SLED frequency: 20
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)

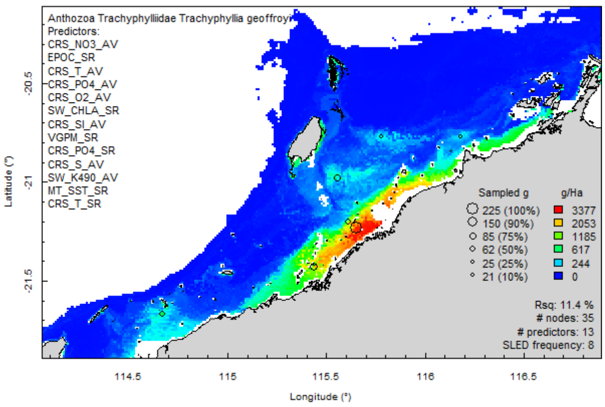

Anthozoa Dendrophylliidae Turbinaria mesenterina
Predictors:
CRS_SI_SR
CRS_T_AV
SW_BIR_AV
CRS_O2_SR
CRS_SI_AV
MT_SST_SR
SW_CHLA_AV
SW_K490_AV
EPOC_SR
SW_CHLA_SR
PAR_AV
SW_BIR_SR
SW_K490_SR
CRS_T_SR
Sampled g
16211 (100%)
8615 (90%)
3947 (75%)
2420 (50%)
242 (25%)
78 (10%)
g/Ha
53157
19750
7180
2450
670
0
Rsq: 16.9 %
nodes: 63
predictors: 14
JOINT frequency: 18
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)


Anthozoa Dendrophylliidae Duncanopsammia axifuga
Predictors:
PAR_AV
CRS_O2_SR
EPOC_SR
EPOC_AV
SW_CHLA_SR
CRS_T_AV
SW_K490_SR
VGPM_SR
SW_CHLA_AV
CRS_SI_AV
MT_SST_SR
SW_BIR_AV
CRS_T_SR
CRS_PO4_AV
CRS_NO3_AV
Sampled g
231 (100%)
180 (90%)
119 (75%)
54 (50%)
15 (25%)
13 (10%)
g/Ha
1762
1164
726
406
171
0
Rsq: 5.1 %
nodes: 37
predictors: 15
SLED frequency: 6
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)

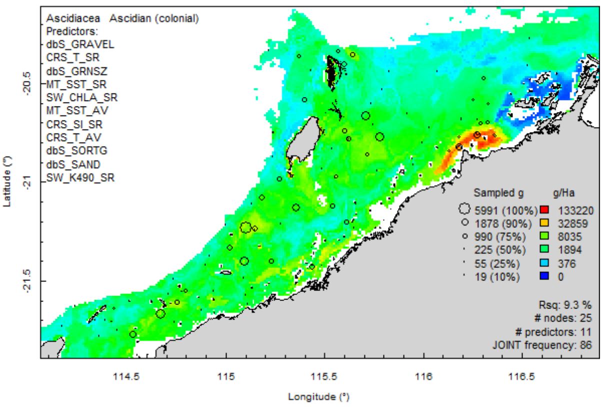

Anthozoa Clavulariidae Carijoa sp. 1
Predictors:
CRS_O2_AV
SW_CHLA_SR
EPOC_SR
MT_SST_AV
SW_CHLA_AV
MT_SST_SR
CRS_SI_AV
EPOC_AV
SW_K490_AV
GorgBATHY
SW_BIR_AV
CRS_O2_SR
Sampled g
2496 (100%)
119 (90%)
60 (75%)
17 (50%)
5 (25%)
3 (10%)
g/Ha
2019
989
467
202
68
0
Rsq: 0.8 %
nodes: 7
predictors: 12
SLED frequency: 11
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)

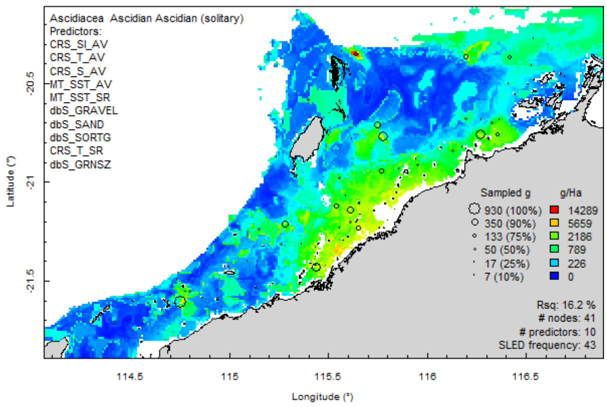

Anthozoa Anthothelidae Iciligorgia brunnea
Predictors:
GorgSLOPE
MT_SST_SR
CRS_NO3_AV
VGPM_SR
SW_BIR_AV
CRS_T_SR
SW_CHLA_SR
CRS_SI_AV
SW_K490_SR
SW_CHLA_AV
SW_K490_AV
CRS_O2_SR
EPOC_SR
GorgBATHY
EPOC_AV
Sampled g
10278 (100%)
3991 (90%)
627 (75%)
255 (50%)
57 (25%)
8 (10%)
g/Ha
2516
713
200
53
12
0
Rsq: 5.6 %
nodes: 39
predictors: 15
JOINT frequency: 17
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)


Anthozoa Anthothelidae Alertigorgia orientalis
Predictors:
CRS_NO3_AV
CRS_SI_AV
SW_K490_AV
SW_CHLA_AV
MT_SST_SR
EPOC_SR
CRS_O2_SR
CRS_PO4_AV
CRS_NO3_SR
PAR_AV
CRS_S_SR
Sampled g
1306 (100%)
955 (90%)
212 (75%)
59 (50%)
13 (25%)
3 (10%)
g/Ha
786
412
207
95
33
0
Rsq: 14.6 %
nodes: 11
predictors: 11
SLED frequency: 21
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)

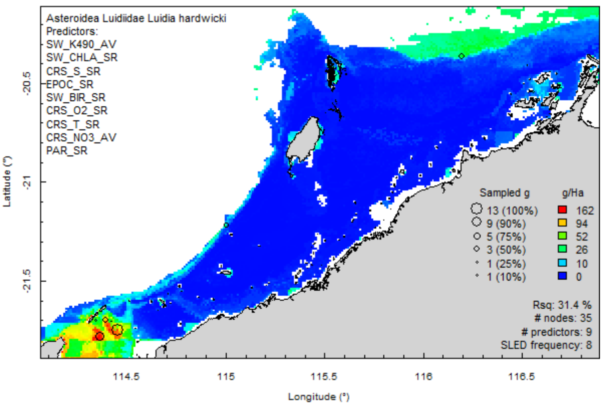

Anthozoa Trachyphylliidae Trachyphyllia geoffroyi
Predictors:
CRS_NO3_AV
EPOC_SR
CRS_T_AV
CRS_PO4_AV
CRS_O2_AV
SW_CHLA_SR
CRS_SI_AV
VGPM_SR
CRS_PO4_SR
CRS_S_AV
SW_K490_AV
MT_SST_SR
CRS_T_SR
Sampled g
225 (100%)
150 (90%)
85 (75%)
62 (50%)
25 (25%)
21 (10%)
g/Ha
3377
2053
1185
617
244
0
Rsq: 11.4 %
nodes: 35
predictors: 13
SLED frequency: 8
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)

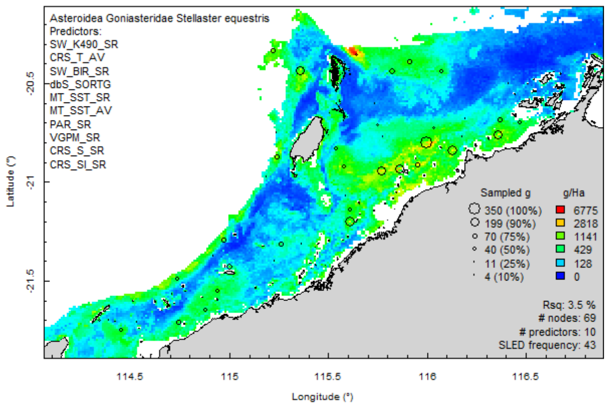
Ascidiacea (ascidians):

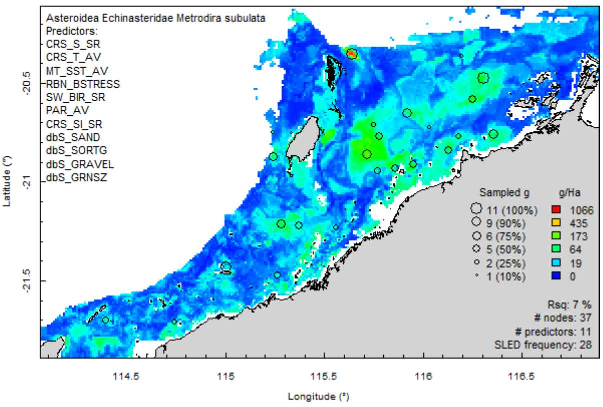


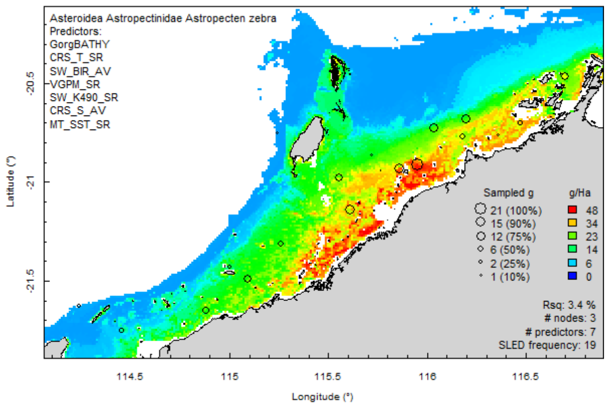


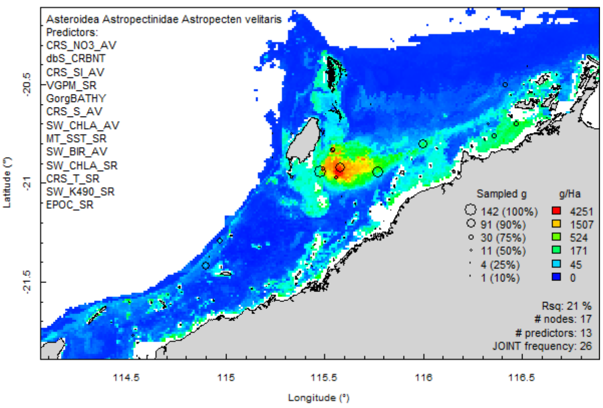
Asteroidea (sea stars):

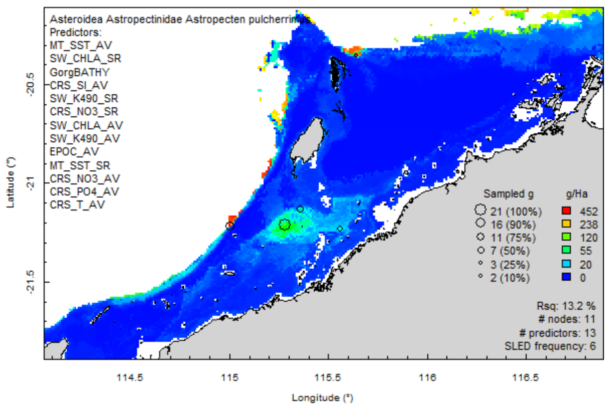


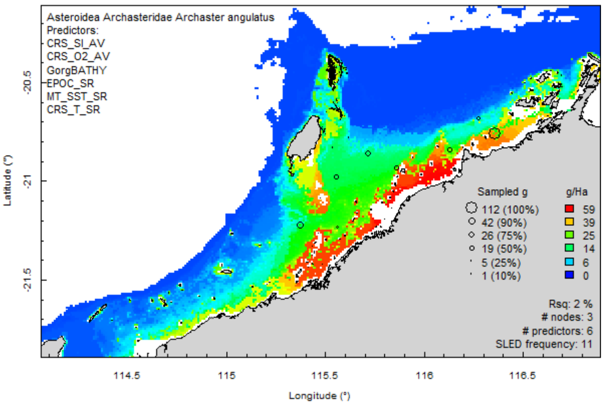


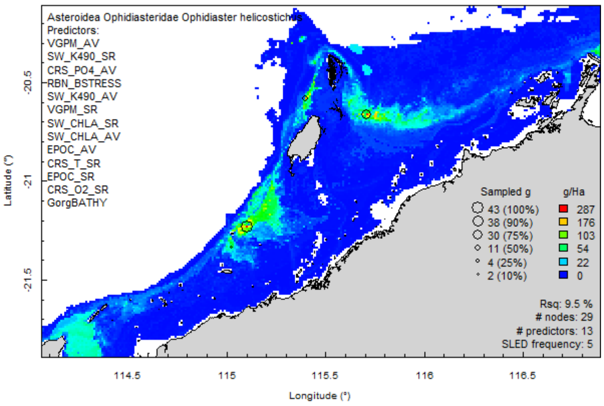




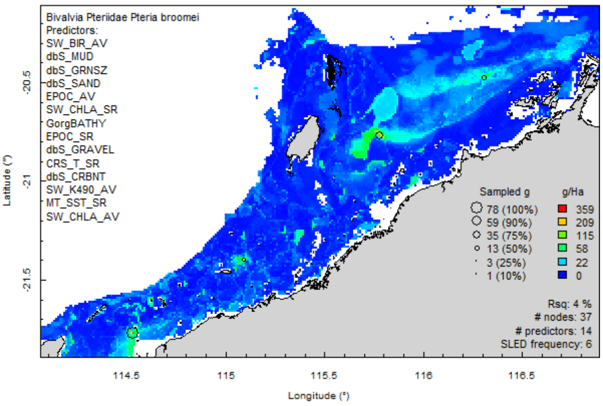


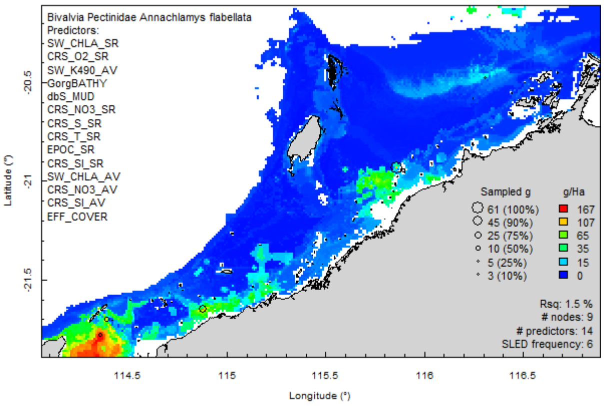


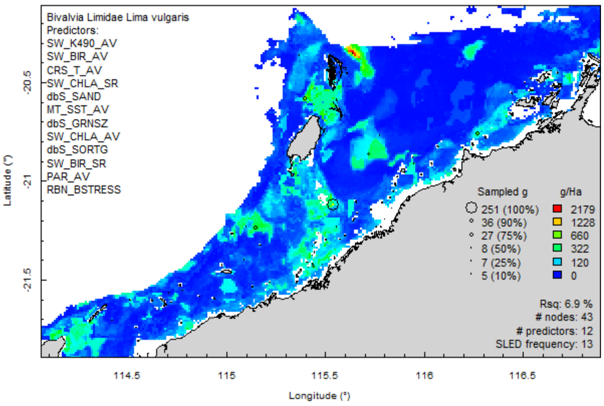


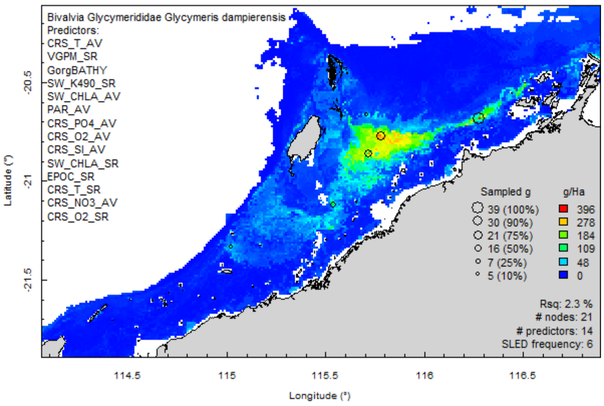


Bivalvia (bivalves):

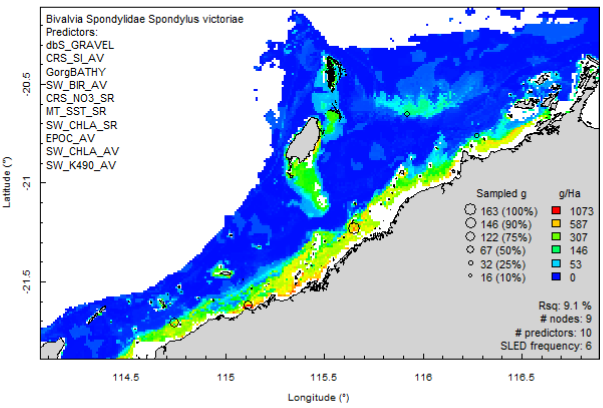


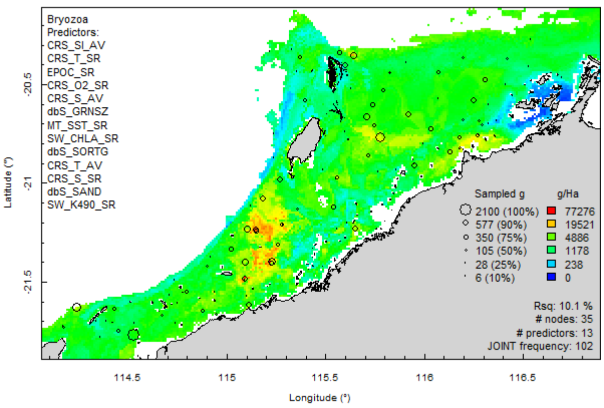




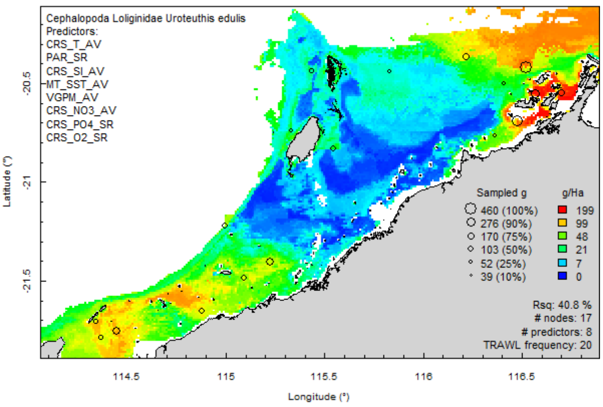


Bryozoa

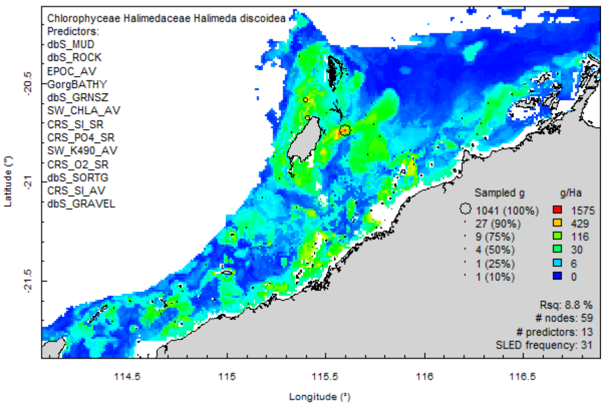


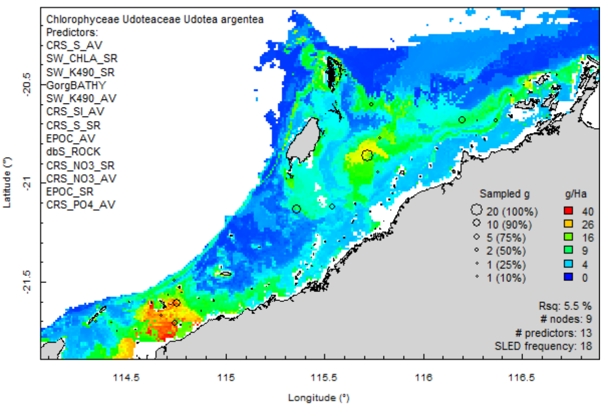


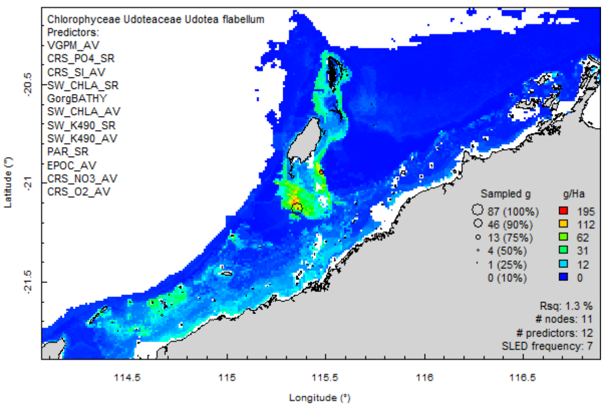
Cephalopoda



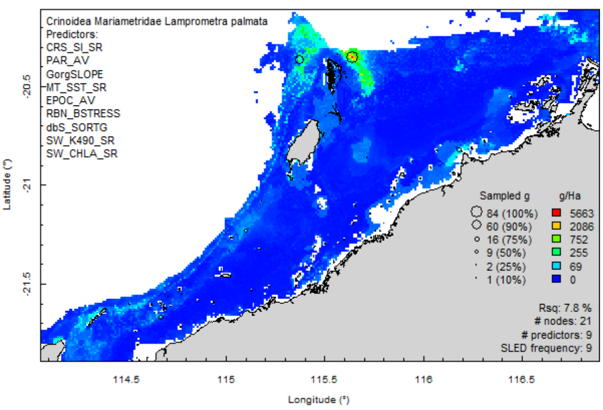
Chlorophyceae (green algae):

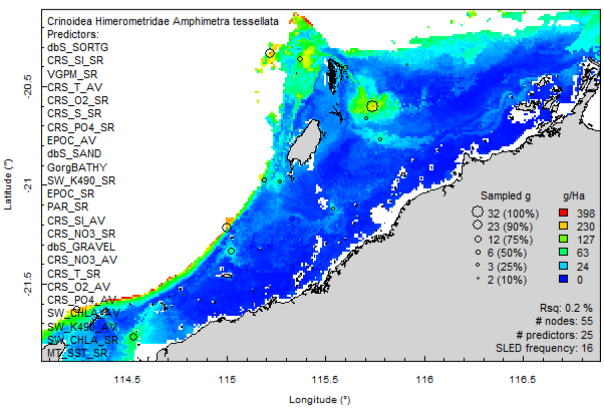


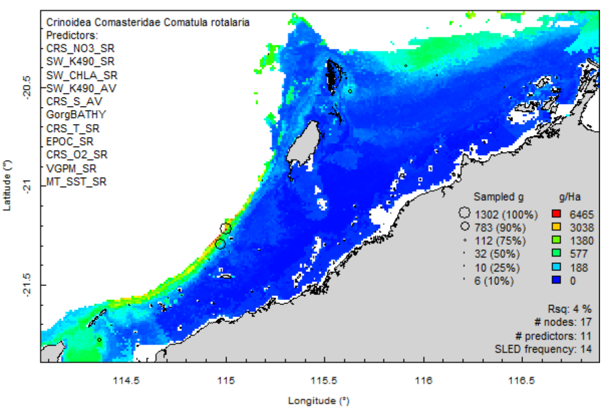


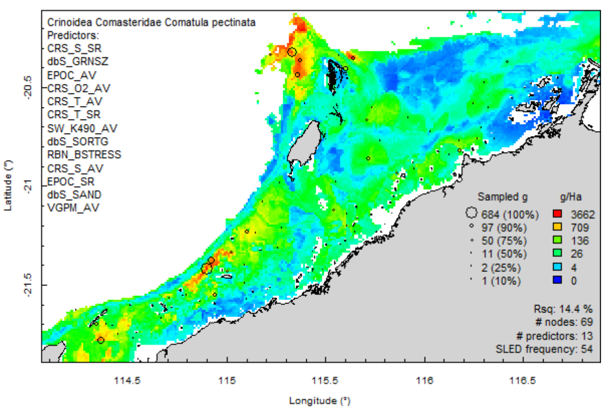


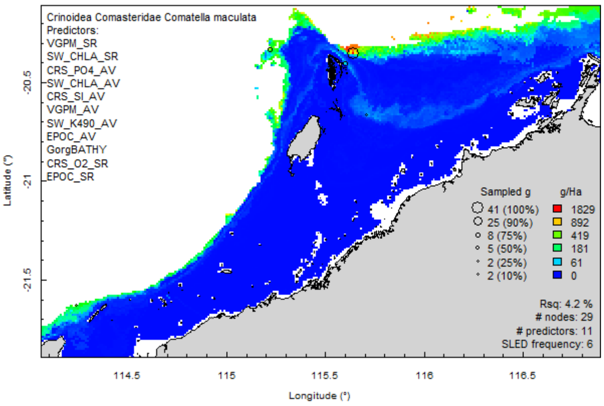
Crinoidea (feather stars):

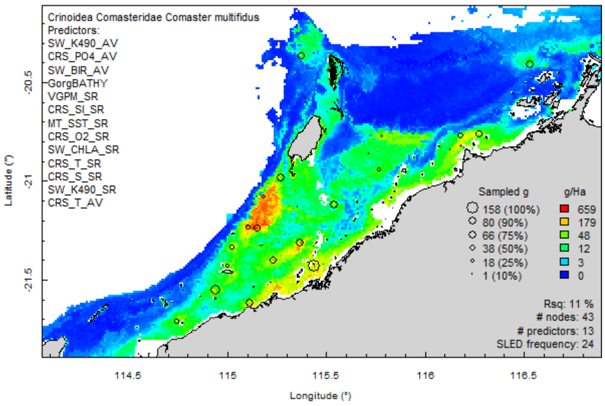


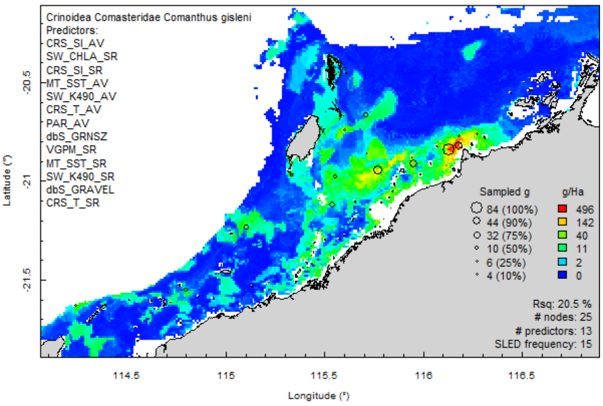


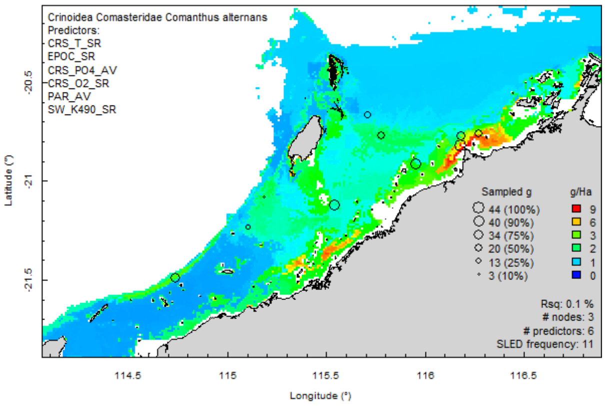


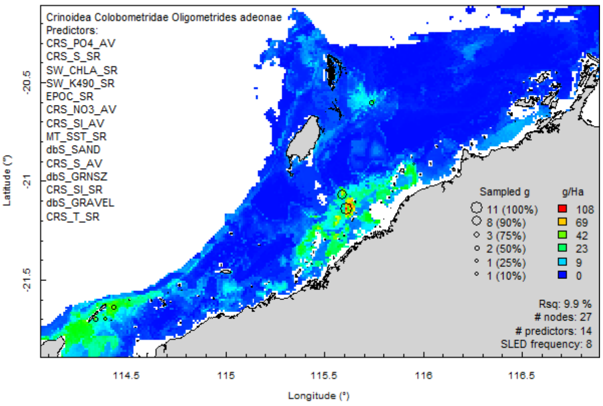


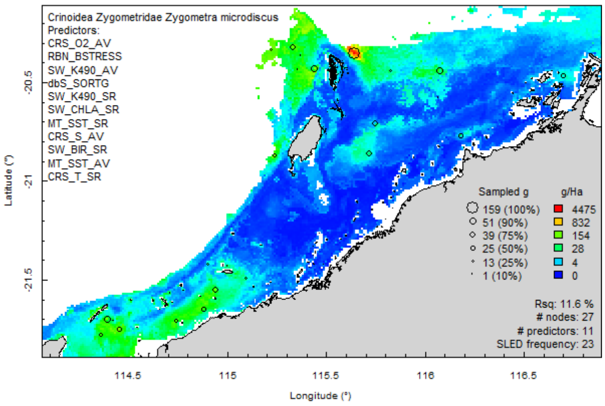




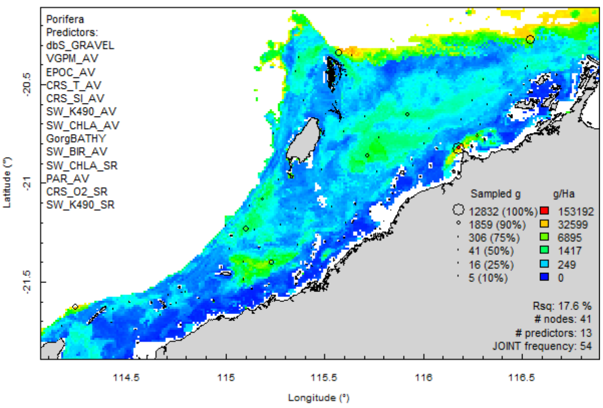


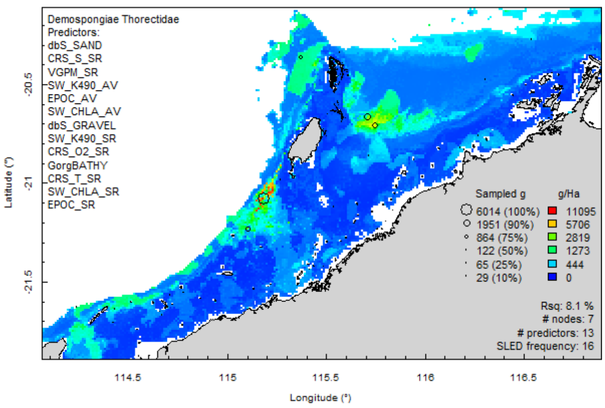


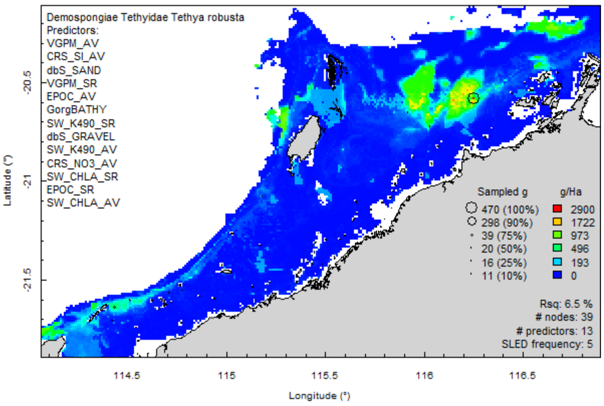


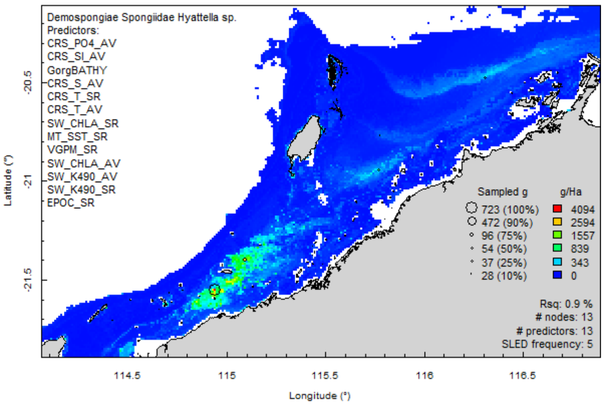


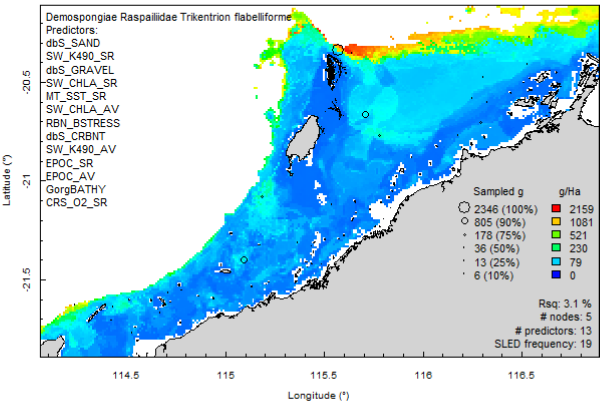
Demospongiae (sponges):

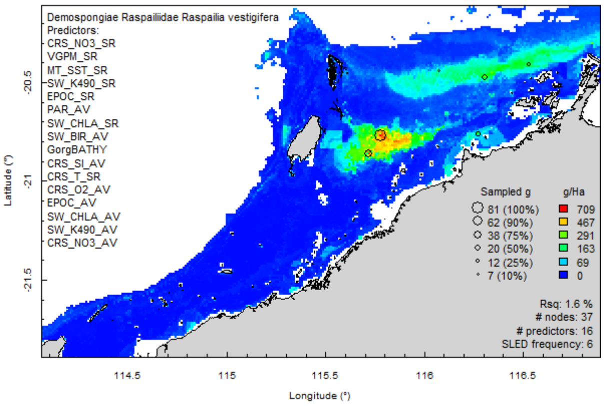


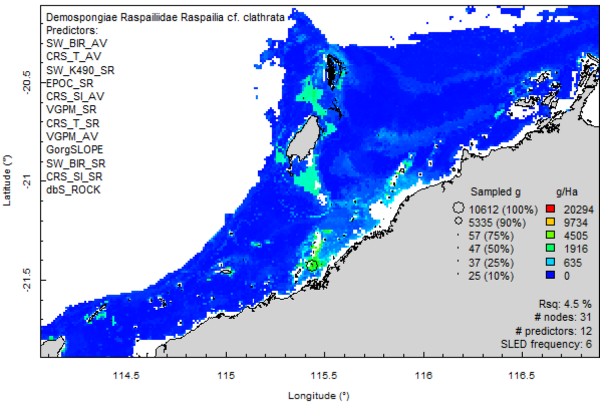


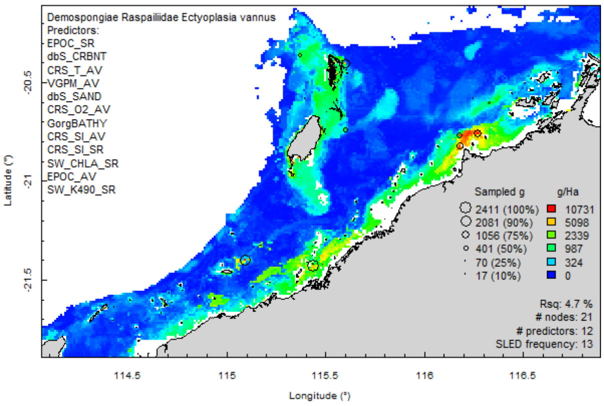

Demospongiae Tethyidae Tethya robusta
Predictors:
VGPM_AV
CRS_SI_AV
dbS_SAND
VGPM_SR
EPOC_AV
GorgBATHY
SW_K490_SR
dbS_GRAVEL
SW_K490_AV
CRS_NO3_AV
SW_CHLA_SR
EPOC_SR
SW_CHLA_AV
Sampled g
g/Ha
470 (100%)
298 (90%)
39 (75%)
20 (50%)
16 (25%)
11 (10%)
2900
1722
973
496
193
0
Rsq: 6.5 %
nodes: 39
predictors: 13
SLED frequency: 5
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)

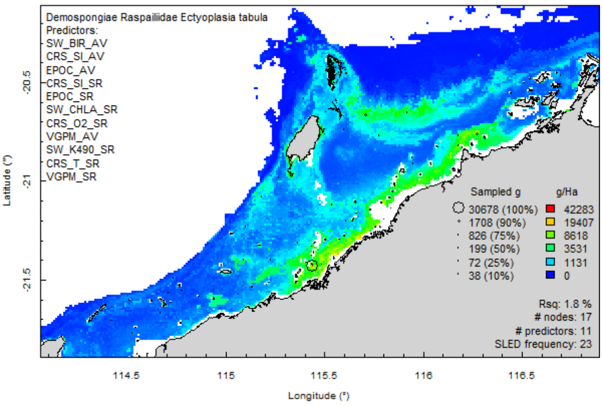

Demospongiae Spongiidae Hyattella sp.
Predictors:
CRS_PO4_AV
CRS_SI_AV
GorgBATHY
CRS_S_AV
CRS_T_SR
CRS_T_AV
SW_CHLA_SR
MT_SST_SR
VGPM_SR
SW_CHLA_AV
SW_K490_AV
SW_K490_SR
EPOC_SR
Sampled g
g/Ha
723 (100%)
472 (90%)
96 (75%)
54 (50%)
37 (25%)
28 (10%)
4094
2594
1557
839
343
0
Rsq: 0.9 %
nodes: 13
predictors: 13
SLED frequency: 5
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)

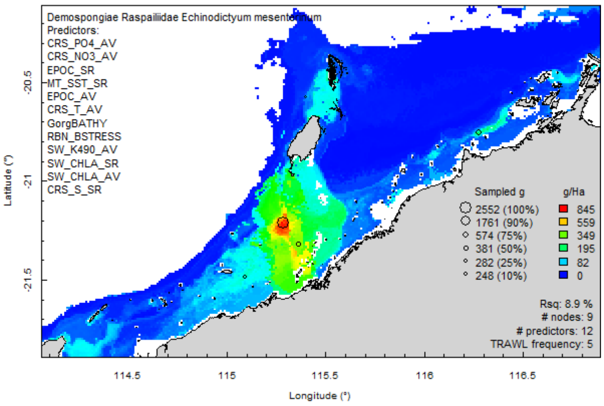

Demospongiae Raspailiidae Trikentrion flabelliforme
Predictors:
dbS_SAND
SW_K490_SR
dbS_GRAVEL
SW_CHLA_SR
MT_SST_SR
SW_CHLA_AV
RBN_BSTRESS
dbS_CRBNT
SW_K490_AV
EPOC_SR
EPOC_AV
GorgBATHY
CRS_O2_SR
Sampled g
g/Ha
2346 (100%)
805 (90%)
178 (75%)
36 (50%)
13 (25%)
6 (10%)
2159
1081
521
230
79
0
Rsq: 3.1 %
nodes: 5
predictors: 13
SLED frequency: 19
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)

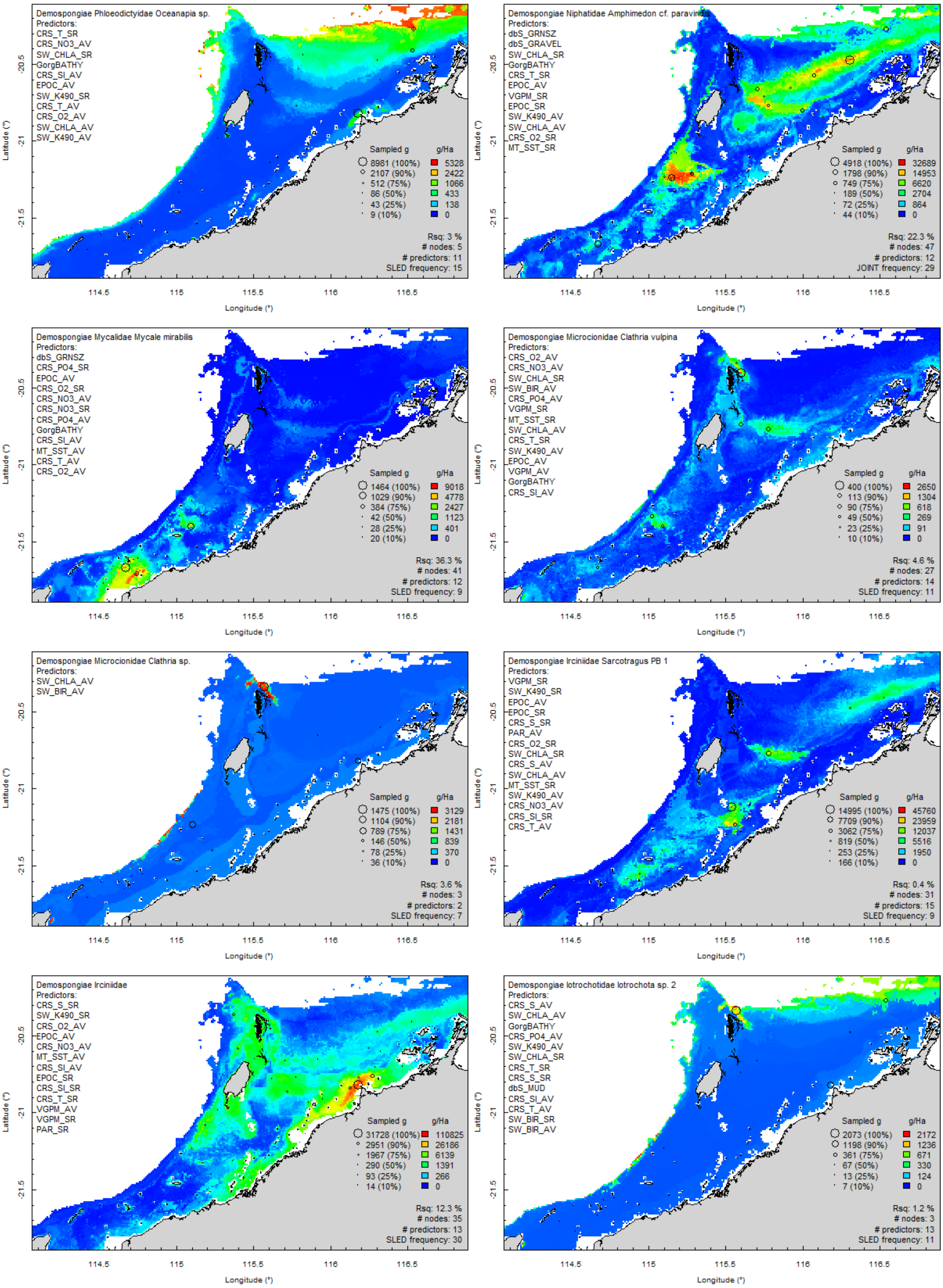

Demospongiae Raspailiidae Raspailia vestigifera
Predictors:
CRS_NO3_SR
VGPM_SR
MT_SST_SR
SW_K490_SR
EPOC_SR
PAR_AV
SW_CHLA_SR
SW_BIR_AV
GorgBATHY
CRS_SI_AV
CRS_T_SR
CRS_O2_SR
EPOC_AV
SW_CHLA_AV
SW_K490_AV
CRS_NO3_AV
Sampled g
g/Ha
81 (100%)
62 (90%)
38 (75%)
20 (50%)
12 (25%)
7 (10%)
709
467
291
163
69
0
Rsq: 1.6 %
nodes: 37
predictors: 16
SLED frequency: 6
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)


Demospongiae Raspailiidae Raspailia cf. clathrata
Predictors:
SW_BIR_AV
CRS_T_AV
SW_K490_SR
EPOC_SR
CRS_SI_AV
VGPM_SR
CRS_T_SR
VGPM_AV
GorgSLOPE
SW_BIR_SR
CRS_SI_SR
dbS_ROCK
Sampled g
g/Ha
10612 (100%)
5335 (90%)
57 (75%)
47 (50%)
37 (25%)
25 (10%)
20294
9734
4505
1916
635
0
Rsq: 4.5 %
nodes: 31
predictors: 12
SLED frequency: 6
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)

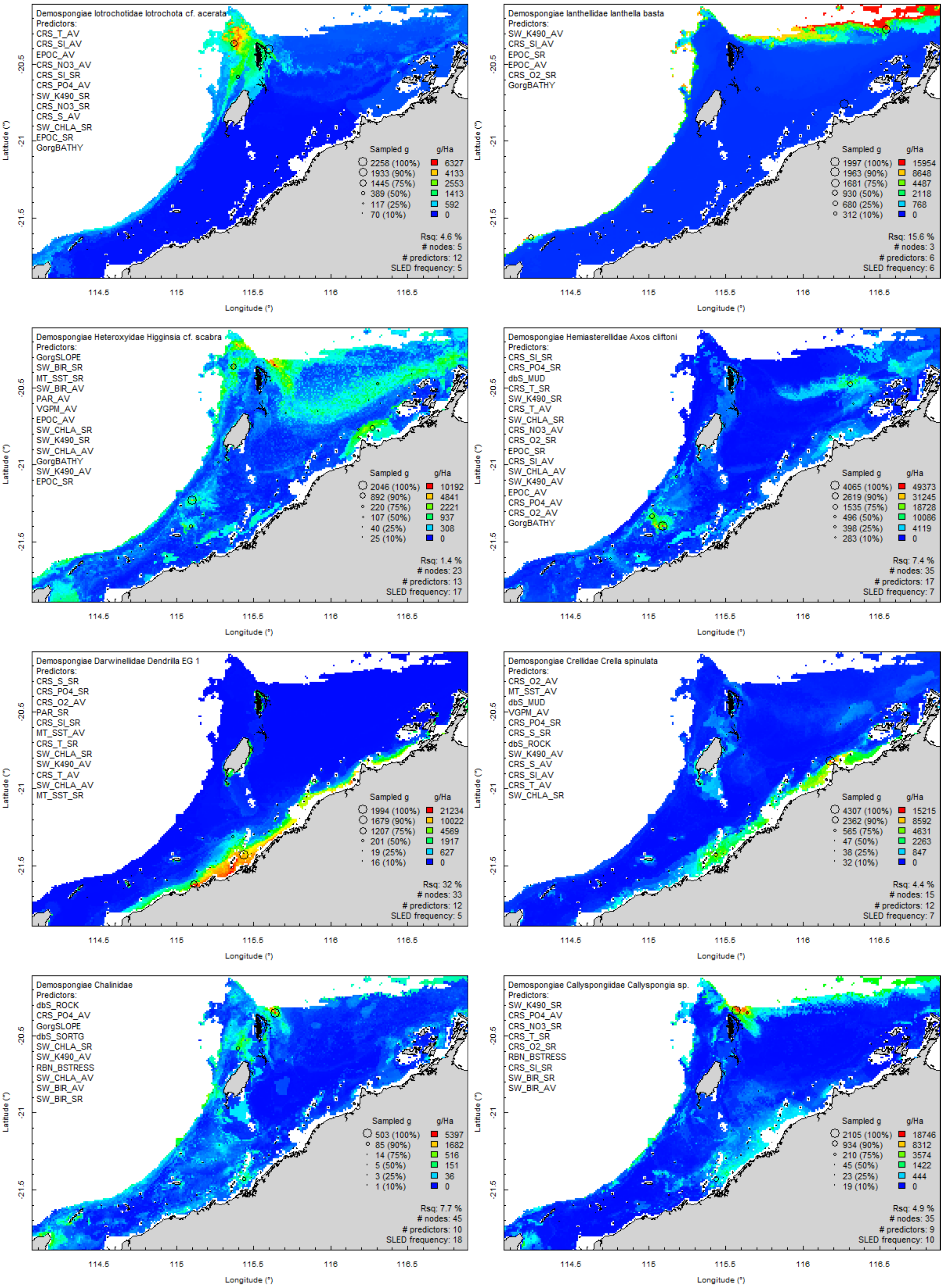

Demospongiae Raspailiidae Ectyoplasia vannus
Predictors:
EPOC_SR
dbS_CRBNT
CRS_T_AV
VGPM_AV
dbS_SAND
CRS_O2_AV
GorgBATHY
CRS_SI_AV
CRS_SI_SR
SW_CHLA_SR
EPOC_AV
SW_K490_SR
Sampled g
g/Ha
2411 (100%)
2081 (90%)
1056 (75%)
401 (50%)
70 (25%)
17 (10%)
10731
5098
2339
987
324
0
Rsq: 4.7 %
nodes: 21
predictors: 12
SLED frequency: 13
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)

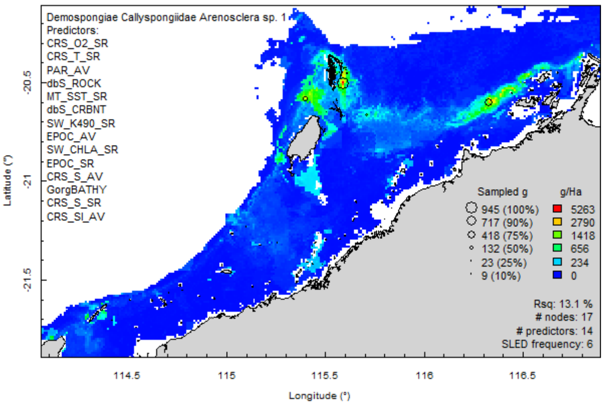

Demospongiae Raspailiidae Ectyoplasia tabula
Predictors:
SW_BIR_AV
CRS_SI_AV
EPOC_AV
CRS_SI_SR
EPOC_SR
SW_CHLA_SR
CRS_O2_SR
VGPM_AV
SW_K490_SR
CRS_T_SR
VGPM_SR
Sampled g
g/Ha
30678 (100%)
1708 (90%)
826 (75%)
199 (50%)
72 (25%)
38 (10%)
42283
19407
8618
3531
1131
0
Rsq: 1.8 %
nodes: 17
predictors: 11
SLED frequency: 23
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)

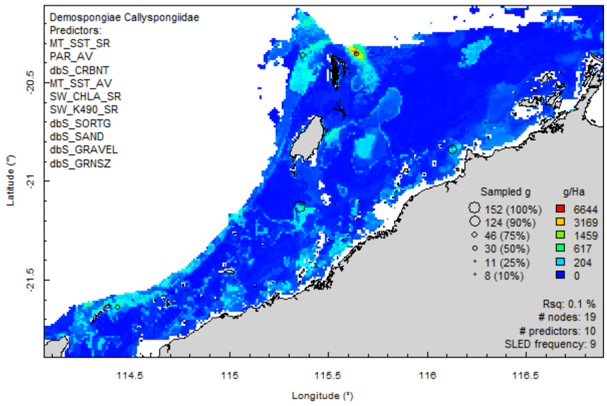

Demospongiae Raspailiidae Echinodictyum mesenterinum
Predictors:
CRS_PO4_AV
CRS_NO3_AV
EPOC_SR
MT_SST_SR
EPOC_AV
CRS_T_AV
GorgBATHY
RBN_BSTRESS
SW_K490_AV
SW_CHLA_SR
SW_CHLA_AV
CRS_S_SR
Sampled g
g/Ha
2552 (100%)
1761 (90%)
574 (75%)
381 (50%)
282 (25%)
248 (10%)
845
559
349
195
82
0
Rsq: 8.9 %
nodes: 9
predictors: 12
TRAWL frequency: 5
Latitude (°)
-20.5
-21
-21.5
114.5
115
115.5
116
116.5
Longitude (°)

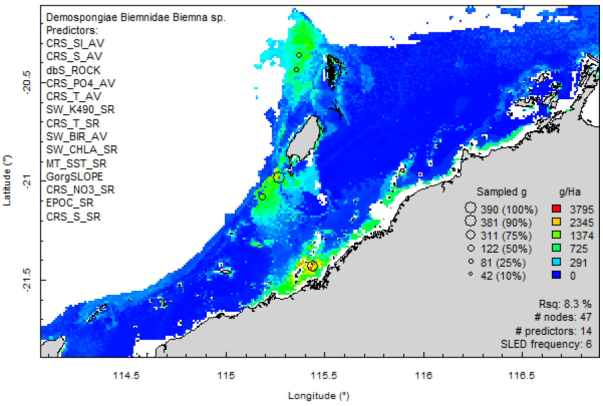


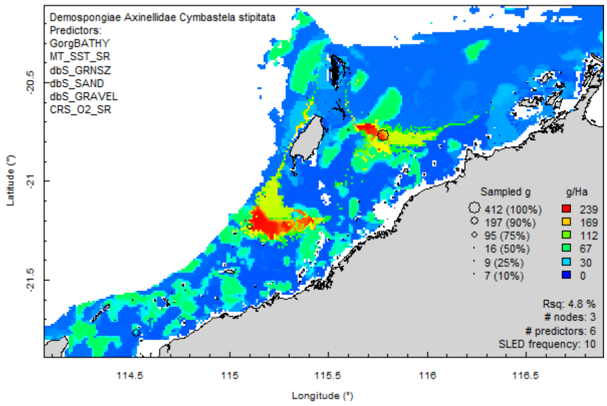
Demospongiae Phloeodictyidae Oceanapia sp.
Predictors:
CRS_T_SR
CRS_NO3_AV
SW_CHLA_SR
GorgBATHY
CRS_SI_AV
EPOC_AV
SW_K490_SR
CRS_T_AV
CRS_O2_AV
SW_CHLA_AV
SW_K490_AV
Sampled g
8981 (100%)
2107 (90%)
512 (75%)
86 (50%)
43 (25%)
9 (10%)
g/Ha
5328
2422
1066
433
138
0
Rsq: 3 %
nodes: 5
predictors: 11
SLED frequency: 15
Demospongiae Niphatidae Amphimedon cf. paravirid
Predictors:
dbS_GRNSZ
dbS_GRAVEL
SW_CHLA_SR
GorgBATHY
CRS_T_SR
EPOC_AV
VGPM_SR
EPOC_SR
SW_K490_AV
SW_CHLA_AV
CRS_O2_SR
MT_SST_SR
Sampled g
4918 (100%)
1798 (90%)
749 (75%)
189 (50%)
72 (25%)
44 (10%)
g/Ha
32689
14953
6620
2704
864
0
Rsq: 22.3 %
nodes: 47
predictors: 12
JOINT frequency: 29
Demospongiae Mycalidae Mycale mirabilis
Predictors:
dbS_GRNSZ
CRS_PO4_SR
EPOC_AV
CRS_O2_SR
CRS_NO3_AV
CRS_NO3_SR
CRS_PO4_AV
GorgBATHY
CRS_SI_AV
MT_SST_AV
CRS_T_AV
CRS_O2_AV
Sampled g
1464 (100%)
1029 (90%)
384 (75%)
42 (50%)
28 (25%)
20 (10%)
g/Ha
9018
4778
2427
1123
401
0
Rsq: 36.3 %
nodes: 41
predictors: 12
SLED frequency: 9
Demospongiae Microcionidae Clathria vulpina
Predictors:
CRS_O2_AV
CRS_NO3_AV
SW_CHLA_SR
SW_BIR_AV
CRS_PO4_AV
VGPM_SR
MT_SST_SR
SW_CHLA_AV
CRS_T_SR
SW_K490_AV
EPOC_AV
VGPM_AV
GorgBATHY
CRS_SI_AV
Sampled g
400 (100%)
113 (90%)
90 (75%)
49 (50%)
23 (25%)
10 (10%)
g/Ha
2650
1304
618
269
91
0
Rsq: 4.6 %
nodes: 27
predictors: 14
SLED frequency: 11
Demospongiae Microcionidae Clathria sp.
Predictors:
SW_CHLA_AV
SW_BIR_AV
Sampled g
1475 (100%)
1104 (90%)
789 (75%)
146 (50%)
78 (25%)
36 (10%)
g/Ha
3129
2181
1431
839
370
0
Rsq: 3.6 %
nodes: 3
predictors: 2
SLED frequency: 7
Demospongiae Irciniidae Sarcotragus PB 1
Predictors:
VGPM_SR
SW_K490_SR
EPOC_AV
EPOC_SR
CRS_S_SR
PAR_AV
CRS_O2_SR
SW_CHLA_SR
CRS_S_AV
SW_CHLA_AV
MT_SST_SR
SW_K490_AV
CRS_NO3_AV
CRS_SI_SR
CRS_T_AV
Sampled g
14995 (100%)
7709 (90%)
3062 (75%)
819 (50%)
253 (25%)
166 (10%)
g/Ha
45760
23959
12037
5516
1950
0
Rsq: 0.4 %
nodes: 31
predictors: 15
SLED frequency: 9
Demospongiae Irciniidae
Predictors:
CRS_S_SR
SW_K490_SR
CRS_O2_AV
EPOC_AV
CRS_NO3_AV
MT_SST_AV
CRS_SI_AV
EPOC_SR
CRS_SI_SR
CRS_T_SR
VGPM_AV
VGPM_SR
PAR_SR
Sampled g
31728 (100%)
2951 (90%)
1967 (75%)
290 (50%)
93 (25%)
14 (10%)
g/Ha
110825
26186
6139
1391
266
0
Rsq: 12.3 %
nodes: 35
predictors: 13
SLED frequency: 30
Demospongiae Iotrochotidae Iotrochota sp. 2
Predictors:
CRS_S_AV
SW_CHLA_AV
GorgBATHY
CRS_PO4_AV
SW_K490_AV
SW_CHLA_SR
CRS_T_SR
CRS_S_SR
dbS_MUD
CRS_SI_AV
CRS_T_AV
SW_BIR_SR
SW_BIR_AV
Sampled g
2073 (100%)
1198 (90%)
361 (75%)
67 (50%)
13 (25%)
7 (10%)
g/Ha
2172
1236
671
330
124
0
Rsq: 1.2 %
nodes: 3
predictors: 13
SLED frequency: 11
Latitude (°)
-20.5
-21
-21.5
Longitude (°)
114.5
115
115.5
116
116.5

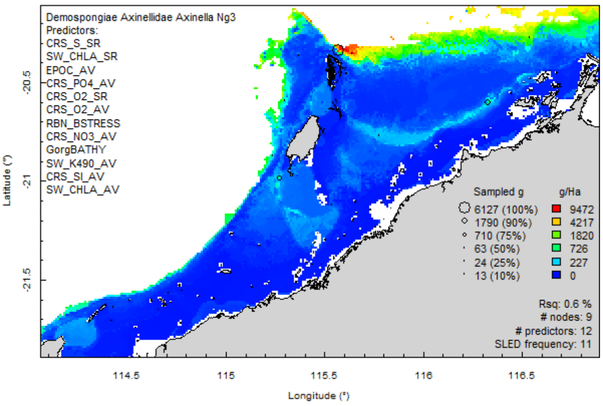

Demospongiae Iotrochotidae Iotrochota cf. acerata
Predictors:
CRS_T_AV
CRS_SI_AV
EPOC_AV
CRS_NO3_AV
CRS_SI_SR
CRS_PO4_SR
SW_K490_SR
CRS_NO3_SR
CRS_S_AV
SW_CHLA_SR
EPOC_SR
GorgBATHY
Sampled g
2258 (100%)
1933 (90%)
1445 (75%)
389 (50%)
117 (25%)
70 (10%)
g/Ha
6327
4133
2553
1413
592
0
Rsq: 4.6 %
nodes: 5
predictors: 12
SLED frequency: 5
Demospongiae Ianthellidae Ianthella basta
Predictors:
SW_K490_AV
CRS_SI_AV
EPOC_SR
EPOC_AV
CRS_O2_SR
GorgBATHY
Sampled g
1997 (100%)
1963 (90%)
1681 (75%)
930 (50%)
680 (25%)
312 (10%)
g/Ha
15954
8648
4487
2118
768
0
Rsq: 15.6 %
nodes: 3
predictors: 6
SLED frequency: 6
Demospongiae Heteroxyidae Higginsia cf. scabra
Predictors:
GorgSLOPE
SW_BIR_SR
MT_SST_SR
SW_BIR_AV
PAR_AV
VGPM_AV
EPOC_AV
SW_CHLA_SR
SW_K490_SR
SW_CHLA_AV
GorgBATHY
SW_K490_AV
EPOC_SR
Sampled g
2046 (100%)
892 (90%)
220 (75%)
107 (50%)
40 (25%)
25 (10%)
g/Ha
10192
4841
2221
937
308
0
Rsq: 1.4 %
nodes: 23
predictors: 13
SLED frequency: 17
Demospongiae Hemiasterellidae Axos cliftoni
Predictors:
CRS_SI_SR
CRS_PO4_SR
dbS_MUD
CRS_T_SR
SW_K490_SR
CRS_T_AV
SW_CHLA_SR
CRS_NO3_AV
CRS_O2_SR
EPOC_SR
CRS_SI_AV
SW_CHLA_AV
SW_K490_AV
EPOC_AV
CRS_PO4_AV
CRS_O2_AV
GorgBATHY
Sampled g
4065 (100%)
2619 (90%)
1535 (75%)
496 (50%)
398 (25%)
283 (10%)
g/Ha
49373
31245
18728
10086
4119
0
Rsq: 7.4 %
nodes: 35
predictors: 17
SLED frequency: 7
Demospongiae Darwinellidae Dendrilla EG 1
Predictors:
CRS_S_SR
CRS_PO4_SR
CRS_O2_AV
PAR_SR
CRS_SI_SR
MT_SST_AV
CRS_T_SR
SW_CHLA_SR
SW_K490_AV
CRS_T_AV
SW_CHLA_AV
MT_SST_SR
Sampled g
1994 (100%)
1679 (90%)
1207 (75%)
201 (50%)
19 (25%)
16 (10%)
g/Ha
21234
10022
4569
1917
627
0
Rsq: 32 %
nodes: 33
predictors: 12
SLED frequency: 5
Demospongiae Crellidae Crella spinulata
Predictors:
CRS_O2_AV
MT_SST_AV
dbS_MUD
VGPM_AV
CRS_PO4_SR
CRS_S_SR
dbS_ROCK
SW_K490_AV
CRS_S_AV
CRS_SI_AV
CRS_T_AV
SW_CHLA_SR
Sampled g
4307 (100%)
2362 (90%)
565 (75%)
47 (50%)
38 (25%)
32 (10%)
g/Ha
15215
8592
4631
2263
847
0
Rsq: 4.4 %
nodes: 15
predictors: 12
SLED frequency: 7
Demospongiae Chalinidae
Predictors:
dbS_ROCK
CRS_PO4_AV
GorgSLOPE
dbS_SORTG
SW_CHLA_SR
SW_K490_AV
RBN_BSTRESS
SW_CHLA_AV
SW_BIR_AV
SW_BIR_SR
Sampled g
503 (100%)
85 (90%)
14 (75%)
5 (50%)
3 (25%)
1 (10%)
g/Ha
5397
1682
516
151
36
0
Rsq: 7.7 %
nodes: 45
predictors: 10
SLED frequency: 18
Demospongiae Callyspongiidae Callyspongia sp.
Predictors:
SW_K490_SR
CRS_PO4_AV
CRS_NO3_SR
CRS_T_SR
CRS_O2_SR
RBN_BSTRESS
CRS_SI_SR
SW_BIR_SR
SW_BIR_AV
Sampled g
2105 (100%)
934 (90%)
210 (75%)
45 (50%)
23 (25%)
19 (10%)
g/Ha
18746
8312
3574
1422
444
0
Rsq: 4.9 %
nodes: 35
predictors: 9
SLED frequency: 10
Latitude (°)
-20.5
-21
-21.5
Longitude (°)
114.5
115
115.5
116
116.5

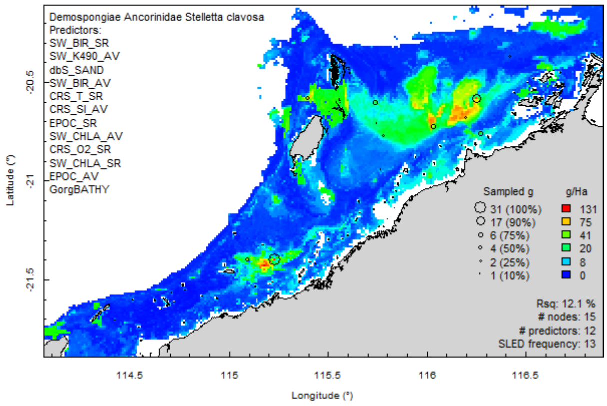




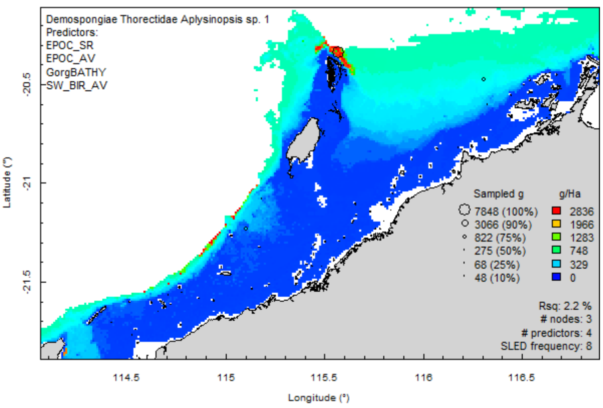


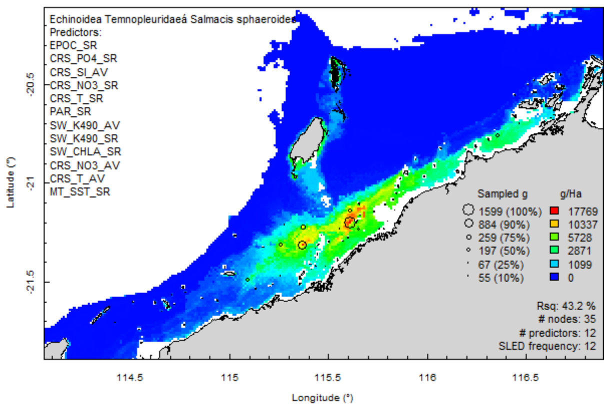


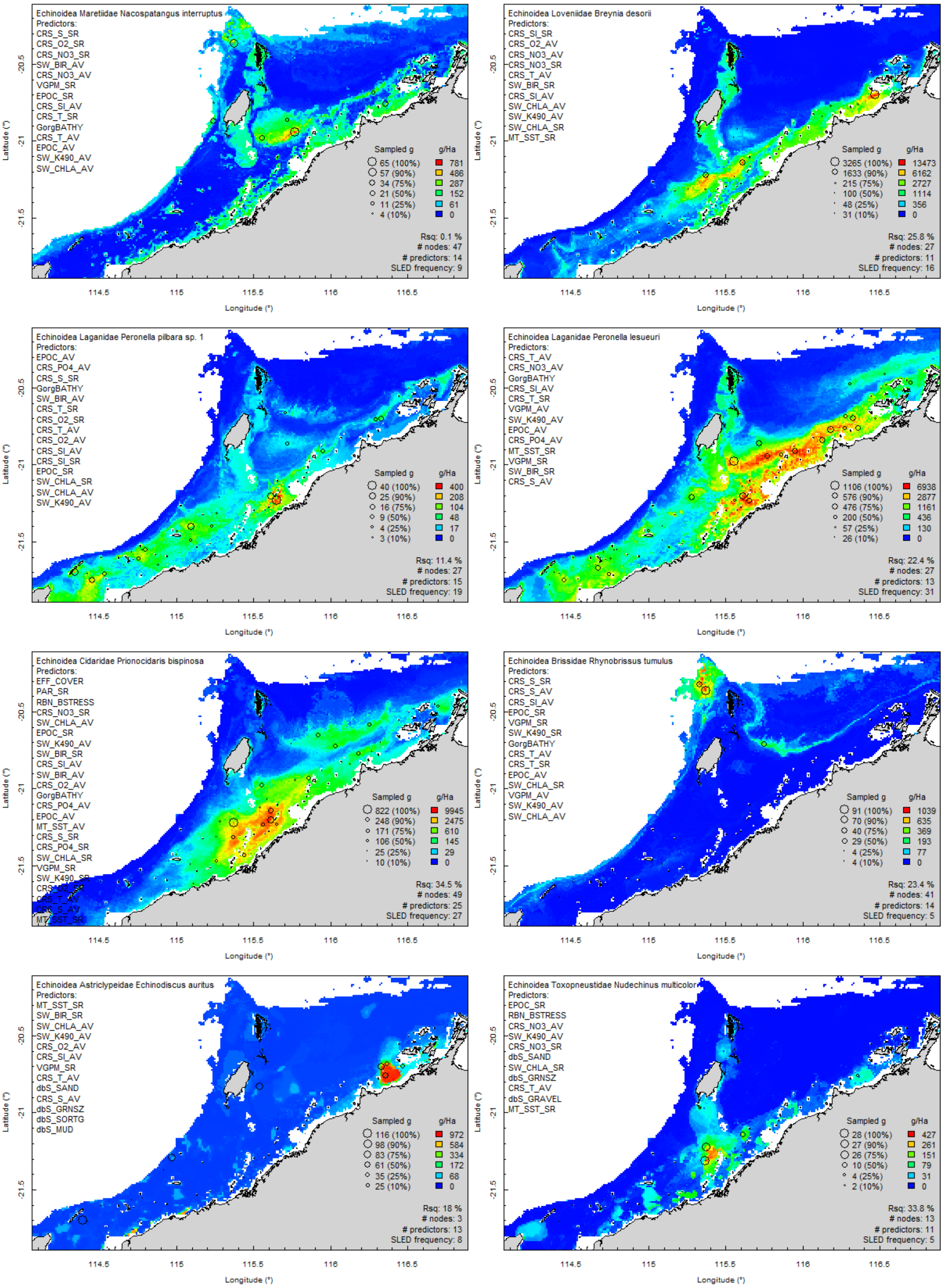




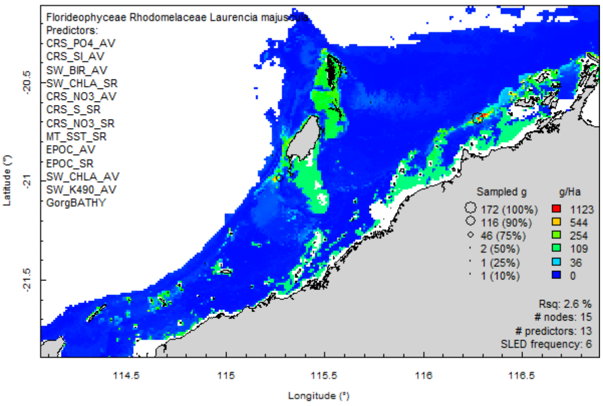
Echinoidea (sea urchins):

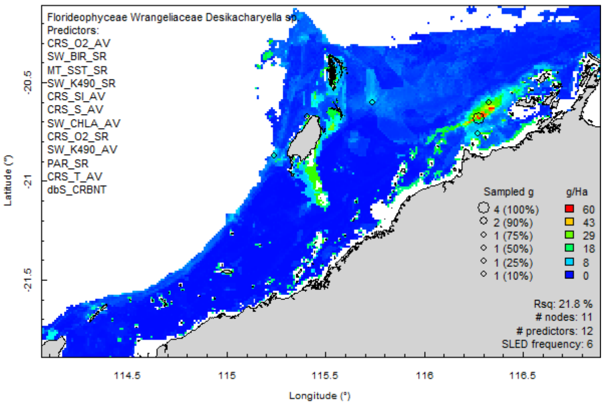




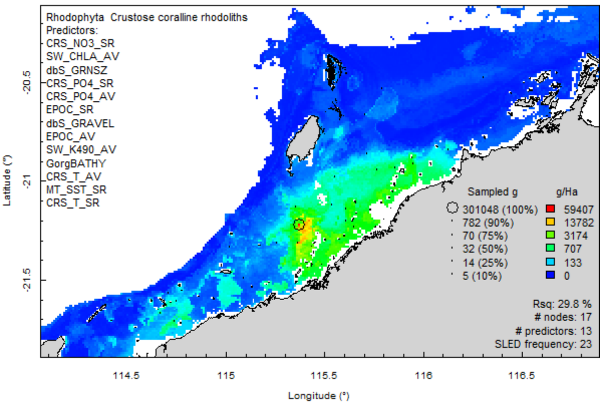

Echinoidea Maretiidae Nacospatangus interruptus
Predictors:
CRS_S_SR
CRS_O2_SR
CRS_NO3_SR
SW_BIR_AV
CRS_NO3_AV
VGPM_SR
EPOC_SR
CRS_SI_AV
CRS_T_SR
GorgBATHY
CRS_T_AV
EPOC_AV
SW_K490_AV
SW_CHLA_AV
Sampled g
65 (100%)
57 (90%)
34 (75%)
21 (50%)
11 (25%)
4 (10%)
g/Ha
781
486
287
152
61
0
Rsq: 0.1 %
nodes: 47
predictors: 14
SLED frequency: 9
Echinoidea Loveniidae Breynia desorii
Predictors:
CRS_SI_SR
CRS_O2_AV
CRS_NO3_AV
CRS_NO3_SR
CRS_T_AV
SW_BIR_SR
CRS_SI_AV
SW_CHLA_AV
SW_K490_AV
SW_CHLA_SR
MT_SST_SR
Sampled g
3265 (100%)
1633 (90%)
215 (75%)
100 (50%)
48 (25%)
31 (10%)
g/Ha
13473
6162
2727
1114
356
0
Rsq: 25.8 %
nodes: 27
predictors: 11
SLED frequency: 16
Echinoidea Laganidae Peronella pilbara sp. 1
Predictors:
EPOC_AV
CRS_PO4_AV
CRS_S_SR
GorgBATHY
SW_BIR_AV
CRS_T_SR
CRS_O2_SR
CRS_T_AV
CRS_O2_AV
CRS_SI_AV
CRS_SI_SR
EPOC_SR
SW_CHLA_SR
SW_CHLA_AV
SW_K490_AV
Sampled g
40 (100%)
25 (90%)
16 (75%)
9 (50%)
4 (25%)
3 (10%)
g/Ha
400
208
104
48
17
0
Rsq: 11.4 %
nodes: 27
predictors: 15
SLED frequency: 19
Echinoidea Laganidae Peronella lesueuri
Predictors:
CRS_T_AV
CRS_NO3_AV
GorgBATHY
CRS_SI_AV
CRS_T_SR
VGPM_AV
SW_K490_AV
EPOC_AV
CRS_PO4_AV
MT_SST_SR
VGPM_SR
SW_BIR_SR
CRS_S_AV
Sampled g
1106 (100%)
576 (90%)
476 (75%)
200 (50%)
57 (25%)
26 (10%)
g/Ha
6938
2877
1161
436
130
0
Rsq: 22.4 %
nodes: 27
predictors: 13
SLED frequency: 31
Echinoidea Cidaridae Prionocidaris bispinosa
Predictors:
EFF_COVER
PAR_SR
RBN_BSTRESS
CRS_NO3_SR
SW_CHLA_AV
EPOC_SR
SW_K490_AV
SW_BIR_SR
CRS_SI_AV
SW_BIR_AV
CRS_O2_AV
GorgBATHY
CRS_PO4_AV
EPOC_AV
MT_SST_AV
CRS_S_SR
CRS_PO4_SR
SW_CHLA_SR
VGPM_SR
Sampled g
822 (100%)
248 (90%)
171 (75%)
106 (50%)
25 (25%)
10 (10%)
g/Ha
9945
2475
610
145
29
0
Rsq: 34.5 %
nodes: 49
predictors: 25
SLED frequency: 27
Echinoidea Brissidae Rhynobrissus tumulus
Predictors:
CRS_S_SR
CRS_S_AV
CRS_SI_AV
EPOC_SR
VGPM_SR
SW_K490_SR
GorgBATHY
CRS_T_AV
CRS_T_SR
EPOC_AV
SW_CHLA_SR
VGPM_AV
SW_K490_AV
SW_CHLA_AV
Sampled g
91 (100%)
70 (90%)
40 (75%)
29 (50%)
4 (25%)
4 (10%)
g/Ha
1039
635
369
193
77
0
Rsq: 23.4 %
nodes: 41
predictors: 14
SLED frequency: 5
Echinoidea Astriclypeidae Echinodiscus auritus
Predictors:
MT_SST_SR
SW_BIR_SR
SW_CHLA_AV
SW_K490_AV
CRS_O2_AV
CRS_SI_AV
VGPM_SR
CRS_T_AV
dbS_SAND
CRS_S_AV
dbS_GRNSZ
dbS_SORTG
dbS_MUD
Sampled g
116 (100%)
98 (90%)
83 (75%)
61 (50%)
35 (25%)
25 (10%)
g/Ha
972
584
334
172
68
0
Rsq: 18 %
nodes: 3
predictors: 13
SLED frequency: 8
Echinoidea Toxopneustidae Nudechinus multicolor
Predictors:
EPOC_SR
RBN_BSTRESS
CRS_NO3_AV
SW_K490_AV
CRS_NO3_SR
dbS_SAND
SW_CHLA_SR
dbS_GRNSZ
CRS_T_AV
dbS_GRAVEL
MT_SST_SR
Sampled g
28 (100%)
27 (90%)
26 (75%)
10 (50%)
4 (25%)
2 (10%)
g/Ha
427
261
151
79
31
0
Rsq: 33.8 %
nodes: 13
predictors: 11
SLED frequency: 5
Latitude (°)
-20.5
-21
-21.5
Longitude (°)
114.5
115
115.5
116
116.5

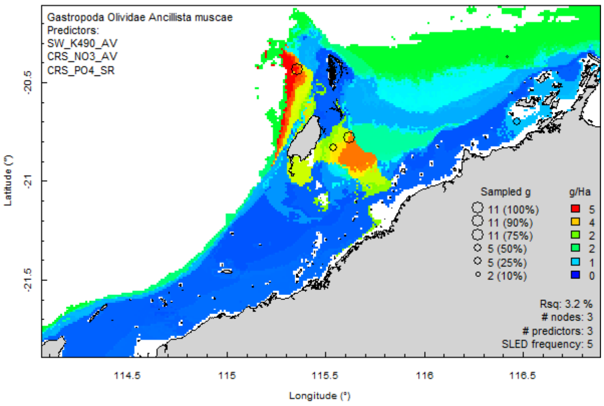
Florideophyceae (red algae):

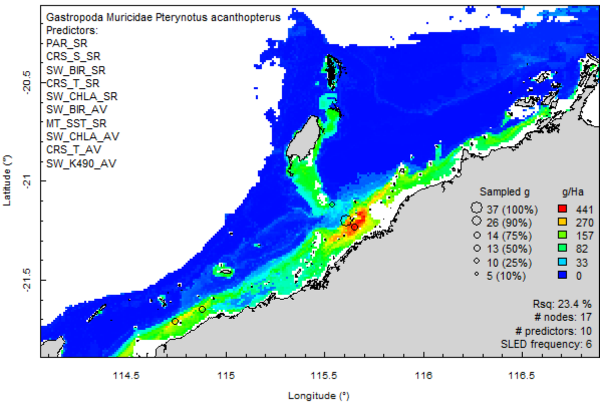


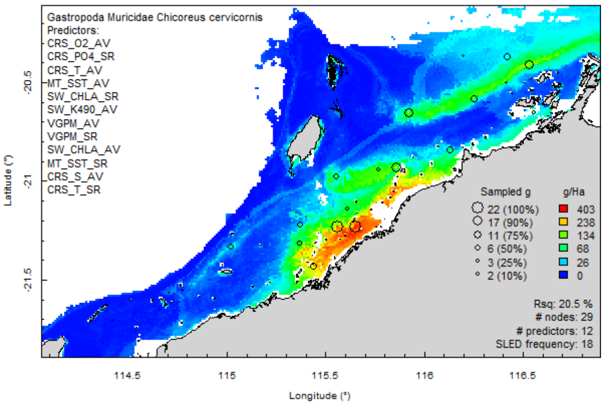


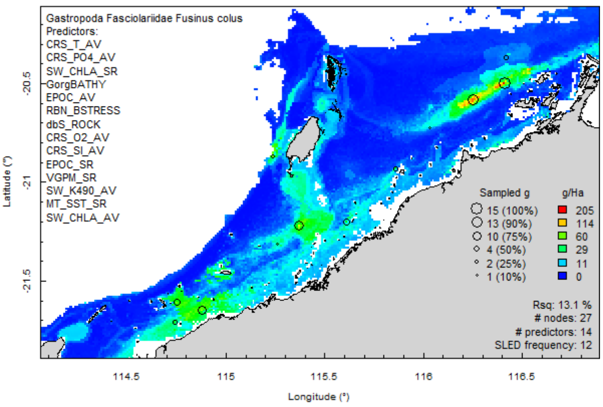
Gastropoda (sea snails):

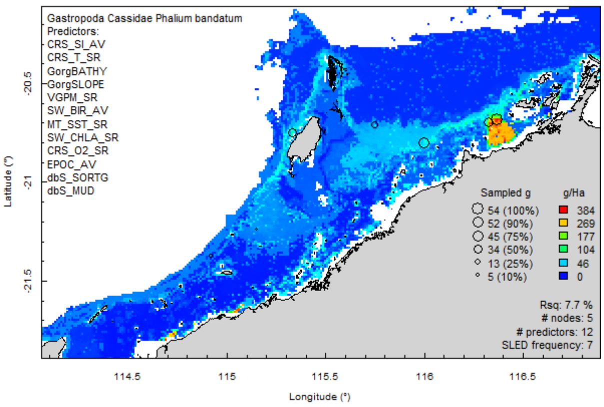




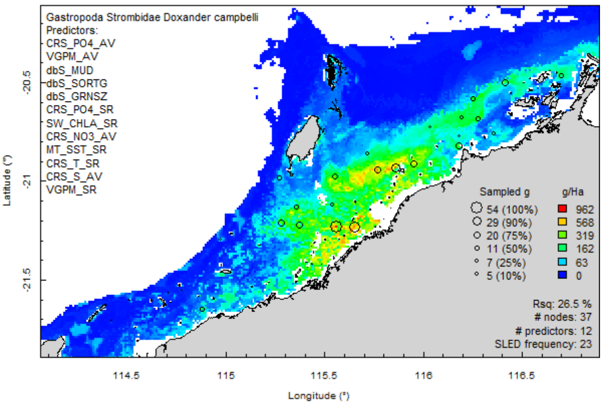


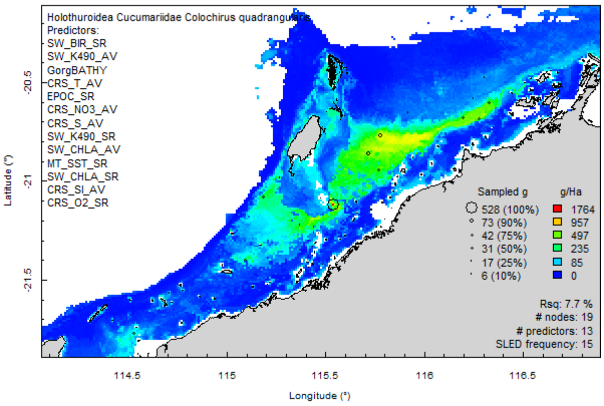


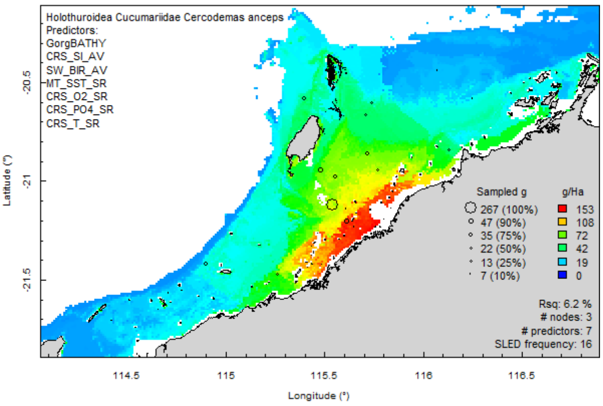


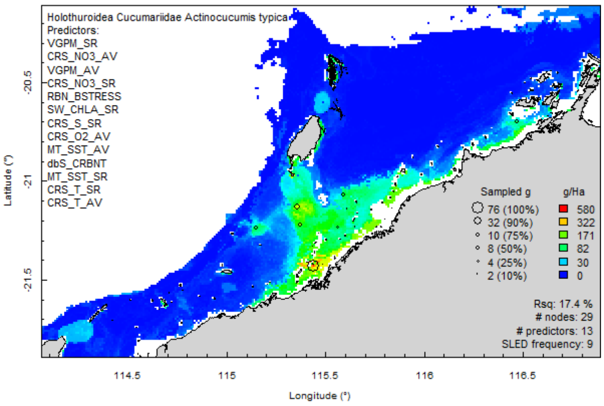


Holothuroidea (sea cucumbers):

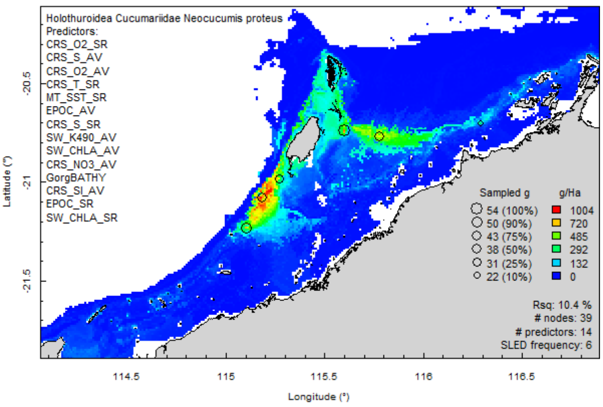


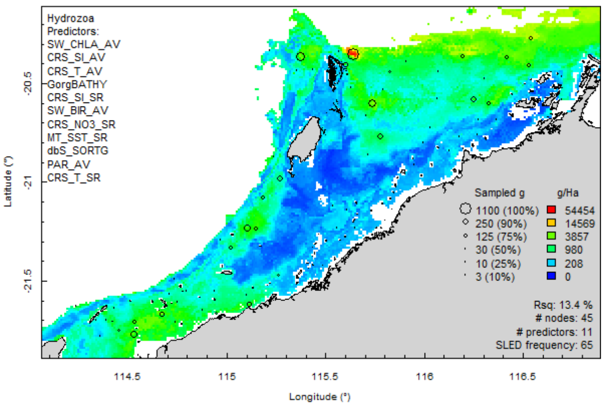




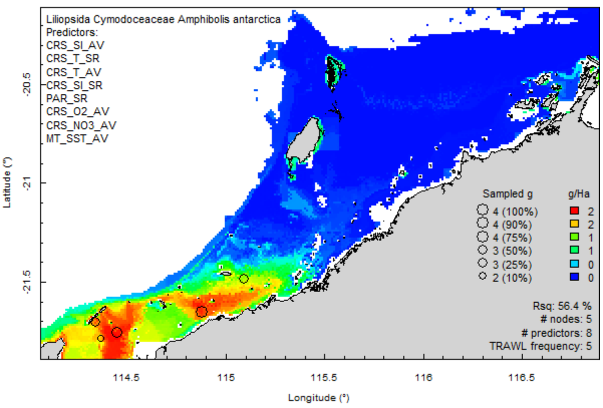


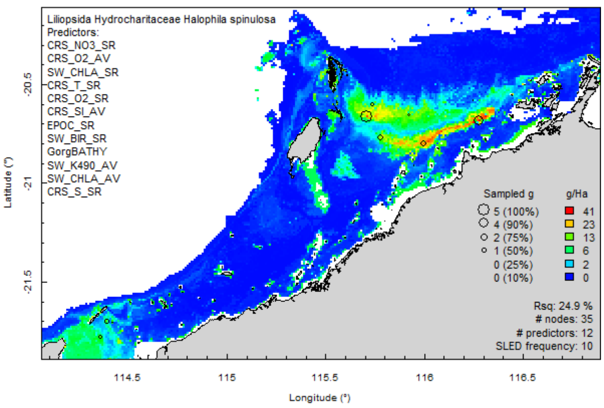
Hydrozoa (hydroids):



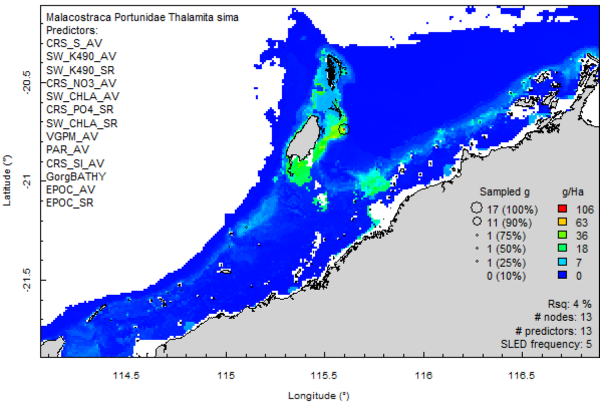


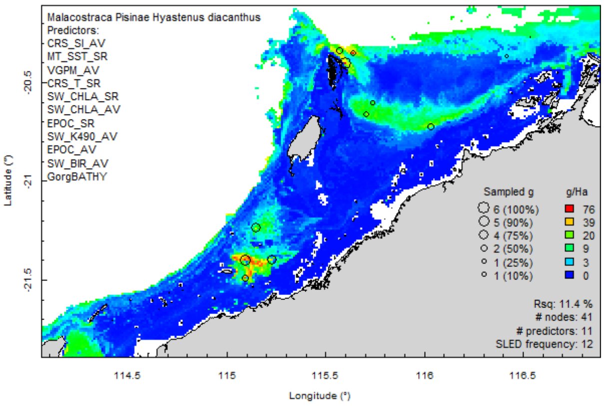
Liliopsoda (sea grasses)

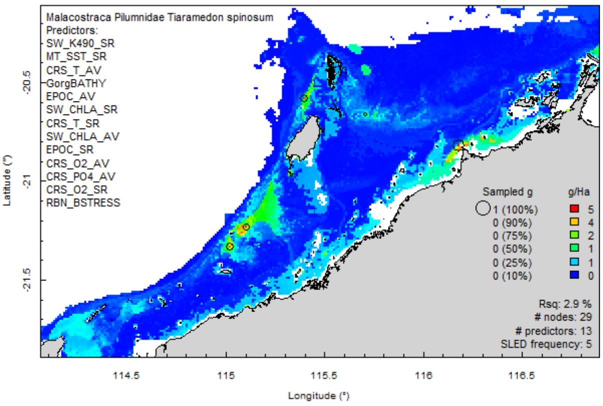


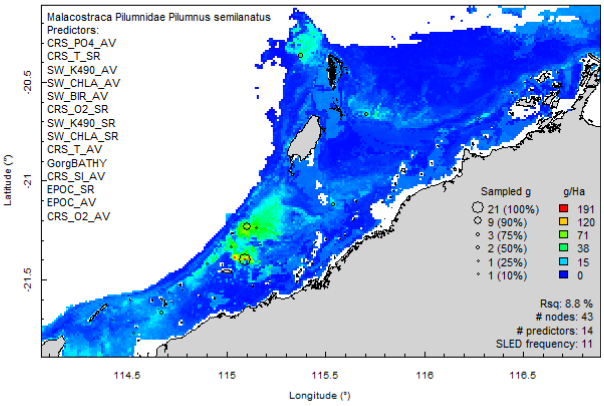


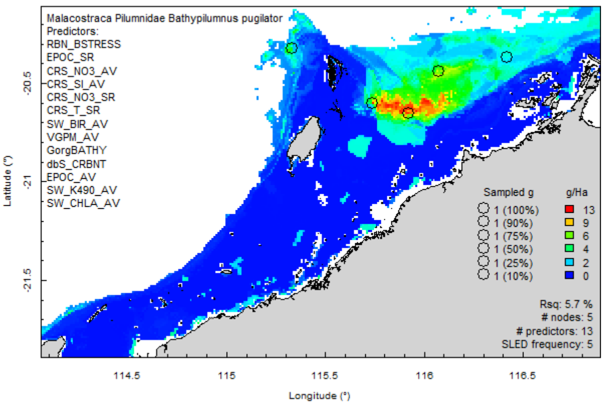
Malacostraca (crustaceans):

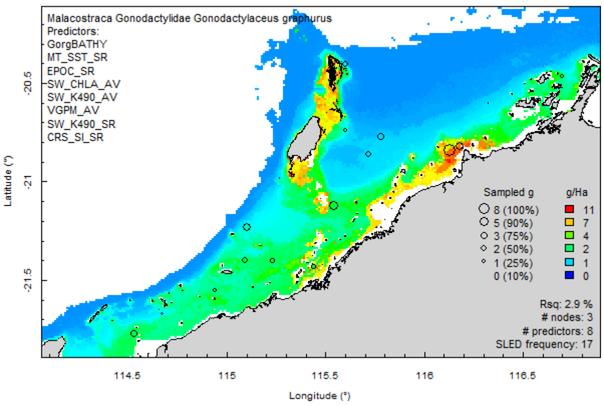


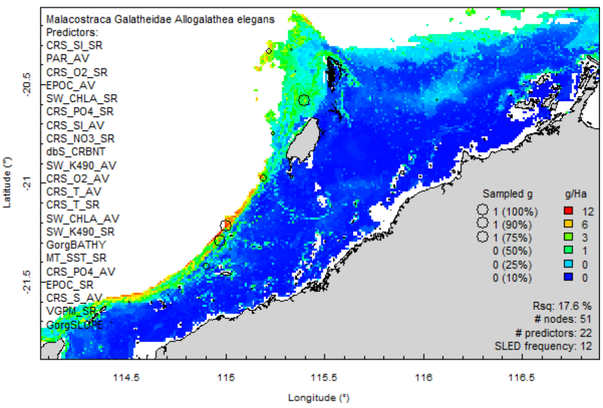


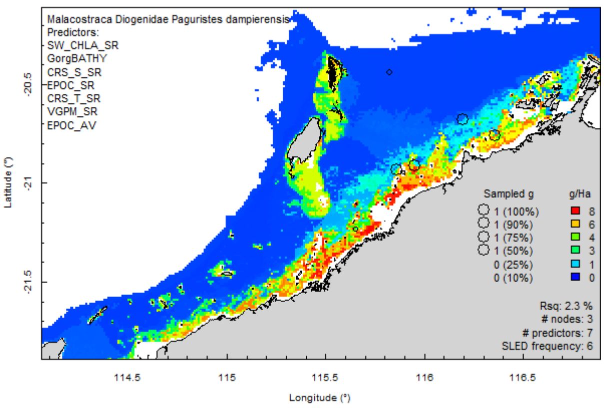


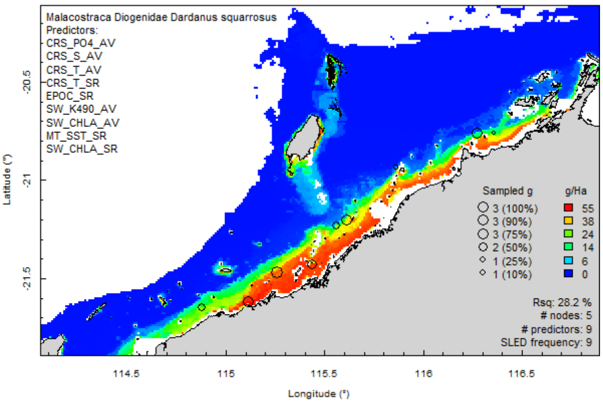


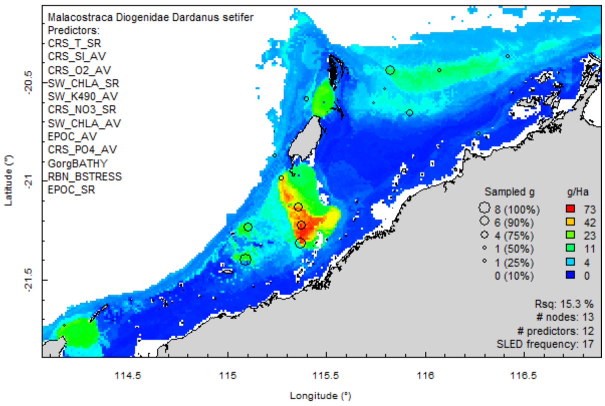


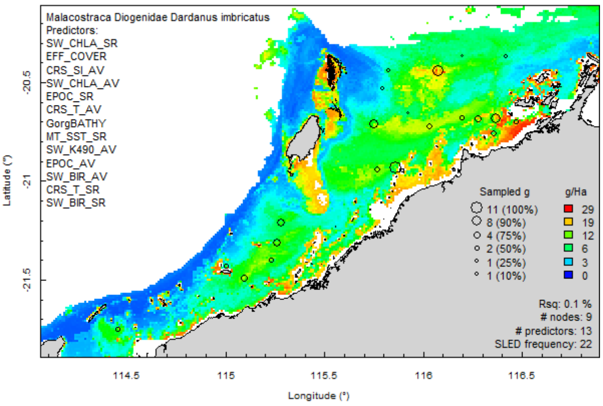


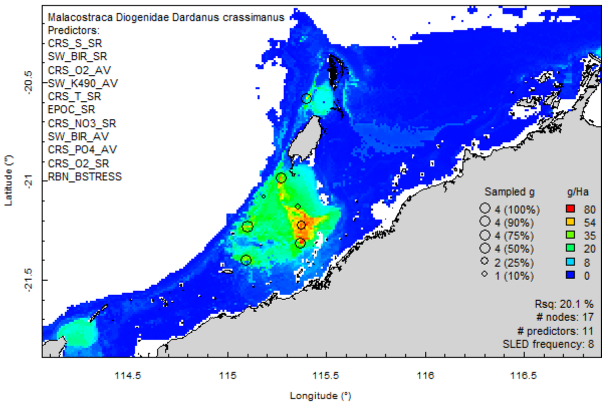


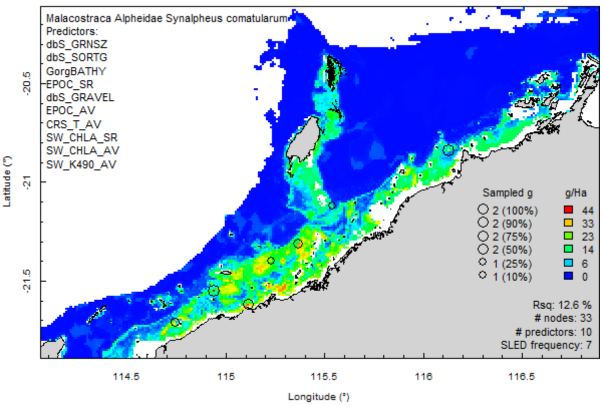


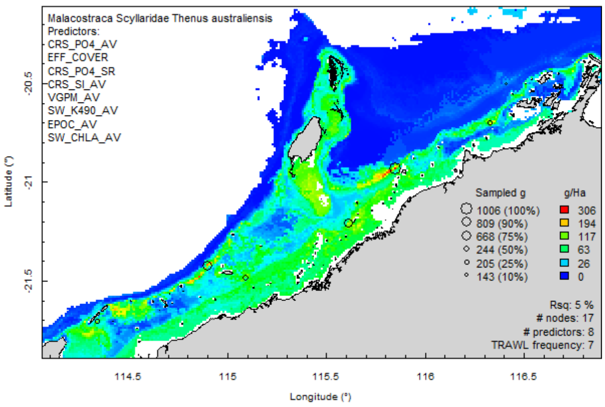




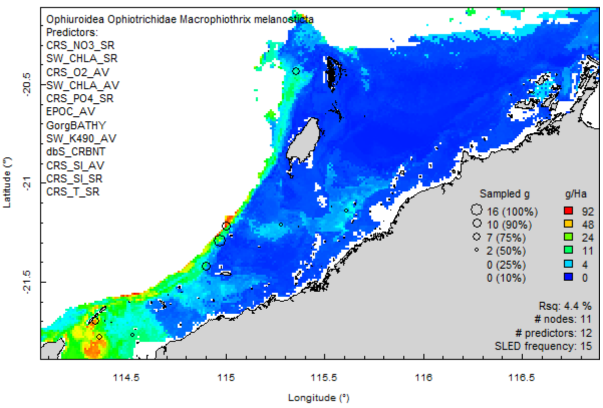


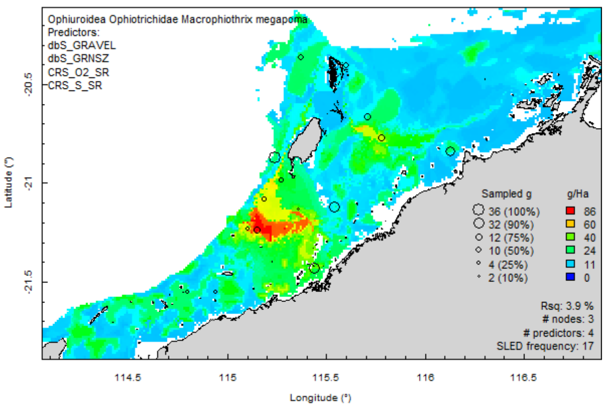


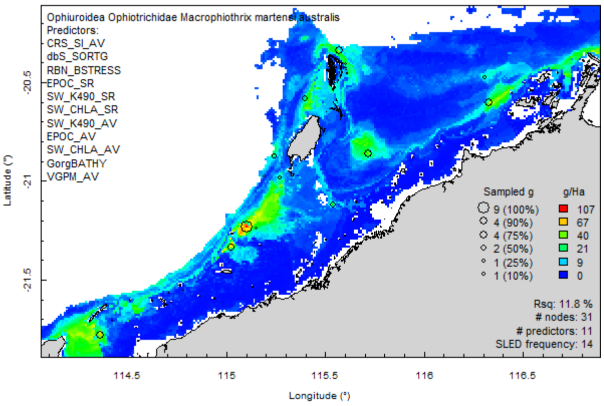


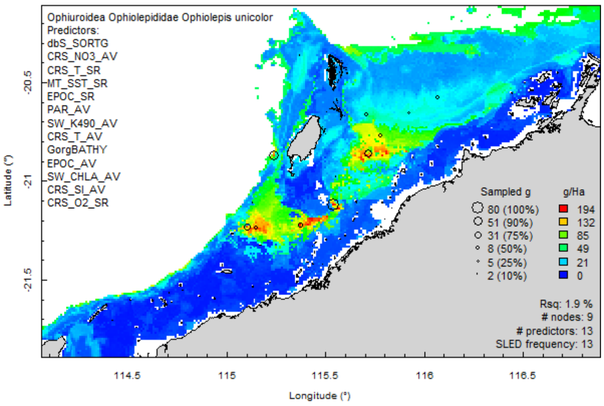


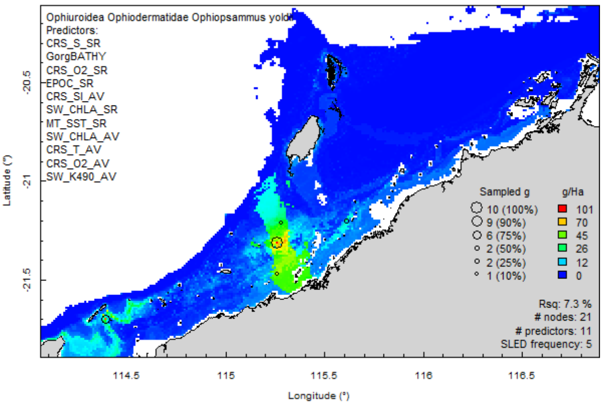
Ophiuroidea (brittle stars):

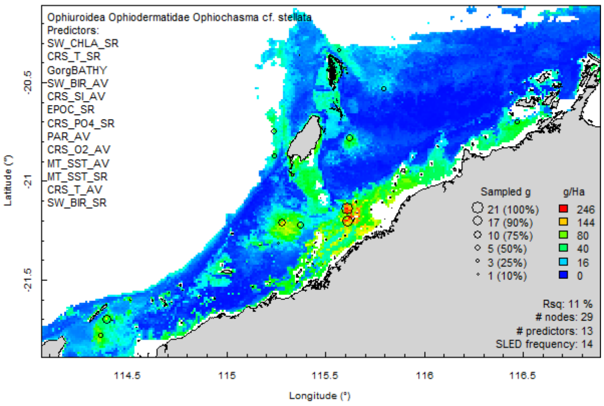


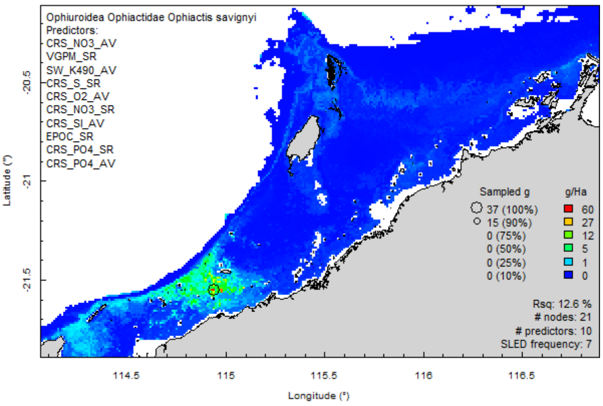


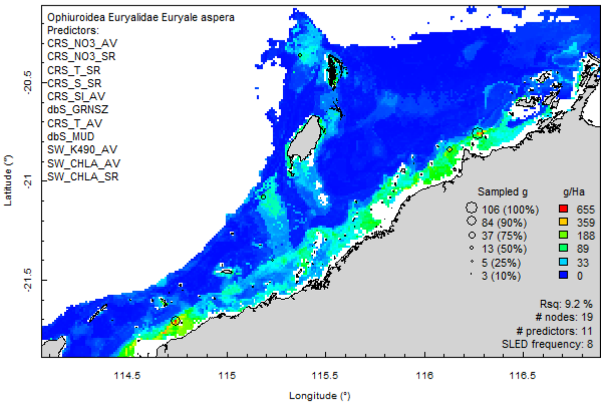




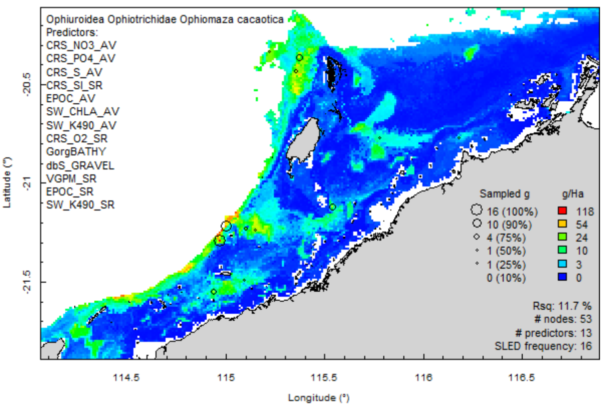


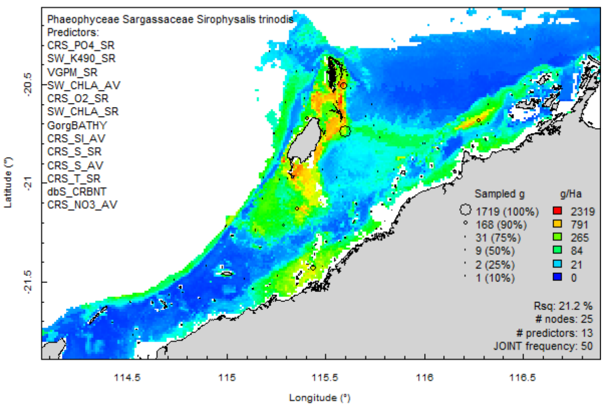


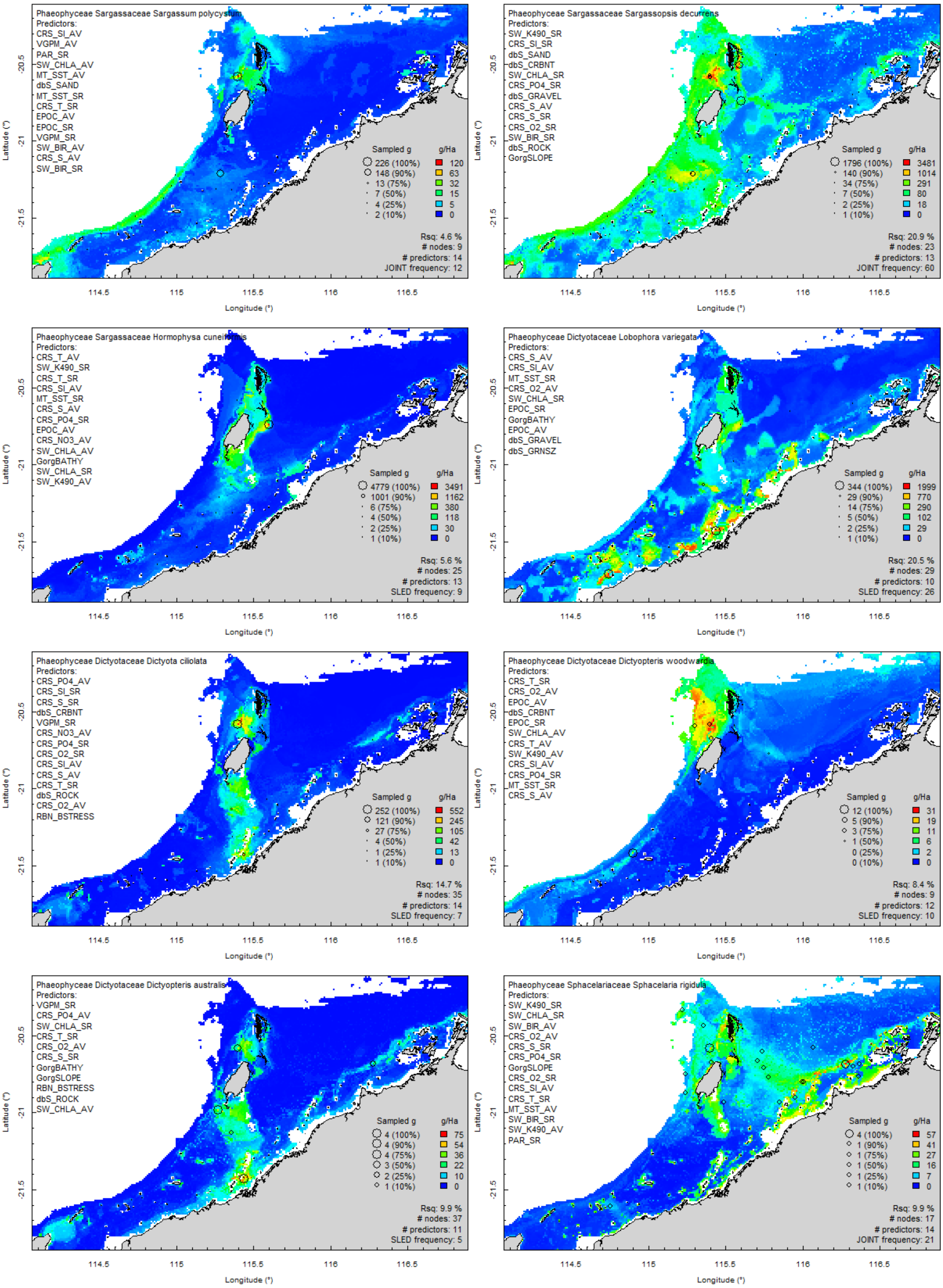




Phaeophyceae (brown algae):






Phaeophyceae Sargassaceae Sargassum polycystum
Predictors:
CRS_SI_AV
VGPM_AV
PAR_SR
SW_CHLA_AV
MT_SST_AV
dbS_SAND
MT_SST_SR
CRS_T_SR
EPOC_AV
EPOC_SR
VGPM_SR
SW_BIR_AV
CRS_S_AV
SW_BIR_SR
Sampled g
g/Ha
226 (100%)
148 (90%)
13 (75%)
7 (50%)
4 (25%)
2 (10%)
120
63
32
15
5
0
Rsq: 4.6 %
nodes: 9
predictors: 14
JOINT frequency: 12
Phaeophyceae Sargassaceae Sargassopsis decurrens
Predictors:
SW_K490_SR
CRS_SI_SR
dbS_SAND
dbS_CRBNT
SW_CHLA_SR
CRS_PO4_SR
dbS_GRAVEL
CRS_S_AV
CRS_S_SR
CRS_O2_SR
SW_BIR_SR
dbS_ROCK
GorgSLOPE
Sampled g
g/Ha
1796 (100%)
140 (90%)
34 (75%)
7 (50%)
2 (25%)
1 (10%)
3481
1014
291
80
18
0
Rsq: 20.9 %
nodes: 23
predictors: 13
JOINT frequency: 60
Phaeophyceae Sargassaceae Hormophysa cuneiformis
Predictors:
CRS_T_AV
SW_K490_SR
CRS_T_SR
CRS_SI_AV
MT_SST_SR
CRS_S_AV
CRS_PO4_SR
EPOC_AV
CRS_NO3_AV
SW_CHLA_AV
GorgBATHY
SW_CHLA_SR
SW_K490_AV
Sampled g
g/Ha
4779 (100%)
1001 (90%)
6 (75%)
4 (50%)
2 (25%)
1 (10%)
3491
1162
380
118
30
0
Rsq: 5.6 %
nodes: 25
predictors: 13
SLED frequency: 9
Phaeophyceae Dictyotaceae Lobophora variegata
Predictors:
CRS_S_AV
CRS_SI_AV
MT_SST_SR
CRS_O2_AV
SW_CHLA_SR
EPOC_SR
GorgBATHY
EPOC_AV
dbS_GRAVEL
dbS_GRNSZ
Sampled g
g/Ha
344 (100%)
29 (90%)
14 (75%)
5 (50%)
2 (25%)
1 (10%)
1999
770
290
102
29
0
Rsq: 20.5 %
nodes: 29
predictors: 10
SLED frequency: 26
Phaeophyceae Dictyotaceae Dictyota ciliolata
Predictors:
CRS_PO4_AV
CRS_SI_SR
CRS_S_SR
dbS_CRBNT
VGPM_SR
CRS_NO3_AV
CRS_PO4_SR
CRS_O2_SR
CRS_SI_AV
CRS_S_AV
CRS_T_SR
dbS_ROCK
CRS_O2_AV
RBN_BSTRESS
Sampled g
g/Ha
252 (100%)
121 (90%)
27 (75%)
4 (50%)
1 (25%)
1 (10%)
552
245
105
42
13
0
Rsq: 14.7 %
nodes: 35
predictors: 14
SLED frequency: 7
Phaeophyceae Dictyotaceae Dictyopteris woodwardia
Predictors:
CRS_T_SR
CRS_O2_AV
EPOC_AV
dbS_CRBNT
EPOC_SR
SW_CHLA_AV
CRS_T_AV
SW_K490_AV
CRS_SI_AV
CRS_PO4_SR
MT_SST_SR
CRS_S_AV
Sampled g
g/Ha
12 (100%)
5 (90%)
3 (75%)
1 (50%)
0 (25%)
0 (10%)
31
19
11
6
2
0
Rsq: 8.4 %
nodes: 9
predictors: 12
SLED frequency: 10
Phaeophyceae Dictyotaceae Dictyopteris australis
Predictors:
VGPM_SR
CRS_PO4_AV
SW_CHLA_SR
CRS_T_SR
CRS_O2_AV
CRS_S_SR
GorgBATHY
GorgSLOPE
RBN_BSTRESS
dbS_ROCK
SW_CHLA_AV
Sampled g
g/Ha
4 (100%)
4 (90%)
4 (75%)
3 (50%)
2 (25%)
1 (10%)
75
54
36
22
10
0
Rsq: 9.9 %
nodes: 37
predictors: 11
SLED frequency: 5
Phaeophyceae Sphacelariaceae Sphacelaria rigidula
Predictors:
SW_K490_SR
SW_CHLA_SR
SW_BIR_AV
CRS_O2_AV
CRS_S_SR
CRS_PO4_SR
GorgSLOPE
CRS_O2_SR
CRS_SI_AV
CRS_T_SR
MT_SST_AV
SW_BIR_SR
SW_K490_AV
PAR_SR
Sampled g
g/Ha
4 (100%)
1 (90%)
1 (75%)
1 (50%)
1 (25%)
1 (10%)
57
41
27
16
7
0
Rsq: 9.9 %
nodes: 17
predictors: 14
JOINT frequency: 21
Latitude (°)
-20.5
-21
-21.5
Longitude (°)
114.5
115
115.5
116
116.5