

## ***10. Studies of the distribution and diversity of biogenic habitat forming taxa in the USA***

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### **Background and overview**

This report summarizes the recent contributions by the USA and its WG 32 members (Sam Georgian, John Guinotte, Chris Rooper and Les Watling) to assess the distribution, abundance and species associations of deep-sea corals and sponges within the US Exclusive Economic Zone (EEZ). It should be noted that the USA conducts extensive research on deep-sea coral and sponge within its EEZ and much of that research is summarized in reports by NOAA's Deep Sea Coral Research and Technology Program (<https://www.fisheries.noaa.gov/national/habitat-conservation/deep-sea-coral-habitat>). The most recent report on the state of deep-sea coral and sponge ecosystems was published in 2017 (Hourigan *et al.*, 2017) and contains an expanded summary of the work on deep-sea corals and sponges in the USA. Here we focus on the research activities that were linked conceptually, temporally or directly to WG 32 activities and Terms of Reference.

### **Coral and sponge ecosystem data in the USA**

Records of deep-sea coral and sponge presence and abundance in the North Pacific Ocean have been collected historically through a number of scientific activities by research organizations in the USA. These include data from the extensive fisheries-independent surveys of ecosystems on the US West Coast and Alaska (both longline and bottom trawl) where the relative abundance and species of corals and sponges are recorded. It also includes a number of other studies using visual survey methods, such as submersibles, remote operated vehicles, autonomous underwater vehicles and towed camera systems. Often these data have records of associated fish and invertebrate assemblages. In North Pacific Ocean waters a number of studies have documented associations of rockfishes (*Sebastes* sp.) and other demersal fish species with deep-sea corals and sponges, as well as identifying some key relationships between fish reproduction and these ecosystems.

Beginning about 2015 these historical data have been housed in a publicly accessible data portal (NOAA Deep Sea Coral and Sponge Portal, <https://deepseacoraldata.noaa.gov/>). From 2014 to 2019, members of WG 32 compiled data from studies in Alaska and the US West Coast and contributed these data ( $n > 10,000$  observations) to the publicly accessible database making it available to the wider PICES community. The database follows the standards of OBIS-USA and is an extension of the international Darwin Core Standard. Key points for these aggregated data are:

- Most studies that collect data on coral and sponge distribution in the USA have records included in a publicly available database that is updated quarterly;
- Care in the use of these data is needed, as the quality can vary. A source listed for each data record can be used to check the validity and suitability for a given analysis.

## Modeling approaches

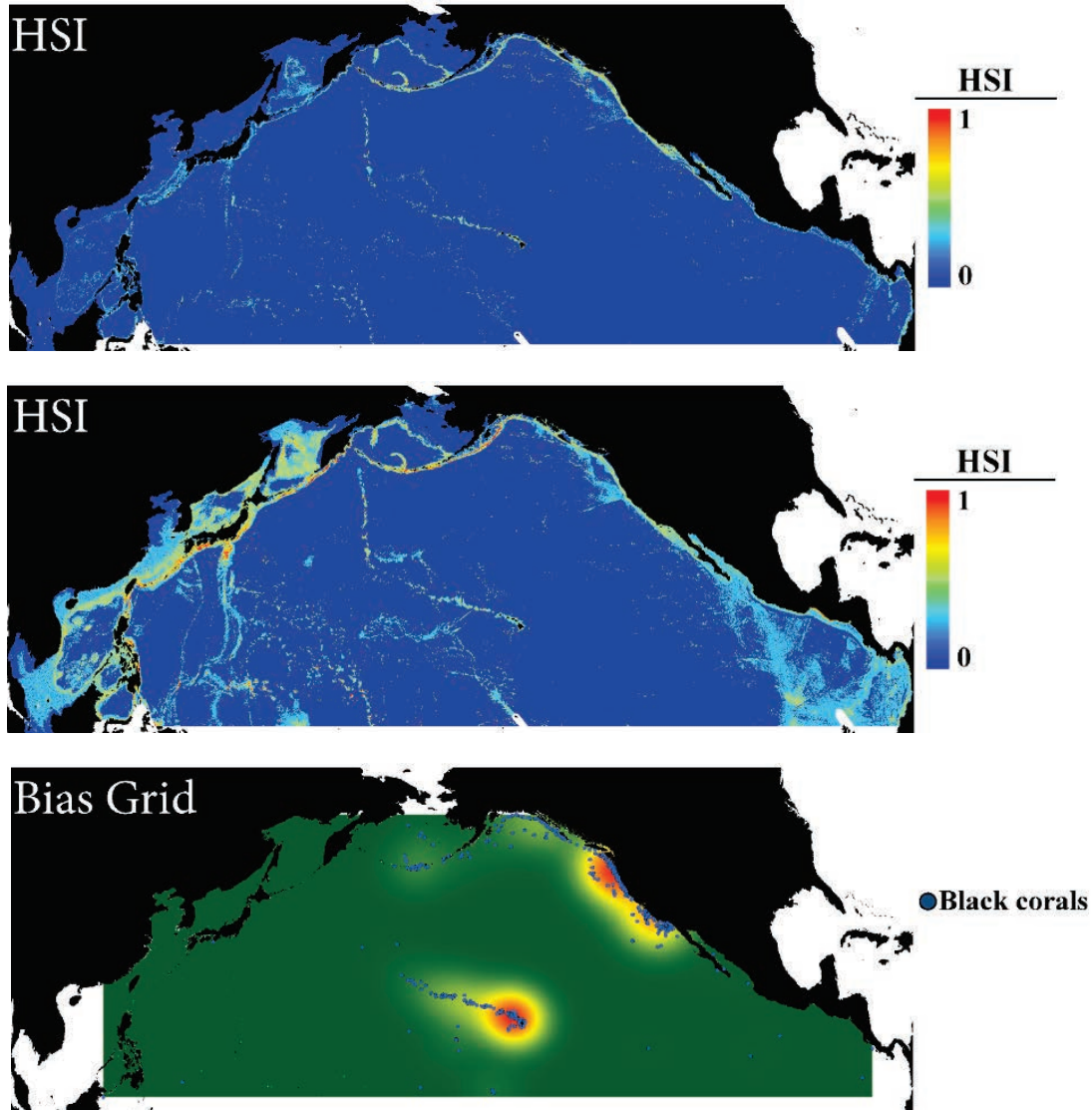
One of the key activities of WG 32 was to review modeling approaches to predict the potential distributions of species and habitat suitability for corals and sponges (*e.g.*, MaxEnt, boosted regression trees, or high resolution bathymetry-based models) within national EEZs. During PICES-2016 (San Diego, USA), a 2-day workshop on “*Distributions of habitat-forming coral and sponge assemblages in the North Pacific Ocean and factors influencing their distributions*” was held on modeling approaches for deep-sea corals and sponges. It was co-convened by Drs. Kwang-Sik Choi (Korea), Janelle Curtis (Canada), Masashi Kiyota (Japan) and Chris Rooper (USA). The outcomes of the workshop were recommendations for data and modeling approaches that should be considered for deep-sea coral and sponge ecosystems. Technical aspects of the species distribution modeling, including the best practices for generating input data, creating models and evaluating the results, data-driven approaches to define bioregions, a multi-scale assessment of species distribution models, and an assessment of the model transferability were examined. The workshop also included a “hands-on” exercise of building some preliminary models of corals and sponges for data-limited taxa in the North Pacific Ocean. The goals of the modeling session were to: 1) evaluate existing environmental variables/mechanisms affecting basin-wide distribution of coral and sponge, 2) construct preliminary basin-wide habitat models for taxa, including glass sponges and corals in the North Pacific Ocean, and 3) provide model-based information for predicting potential changes in distributions of coral and sponge with climate change. An example of the model predictions for *Antipatharia* in the North Pacific Basin developed during the workshop is shown in Figure 10.1, with the important variables predicting the distribution shown in Table 10.1.

**Table 10.1** Variables important in modeling the distribution of *Antipatharia* in the North Pacific Ocean for two alternative models, one without a bias grid correction for sampling distribution and one corrected for the sampling bias.

Variable	% Contribution without bias grid	% Contribution with bias grid
Calcite	58.6	65.5
Roughness	14.3	3.6
Temperature	7.8	11.2
Silicate	4.2	–
TPI 20,000 m	3.6	3.8
Dissolved oxygen	3.3	–
Dissolved inorganic carbon	3.2	–
Alkalinity	–	2.1
Regional currents	–	2.1
Vertical currents	–	2.0
AUC	0.945 (0.004)	0.925 (0.003)

TPI = Topographic Position Index

AUC = the area under the receiver-operator curve (an indication of overall model fit).



**Fig. 10.1** Example models of the distribution for *Antipatharia* developed by WG 32 during the PICES-2016 modeling workshop. The predictions were developed from maximum entropy models without (top) and with (middle) a correction for sampling density (bottom). HSI = habitat suitability index.

In addition to the PICES workshop in 2016, a number of concurrent modeling efforts for Alaska and US West Coast were conducted by WG 32 members. A maximum entropy model was used to predict habitat suitability for deep-sea corals on the US West Coast (Guinotte and Davies, 2014) and a generalized additive modeling approach was used to predict the distribution, abundance and diversity of corals and sponges in the Aleutian Islands and eastern Bering Sea (Rooper *et al.*, 2014, 2016). In the Gulf of Alaska, a suite of modeling methods (maximum entropy, general linear models, generalized additive models, boosted regression tree and random forest) were evaluated and used in an ensemble to predict the distribution of corals and sponges. In all, these efforts resulted in predictions of the distribution of coral taxa for the entire USA EEZ in the North Pacific. These models continue to be developed and improved (Guinotte *et al.*, 2017) as new data and techniques become available. Key findings from this work are:

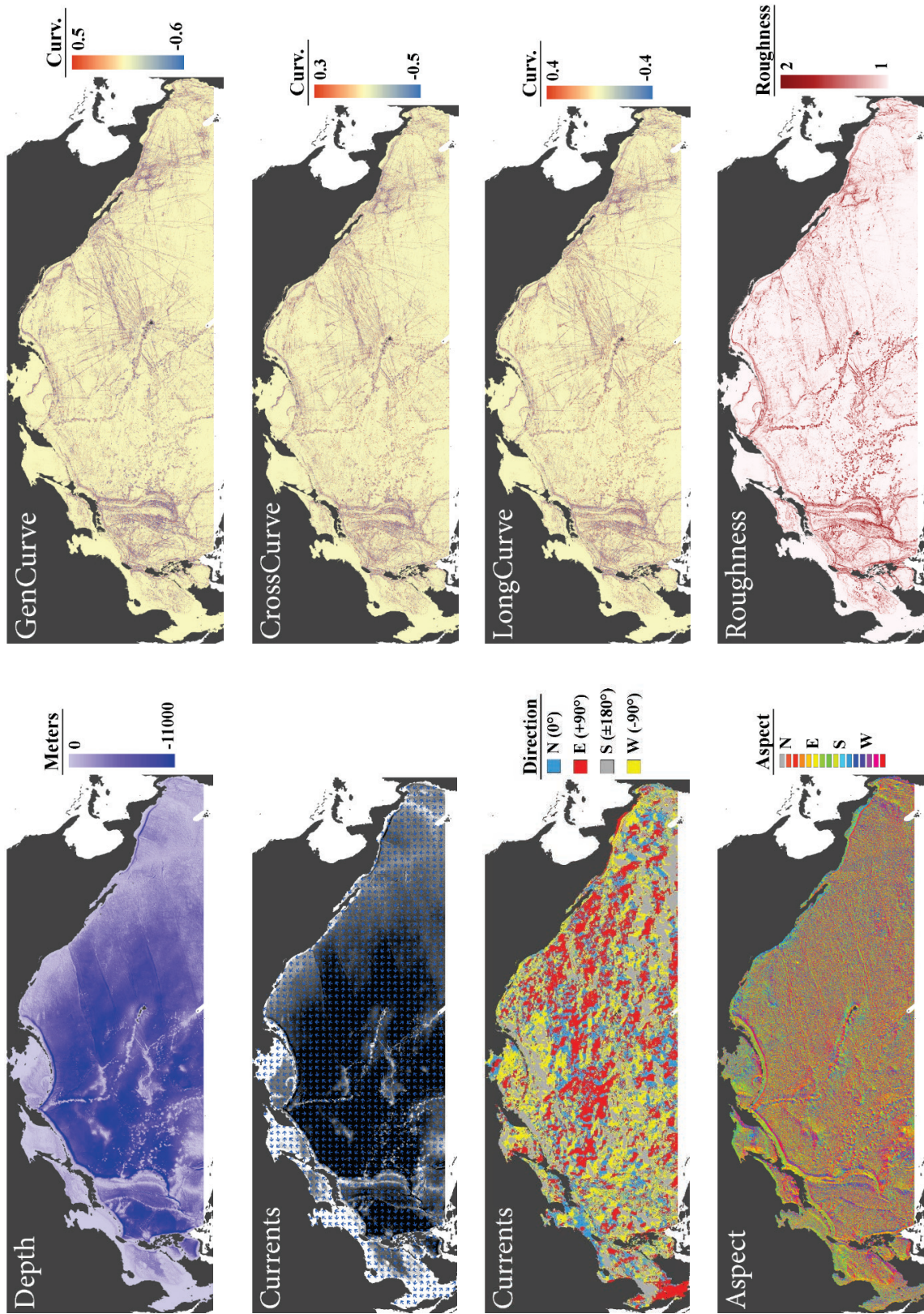
- Model validation using independently collected data is important to consider;
- Ensemble models can perform better across a range of species than individual models;
- The modeling method has less effect on the result than the quality of the underlying predictor and distribution data.

### Environmental and ecological predictors

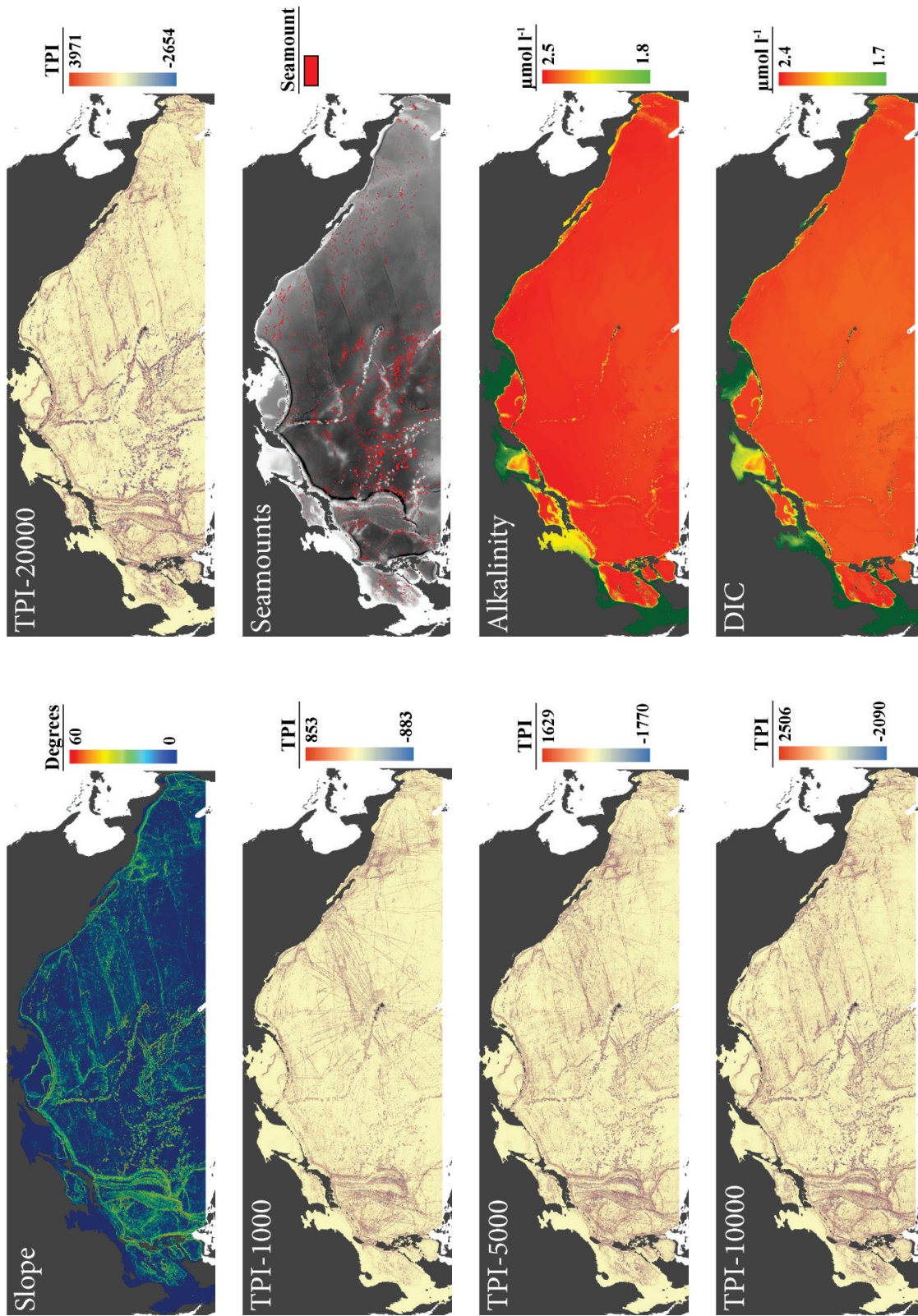
A key outcome in modeling the distribution of deep-sea coral and sponge ecosystems in the North Pacific Ocean that was advanced within WG 32 was the identification of large-scale environmental and ecological predictors for the distribution and biodiversity of coral, sponge and associated taxa. Dr. Samuel Georgian (USA) and colleagues put together an exhaustive group of measured and derived predictor variables for the North Pacific Ocean on a 1 km<sup>2</sup> grid (Table 10.2; Fig. 10.2). These included bathymetric and terrain variables as well as environmental variables thought to influence the distribution of deep-sea corals and sponges. A number of topographical variables were created, as complex seafloor features generally elevate local currents, which increase larval dispersal, food supply, sediment and waste removal, and dissolved oxygen flux (*e.g.*, Dorschel *et al.*, 2007). Since cold-water corals are filter feeders and therefore, reliant on the vertical transfer of surface productivity (Duineveld *et al.*, 2007), the particulate organic carbon (POC) flux (mg C m<sup>-2</sup> yr<sup>-1</sup>) to the seafloor was also included as a proxy for food availability. The saturation state of the calcite polymorph of calcium carbonate, temperature (°C), salinity (psu), and dissolved oxygen (ml l<sup>-1</sup>) were included due to their known biological relevance to cold-water octocorals (Mortensen and Buhl-Mortensen, 2004) and importance in previous habitat suitability models (Quattrini *et al.*, 2013; Georgian *et al.*, 2014; Etnoyer *et al.*, 2017). Finally, the distribution of hard bottom substrates was included as the availability of hard substrata is essential for coral recruitment in a number of cold-water corals (*e.g.*, Georgian *et al.*, 2014) including Paramuricea (Mortensen *et al.*, 2007).

**Table 10.2** Geophysical and environmental variables available for modeling the distribution of deep-sea corals and sponges in the North Pacific Ocean.

Variable name	Filename	Unit	Native resolution	Reference
Bathymetry	srtm30	meters	0.0083°	Becker <i>et al.</i> , 2009 Sandwell <i>et al.</i> , 2014
<i>Terrain variables</i>				
Aspect	aspect	degrees	0.0083°	Jenness, 2013a
Aspect – Eastness	eastness		0.0083°	Jenness, 2013a
Aspect – Northness	northness		0.0083°	Jenness, 2013a
Curvature – General	gencurve		0.0083°	Jenness, 2013a
Curvature – Cross-sectional	crosscurve		0.0083°	Jenness, 2013a
Curvature – Longitudinal	longcurve		0.0083°	Jenness, 2013a
Roughness	roughness		0.0083°	Jenness, 2013a
Slope	slope	degrees	0.0083°	Jenness, 2013a
Topographic Position Index	tpi		0.0083°	Jenness, 2013b
Seamounts	seamounts			Yesson <i>et al.</i> , 2011
<i>Environmental variables</i>				
Alkalinity	alk_stein	$\mu\text{mol l}^{-1}$	$3.6 \times 0.8\text{--}1.8^\circ$	Steinacher <i>et al.</i> , 2009
Dissolved inorganic carbon	dic_stein	$\mu\text{mol l}^{-1}$	$3.6 \times 0.8\text{--}1.8^\circ$	Steinacher <i>et al.</i> , 2009
Omega aragonite ( $\Omega_{\text{ARAG}}$ )	arag_stein		$3.6 \times 0.8\text{--}1.8^\circ$	Steinacher <i>et al.</i> , 2009
Omega calcite ( $\Omega_{\text{CALC}}$ )	calc_stein		$3.6 \times 0.8\text{--}1.8^\circ$	Steinacher <i>et al.</i> , 2009
Dissolved oxygen	dissox	$\text{ml l}^{-1}$	1°	Garcia <i>et al.</i> , 2014a
Salinity	salinity	pss	0.25°	Zweng <i>et al.</i> , 2013
Temperature	temp	°C	0.25°	Locarnini <i>et al.</i> , 2013
Phosphate	phosphate	$\mu\text{mol l}^{-1}$	1°	Garcia <i>et al.</i> , 2014b
Silicate	silicate	$\mu\text{mol l}^{-1}$	1°	Garcia <i>et al.</i> , 2014b
Nitrate	nitrate	$\mu\text{mol l}^{-1}$	1°	Garcia <i>et al.</i> , 2014b
Particulate organic carbon	POC	$\text{g C m}^{-2} \text{yr}^{-1}$	0.05°	Lutz <i>et al.</i> , 2007
Regional current velocity	regfl	$\text{m s}^{-1}$	0.5°	Carton and Giese, 2008
Vertical current velocity	vertfl	$\text{m s}^{-1}$	0.5°	Carton and Giese, 2008
Current direction	curdir	degrees	0.5°	Carton and Giese, 2008
Current relative to aspect	curaspect	degrees	0.5°	Rooper <i>et al.</i> , 2014
Chlorophyll a	chl-a	$\text{mg m}^{-3}$	4 km	Aqua MODIS, 2014
Photosynthetically available radiation	PAR	$\text{W m}^{-2}$	4 km	Aqua MODIS, 2014
Sea Surface Temperature	SST	°C	4 km	Aqua MODIS, 2014



**Fig. 10.2** Maps of individual variables available for modeling the distribution of deep-sea corals and sponges in the North Pacific Ocean.



**Fig. 10.2** Continued. TPI = topographic position index, DIC = dissolved inorganic carbon.

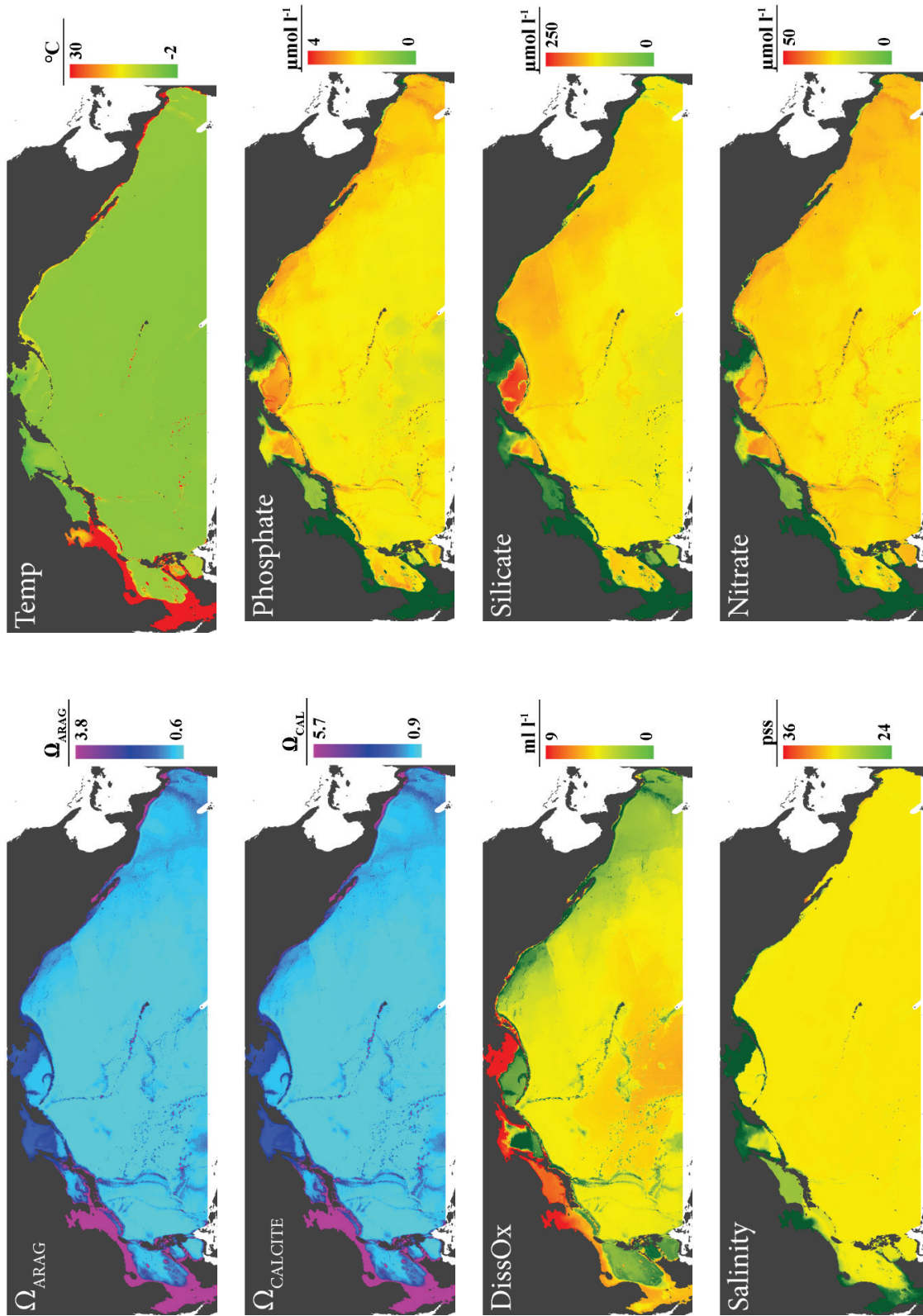
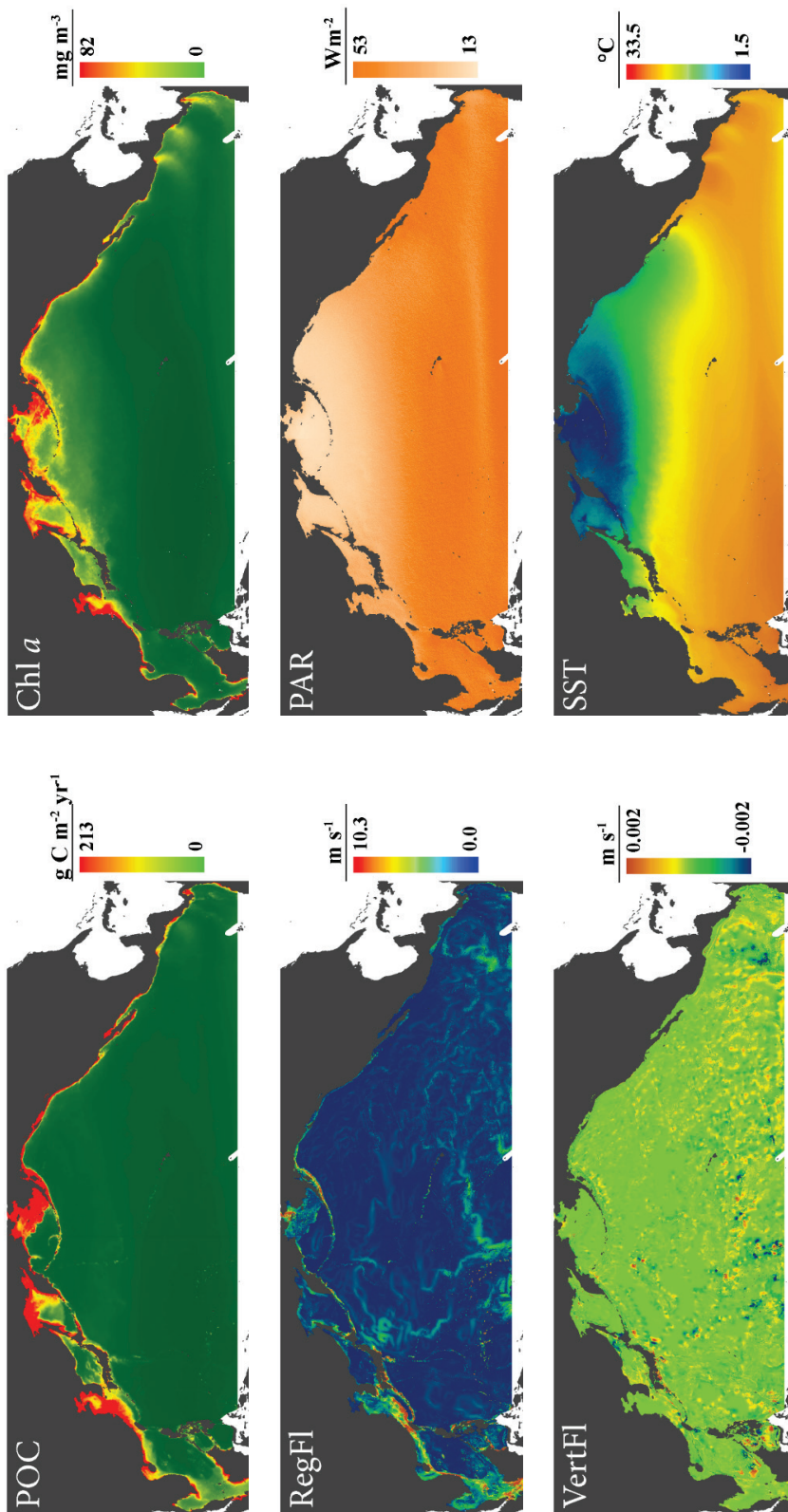


Fig. 10.2 Continued.



**Fig. 10.2** Continued. POC = particulate organic carbon, RegFl = regional current flow, VertFl = vertical current flow, PAR = photosynthetically available radiation, SST = sea surface temperature.

Bathymetric data for the North Pacific were obtained from the SRTM30+ layer (Becker *et al.*, 2009; Sandwell *et al.*, 2014) downloaded from: [topex.ucsd.edu/WWW\\_html/srtm30\\_plus.html](http://topex.ucsd.edu/WWW_html/srtm30_plus.html). Ocean data in the SRTM30+ layer were derived from Sandwell *et al.* (2014), the LDEO Ridge Multibeam Synthesis Project, the JAMSTEC Data Site for Research Cruises, the NGDC Coastal Relief Model, and the International Bathymetric Chart of the Oceans. The native resolution of the SRTM30+ layer was  $0.0083^\circ$  or approximately one kilometer.

A suite of terrain variables was constructed using the SRTM30+ bathymetry layer. Slope, aspect, roughness, and curvature were calculated using the ArcGIS (v.10.4, ESRI) toolkit ‘DEM Surface Tools’ (v.2, Jenness, 2004, 2013a), and the topographic position index (TPI) was calculated using the toolkit ‘Land Face Corridor Designer (v1.2, Jenness, 2013b). The slope of each grid was measured in degrees and calculated using the 4-cell method which has been shown to outperform other methods (Horn 1981; Jones 1998). Aspect represents the direction of the maximum slope and was converted to an index of ‘eastness’ using a sine transformation and an index of ‘northness’ using a cosine transformation. Curvature describes the shape of the seafloor to quantify how water should interact with the terrain. We calculated three types of curvature: general curvature, cross-sectional curvature, and longitudinal curvature. General curvature assigns more positive values to more convex features, and more negative values to more concave features. Cross-sectional curvature assigns positive values to features where water is expected to locally diverge, and negative values to features where water is expected to locally converge. Longitudinal curvature assigns positive values to features where water is expected to decelerate, and negative values to features where water is expected to accelerate. Roughness is a measure of topographical complexity and was calculated as the ratio of surface area to planimetric area. TPI quantifies the elevation of a feature relative to the surrounding seafloor, with positive values indicating features that are elevated and negative values indicating features that are depressed. Values close to zero may indicate either flat surfaces or areas with constant slopes. As TPI is heavily dependent on the analysis scale, and because benthic organisms may be simultaneously affected by both fine- and broad-scale features, we calculated TPI at multiple scales: 1,000 m (the finest resolution allowed by the bathymetry), 5,000 m, 10,000 m, and 20,000 m. Seamount locations were obtained from Yesson *et al.* (2011), and include all seafloor features greater than 1,000 m in height with a conical shape.

Environmental variables believed *a priori* to influence the distribution of benthic marine organisms were obtained from a variety of sources (Table 10.1). Dissolved oxygen, salinity, temperature, and nutrient data were obtained from the World Ocean Atlas (v.2 2013). Carbonate data ( $\Omega_{\text{ARAG}}$ ,  $\Omega_{\text{CAL}}$ , dissolved inorganic carbon, and total alkalinity) were obtained from Steinacher *et al.* (2009). Chlorophyll a, sea surface temperature (SST), and photosynthetically available radiation (PAR) data were obtained as mission composites (average of 2002–2016 data) from NOAA’s Aqua MODIS program at a resolution of 4 km, and were resampled to match the extent and resolution of the bathymetry data with no interpolation. Particulate organic carbon (POC) flux at the seafloor was obtained from Lutz *et al.* (2007). Bottom current velocity data were obtained from the Simple Ocean Data Assimilation (SODA v.3.4.1) model (Carton and Giese, 2008), with data averaged as the composite of the years 1990–2007. Current velocities were calculated as both horizontal and vertical velocities ( $\text{m s}^{-1}$ ). Current direction for each grid cell was calculated from zonal ( $u$ ) and meridional ( $v$ ) velocities according to the formula:

$$\text{Direction} = 180/\pi \times \text{atan2}([v],[u])$$

with values of  $+180^\circ$  and  $-180^\circ$  indicating that the current flows to the south,  $+90^\circ$  to the east,  $-90^\circ$  to the west, and  $0^\circ$  to north. A current layer that quantifies the direction of current flow relative to the

aspect of the seafloor was also calculated, with values of 0° indicating that the current flows in the same direction that the steepest slope is facing, and values of 180° indicating that the current flows opposite to the direction of the steepest slope (*sensu* Rooper *et al.*, 2014).

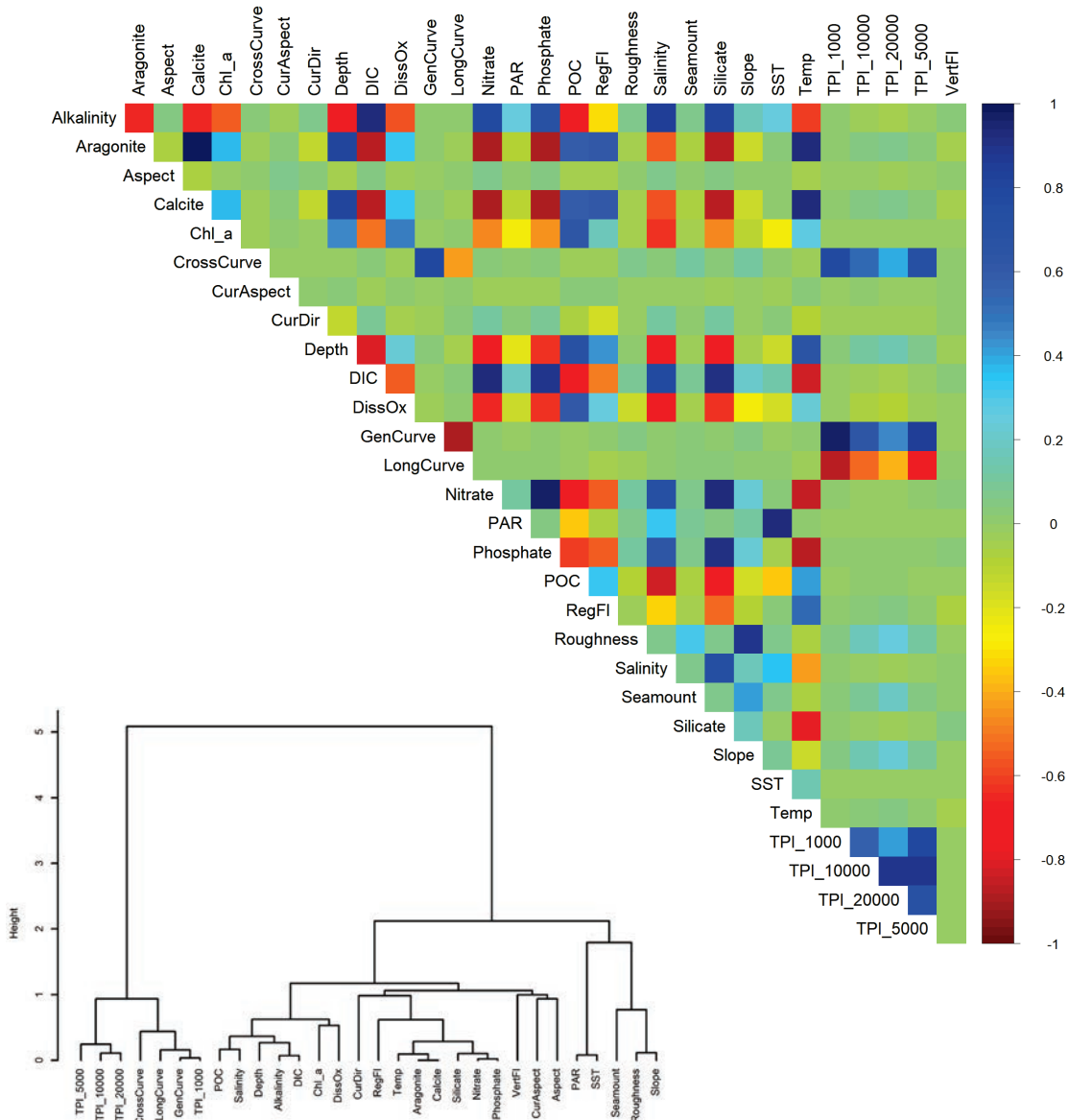
Benthic variables (WOA data, carbonate data, and current data) were transformed to match the extent and resolution of the bathymetry layer using a variable up-scaling approach that approximates conditions at the seafloor (Davies and Guinotte, 2011). Briefly, each gridded layer was first interpolated to a slightly higher resolution (0.5°) than its native resolution using inverse distance weighting, resampled to match the extent and resolution of the bathymetry data, and draped over the bathymetry data within its depth range. This technique has been demonstrated to work effectively for many global and regional scale variables (Davies and Guinotte, 2011; Yesson *et al.*, 2012). World Ocean Atlas data were available as 102 depth-binned layers from depths of 0–5500 m, with a vertical resolution of 5 m (from 0–100 m), 25 m (100–500 m), 50 m (500–2000 m), and 100 m (2000–5500 m). Carbonate data (Steinacher *et al.*, 2009) were available in 25 depth-binned layers: 6, 19, 38, 62, 93, 133, 183, 245, 322, 415, 527, 661, 818, 1001, 1211, 1449, 1717, 2014, 2340, 2693, 3072, 3473, 3894, 4329, and 4775 m. SODA current data were available in 50 depth bins: 5.03355, 15.10065, 25.21935, 35.35845, 45.57635, 55.86325, 66.26175, 76.80285, 87.57695, 98.62325, 110.0962, 122.1067, 134.9086, 148.7466, 164.0538, 181.3125, 201.2630, 224.7773, 253.0681, 287.5508, 330.0078, 382.3651, 446.7263, 524.9824, 618.7031, 728.6921, 854.9935, 996.7153, 1152.376, 1319.997, 1497.562, 1683.057, 1874.788, 2071.252, 2271.323, 2474.043, 2678.757, 2884.898, 3092.117, 3300.086, 3508.633, 3717.567, 3926.813, 4136.251, 4345.864, 4555.566, 4765.369, 4975.209, 5185.111, and 5395.023 m.

These predictor variables were made available to all WG 32 members through a shared drive and allowed individuals and groups from the PICES community to utilize the layers in their own modeling efforts within their own EEZs. Key aspects of this predictor data set are:

- A wide variety of variables have been compiled into raster layers for use in modeling the distribution of deep-sea corals and sponges;
- The data captures long-term and large-scale patterns in variables for the North Pacific Ocean.

### **Preliminary North Pacific-wide deep-sea coral models**

This suite of environmental data was used to construct preliminary habitat suitability models for a number of deep-sea coral taxa across the North Pacific Ocean. Models were constructed using a presence-only MaxEnt approach. The inclusion of correlated environmental variables may inhibit model performance and interpretation (*e.g.*, Huang *et al.*, 2011). Therefore, highly correlated variables (Fig. 10.3) were removed based on their relationship with other variables and performance in preliminary MaxEnt models. The final variable set included the saturation state of calcium carbonate (either as calcite or aragonite depending on the biology of each taxon), seafloor roughness, temperature, silicate, TPI (20,000 m scale), dissolved oxygen, dissolved inorganic carbon, total alkalinity, regional current flow, and vertical current flow.



**Fig. 10.3** Pearson correlations and cluster analysis of variables available for modeling the distribution of corals and sponges in the Pacific Ocean.

Georeferenced occurrence data were obtained for each taxon from the NOAA Deep Sea Coral Portal (DSCDP). While a common source of error in species distribution models, spatial bias in the sampling of occurrence data considerably weakens the performance and interpretability of models (Phillips *et al.*, 2009), and is often found in presence-only deep-sea species datasets due to the difficulties associated with sampling design in the deep-sea. However, it is possible to reduce the effects of sampling bias by selecting targeted background data that reflect the same bias as the occurrence data (Phillips *et al.*, 2009). Given the relatively high sampling bias observable in our field surveys, we generated a targeted set of background points in addition to a random set of points (see Fig. 10.1). To generate background points preferentially in areas that have been more extensively surveyed, we first created a two-dimensional kernel density estimate of sampling effort based on the presence locations for each taxon.

This created a probability grid from which 10,000 background points were sampled according to the probability grid weights. Previous studies using a similar approach to reduce the influence of sampling bias found that model performance was significantly improved (Fitzpatrick *et al.*, 2013). Habitat suitability models were produced using this targeted-background approach in a MaxEnt environment run with default model parameters for the following taxa: Scleractinia (stony corals), Antipatharia (black corals), Pennatulacea (sea pens), and *Primnoa* (preliminary results in Fig. 10.4).

### **Proposed biogeography of the Upper Bathyal benthos in the Pacific Ocean based on octocoral distributions**

One of the topics for discussion during WG 32 meetings was the global biogeography of benthic invertebrates and how invertebrates are taxonomically organized in the PICES area. Biogeographical classification schemes such as Briggs' biogeographic provinces (Briggs, 1974) and the Marine Ecoregions of the World (MEOW) (Spaulding *et al.*, 2007) have been developed for continental shelf depths. However, the lack of faunal data in the deep sea has led to the development of biogeographical units based on oceanographic characteristics (Watling *et al.*, 2013). During the lifetime of WG 32, Dr. Natalie Summers and Dr. Les Watling developed a biogeographical scheme for the Upper Bathyal (200–1000 m) in the Pacific Ocean using octocoral distributions.

They retrieved over 200,000 octocoral data records from the DSCDP, Ocean Biogeographic Information System (OBIS), Tropical Deep-Sea Benthos program (French National Museum of Natural History), Queensland Museum from the CIDARIS expeditions, and records retrieved from the Siboga expedition reports. They used cluster analysis to test octocoral distributions against four different biogeographical classification schemes used in the shallower and deeper zones of the ocean as well as one used for subdividing the mesopelagic region.

The four classifications used were based on: 1) The MEOW classification in the Pacific (Spaulding *et al.*, 2007) from the coast to 200 m depth (immediately above the Upper Bathyal), which consisted of 72 ecoregions containing at least one octocoral genus; 2) Watling *et al.* (2013) Lower Bathyal Provinces from 800 to 3,500 m in the Pacific; 3) Sutton *et al.* (2017) 14 Mesopelagic Provinces in the Pacific based on daytime mesopelagic faunal communities as well as environmental proxies derived from the MEOW ecoregions; 4) the three-dimensional Ecological Marine Unit (EMU) classification based on temperature, salinity, dissolved oxygen, nitrate, phosphate, and silicate data obtained from the 2013 World Ocean Atlas which, using cluster analysis, resulted in 9 EMUs in the Pacific Ocean. The latter is the only scheme that divides the Upper Bathyal into several depth zones (Sayre *et al.*, 2017).

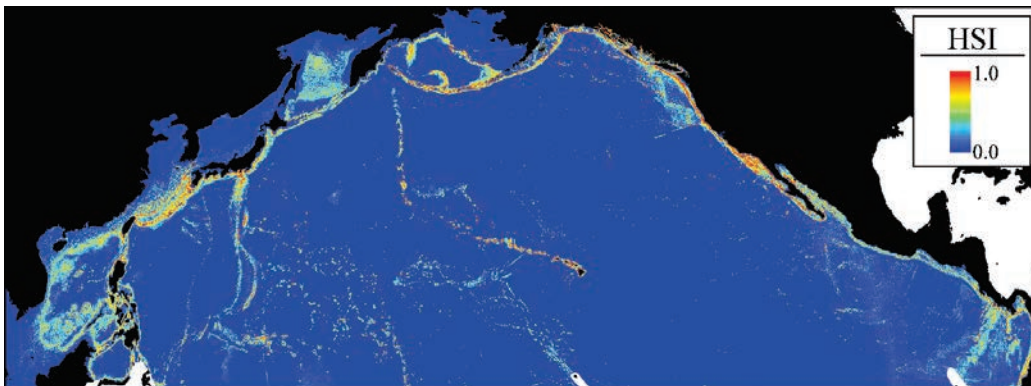
All classification schemes produced mostly concordant patterns with three major faunal distribution barriers: the North Pacific Current isolates the subarctic units by creating a steep temperature gradient; the Subantarctic Front separates the Subantarctic from the rest of the Pacific Ocean; and the East Pacific Barrier separates the East Pacific Ocean from the Central and West Pacific Ocean. Two other smaller but distinct provinces are the Indo-Pacific where Lower Bathyal genera are found in the Upper Bathyal, and Torres Strait/Coral Sea characterised by mesophotic genera. Dr. Summers and Dr. Watling proposed 12 Upper Bathyal provinces for the Pacific Ocean based on octocoral distributions (Fig. 10.4). The main driver for these units seems to be temperature, a defining feature of water masses. These units could potentially be subdivided into smaller regions based on habitat. Additionally, the clustering of EMUs provides evidence that the Upper Bathyal should in certain regions be divided vertically into two depth zones based on water masses. Key findings recommended to WG 32 members from this work include:

- There was consistency in results across multiple biogeographic classification schemes indicating strong trends in the data on octocorals;
- The biogeography of octocorals in the North Pacific is largely consistent with the oceanographic barriers created by temperature;
- There are four separate biogeographic provinces for octocoral (Fig. 10.5) found in the PICES region.

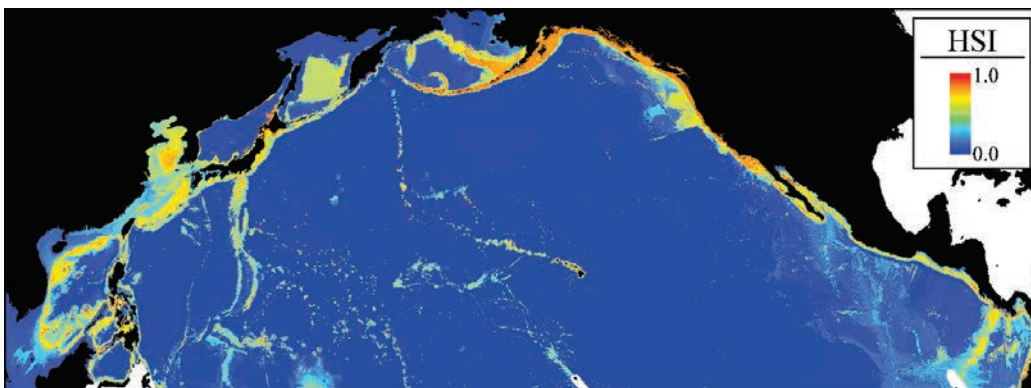
### Scleractinia (Stony Corals)



### Antipatharia (Black Corals)



### Pennatulacea (Sea Pens)



**Fig. 10.4** Preliminary habitat suitability models for deep-sea coral taxa in the North Pacific Ocean.

*Primnoa*

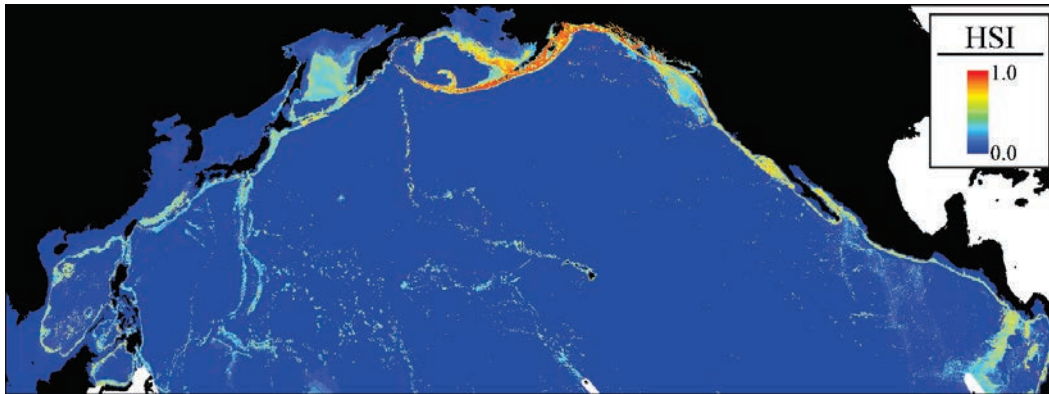


Fig. 10.4 Continued.

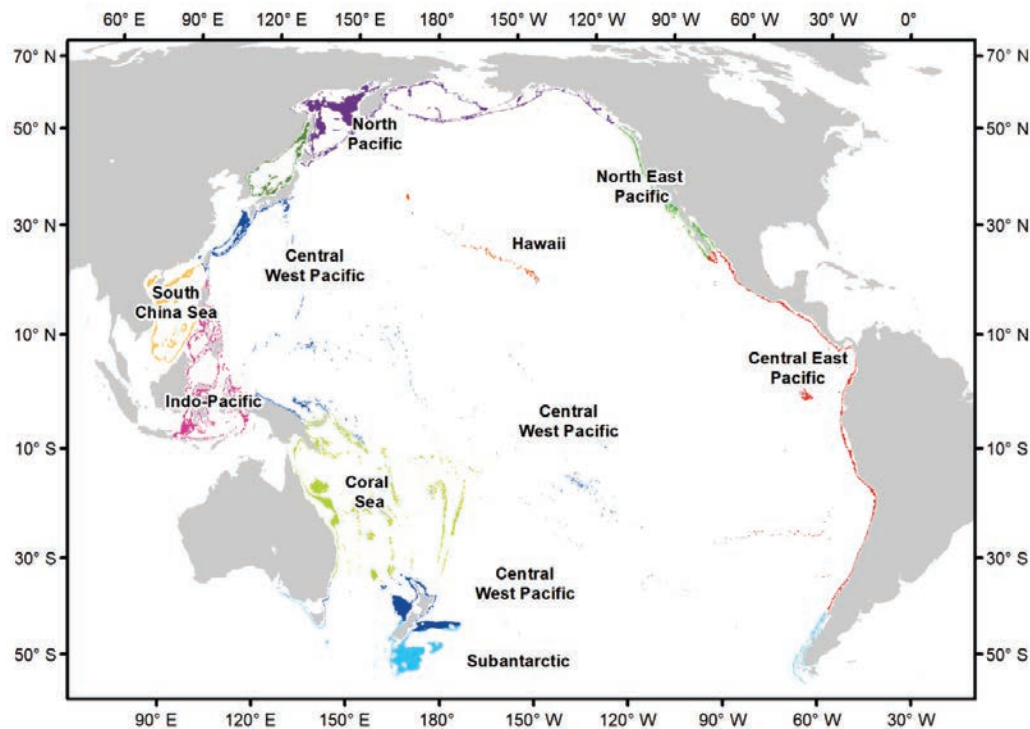


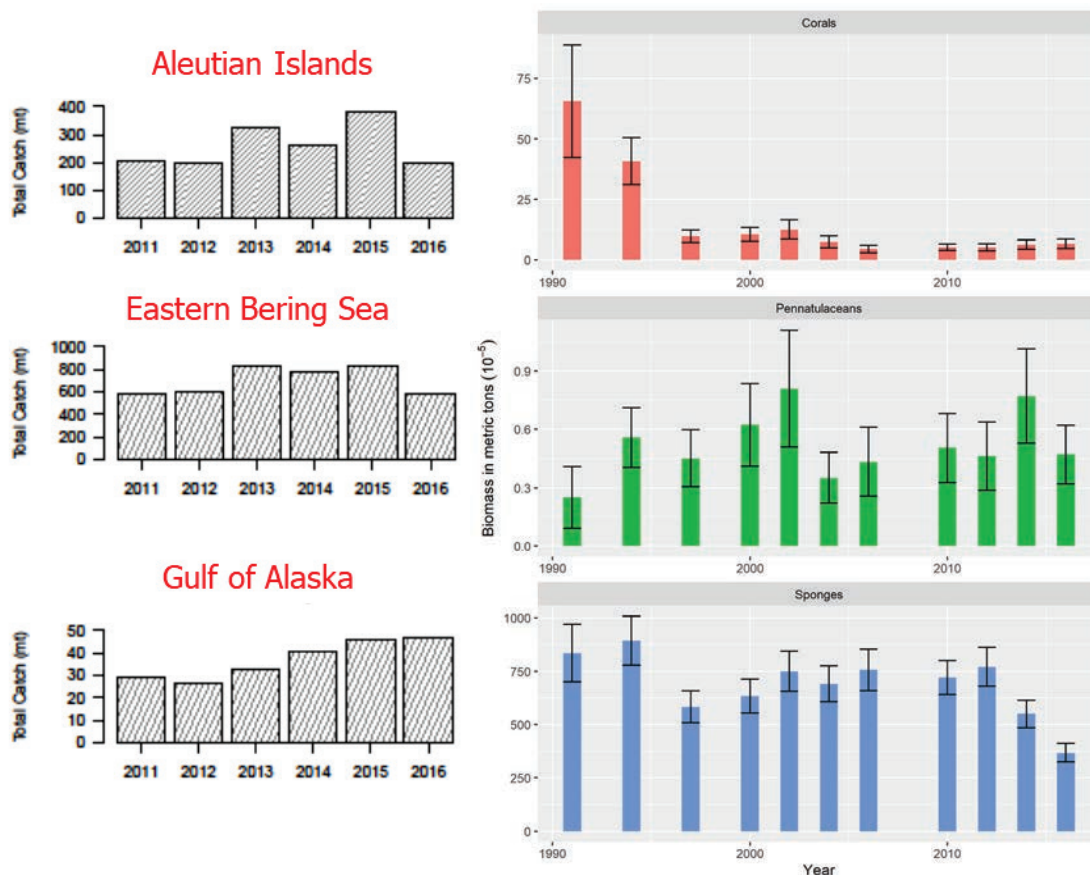
Fig. 10.5 Proposed Upper Bathyal Provinces for the Pacific Ocean based on analysis of 200,000 records of octocorals in the Pacific Ocean.

**Indicators of diversity of biogenic habitats**

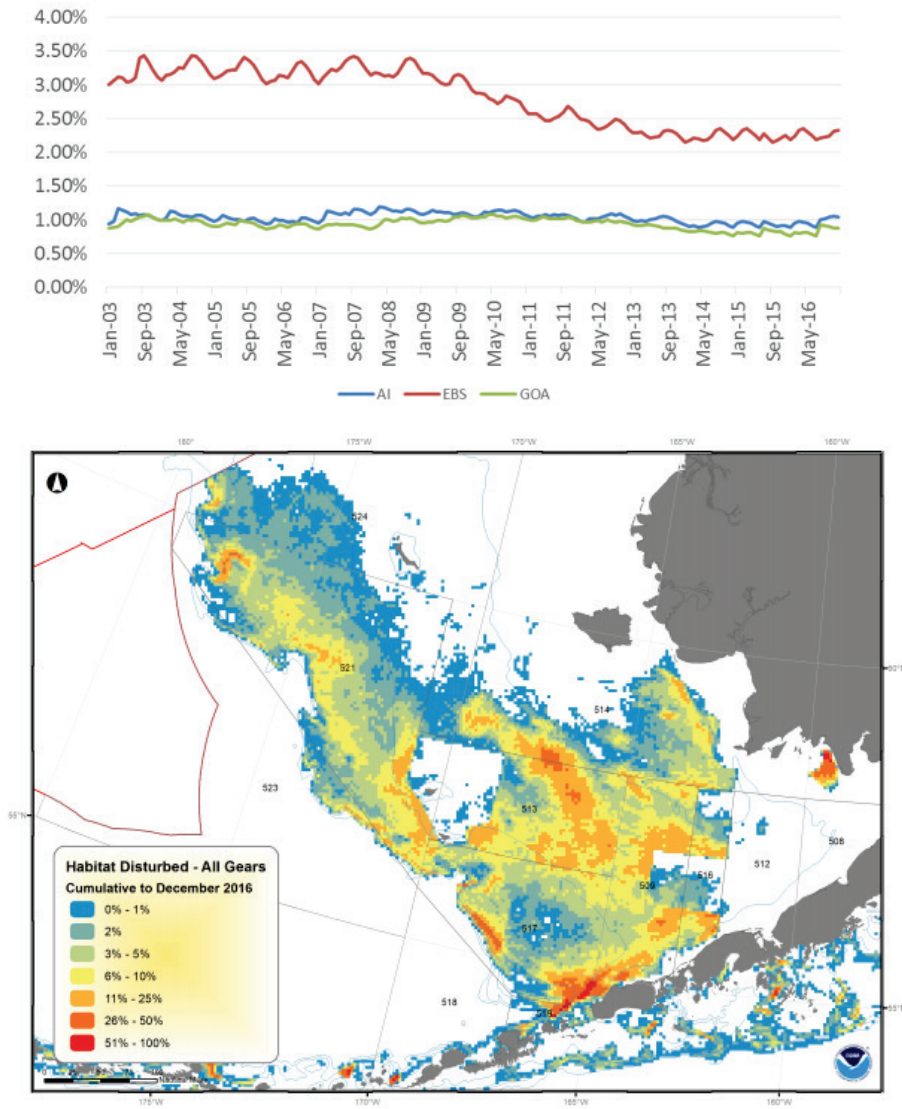
Deep-sea coral and sponge ecosystems in the North Pacific Ocean are influenced by multiple climatological threats, such as rising sea temperature, harmful algal blooms, marine invasive species, hypoxia, and eutrophication. They are also affected by direct anthropogenic activities such as sea bed mining and bottom fishing. These multiple threats can act synergistically, but perhaps differently, from region to region to change ecosystem structure, function and dynamics. A goal of WG 32 was to advance the monitoring of deep-sea coral and sponge ecosystems.

In the US, the major threats to deep-sea corals and sponges are fishing and climate change. Monitoring the status of deep-sea corals and sponges is difficult and costly, so effective indicators of biogenic habitat health are needed. One group of indicators that has been developed in the US is trends in bycatch (Fig. 10.6) in commercial fisheries. Another indicator is the abundance of deep-sea corals and sponges estimated using multispecies geo-spatial modeling techniques (Thorson *et al.*, 2015) applied to fishery-independent trawl survey data. Finally, the spatial extent and trend over time in bottom contacting fishing effort can be used as an indicator of potential fishing impacts on deep-sea corals and sponges. These data and indicators are currently updated and reported annually in the Ecosystem Status Reports of Stock Assessment and Fishery Evaluation documents for Alaska (Siddon and Zador, 2018). The data and trends over time are also available to be downloaded (<https://access.afsc.noaa.gov/reem/ecoweb/index.php>). These indicators do not necessarily capture the diversity of deep-sea corals and sponges, but they indicate instead what the population status might be and document the potential threats due to fishing activity. Further work is needed on this topic, especially work to integrate the spatially explicit fishing effort with the distribution models for deep-sea corals and sponges. Key recommendations to WG 32 members for this work include:

- There is a need to share relevant fisheries and environmental data that addresses trends and threats to biodiversity;
- There is a need for the development of marine spatial planning tools and tools to measure marine protected area performance.



**Fig. 10.6** Examples of indices used for monitoring biogenic habitats in Alaska. Total bycatch (left) in groundfish fisheries (A. Whitehouse, Alaska Fisheries Science Center, NMFS), time series of abundance of deep-sea corals and sponges in the Gulf of Alaska (right).



**Fig. 10.6** Continued. Time series of area impacted by fishing gear in Alaska regions (top; AI = Alaska, EBS = eastern Bering Sea, GOA = Gulf of Alaska), cumulative spatial distribution of fishing effort (bottom). From J. Olson, Alaska Regional Office, NMFS.

### Associations between commercial species and biogenic habitats

In the USA EEZ of the North Pacific Ocean, there have been a number of recent studies that have examined the association of commercially important fish and invertebrate species and deep-sea coral and sponge ecosystems. On a larger scale (ecosystem) the studies have demonstrated a strong correlation between rockfishes (*Sebastes* sp.) and corals and sponges in bottom trawl survey catches (Sigler *et al.*, 2015; Laman *et al.*, 2015, 2018; Thorson and Barnett, 2017). In these studies, higher catches of rockfishes (and some other commercially important species) are higher where corals or sponges also occur in the catch. This indicates spatial correlation in density across large areas. The strength of these correlations is variable, with stronger associations in Alaska than on the US West Coast. However, functional relationships are difficult to resolve using bottom trawl survey data.

Two new studies conducted by members of WG 32 have examined the seasonal use of deep-sea coral and sponge habitat and cross-ecosystem associations at differing scales in Alaska. These studies found that the associations documented for rockfishes were consistent across seasons, indicating that rockfishes exhibit the same habitat associations during all times of the year (Conrath *et al.*, 2019). Since most previous work in Alaska has focused on only summertime distributions, this is an important finding.

In a second study, comparisons of habitat associations for rockfishes were made for the same species group across two different ecosystems (the Aleutian Islands and eastern Bering Sea) at scales ranging from 1 m to 1000s of km. The study found that rockfishes, in particular, utilized habitat in the same way in both ecosystems (Rooper *et al.*, 2019). This was in spite of the large differences in quantity and quality of habitat between the two ecosystems. In all, this study found that having more structured habitats (deep-sea coral and sponge) led to a greater abundance of rockfishes, regardless of the larger ecosystem characteristics. The key findings of these studies and others assessed by WG 32 were:

- Deep-sea corals and sponges serve as important habitats for commercially important rockfishes in the northeastern Pacific Ocean;
- The associations between rockfishes and habitat are constant over seasonal and annual time periods and over all spatial scales examined;
- A higher abundance of structured habitats, such as deep-sea corals and sponges, leads to an increased abundance of rockfishes.

## Conclusions

Deep-sea coral and sponge ecosystems in the USA EEZ of the North Pacific Ocean are widely distributed. Data on deep-sea corals and sponges have been collated into a global database that is publicly available. The work of WG 32 has advanced our knowledge of deep-sea coral and sponge ecosystem distributions by providing a motivation and tools for modeling presence, absence and abundance of deep-sea corals and sponges. Variables developed in the workshop sponsored by WG 32 have also been crucial to moving the distribution modeling forward on a relevant scale (1 km<sup>2</sup>) for management. Since the Working Group was formed, published models for all regions of the USA EEZ have been developed and used in management. In addition, some key work in the USA has documented the importance of deep-sea coral and sponge ecosystems to supporting productivity of commercially important fish stocks, particularly rockfishes. Current monitoring efforts relative to deep-sea corals and sponges in the USA EEZ focus primarily on time series of abundance, bycatch and fishing effort. The monitoring could be improved with more focused studies that address the biodiversity of biogenic habitats.

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