Ocean Accounts

Feasibility Study

for Mapping Global Ocean Ecosystems

Feixue LI Ph.D
Consultant
Statistics Division, ESCAP
Associate Professor
School of Geography and Ocean Science, Nanjing University
Email: lifeixue@nju.edu.cn

ESCAP Statistics Division: stat.unescap@un.org

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1 Introduction

The proposed Mapping Global Ocean Ecosystem (MGOE) program aims to produce a series of maps of global coastal and marine ecosystems (e.g. substrate, seagrass, mangrove, coral reef and biotic *etc.*). The maps will be based on existing spatial datasets and ecosystem classifications of ocean and marine areas.

The ongoing benefits of the Mapping Global Ocean Ecosystem program will facilitate international collaborations for ocean and coastal research, establish a common ocean ecosystem mapping vocabulary and encourage an internationally consistent approach for global ocean ecosystem mapping into the future. We anticipate that the output of this program will facilitate international-scale cross-disciplinary studies of ocean ecosystems. It is our intent that, by collating all the available marine and ocean ecosystem datasets into a single framework, a single classification system and a spatial coordinate, and promoting and extending the availability of these through public use rules, institutions will work collaboratively to address worldwide data gaps and solutions. It is encouraged for researchers worldwide to share their ocean and marine ecosystem data.

Two major tasks are included in this study: reviewing both the existing datasets and the classification frameworks and then summarize recommendations on the best datasets and suitable classification methods for mapping global ocean ecosystems. We have reviewed some of the spatial databases of global ocean. The rules for the database selection focus on open-to-the-public, downloadable and updatability *etc*. Multiple global datasets are analyzed including the World Ocean Database (WOD), the Ocean+ Habitat Atlas and the AquaMaps *etc*. Datasets of major ecosystems (e.g. substrate, seagrass, mangrove, coral reef and biotic *etc.*), bathymetry and substrate are analyzed and summarized in the following sections. Furthermore, we have reviewed ecosystem classifications for oceans (CMECS, CBiCS, MEOW, GOODS, *etc.*), in which the Coastal and Marine Ecological Classification Standard (CMECS) is the most systematic and flexible. The framework of CMECS is introduced in the following section in detail.

We have also suggested a work plan and timeline for creating an initial map of global ocean ecosystems, including areas where data are not available.

2 Overview of the ecosystem classifications

2.1 Brief introduction of ecosystem classifications for oceans

In the marine and coastal environment, existing global classification systems remain limited in their spatial resolution. In the absence of compelling global coverage, numerous regional classifications have been created to meet regional needs, such as Coastal and Marine Ecological Classification Standard (CMECS) focusing on United States, Combined Biotope Classification Scheme (CBiCS) focusing on Australia which is based on CEMCS framework, South African National Biodiversity Index, Global Open Oceans and Deep Seabed (GOODS) Biogeographic Classification, the National

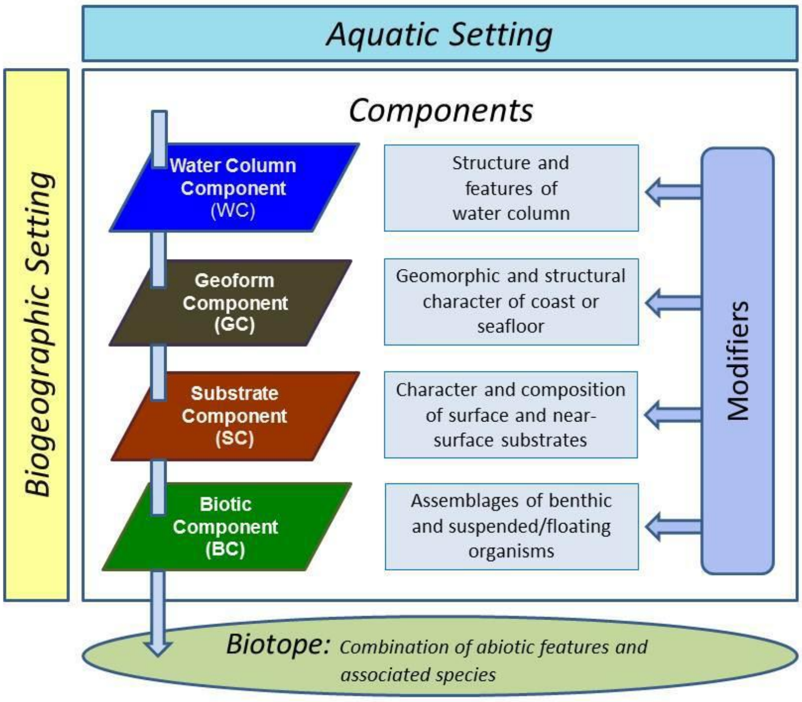
Intertidal/Subtidal Benthic classification (NISB) and Marine Ecosystems of the World (MEOW) with definition of 232 marine ecoregions all over the world, *etc*.

2.2 Coastal and Marine Ecological Classification Standard (CMECS)

The CMEC Standard[1] (https://iocm.noaa.gov/cmecs/) was developed by the US Federal Geographic Data Committee to describe habitat types in Northern America, and is arguably one of the most thorough and well-accepted systems endorsed by the scientific community.

It classifies marine and coastal environments according to two settings – aquatic and biogeographic – and four components – water column (WC), geoform component (GC), substratum component (SC), and biotic component (BC) (Figure 1). The six elements of the standard represent the different aspects of the seascape, starting with the broadest systems (marine, estuarine, and lacustrine) and narrowing to the most detailed physical and biological features associated with a specific habitat type (biotic community). Descriptive information such as salinity, turbidity, and percent cover are included in CMECS as modifiers. Mapping guidance and protocols, along with dichotomous keys, will be produced to support the implementation of the standard. The Federal Geographic Data Committee (FGDC) has endorsed CMECS as a national standard. Their endorsement followed a long period of public review that included input from a wide variety of stakeholders. As an approved Federal Geographic Data Committee (FGDC) standard, CMECS would be required if federal funds are used for the project.

Figure 1 Relationship between CMECS Settings, Components, Modifiers and Biotopes



[1] FGDC (2012). Coastal and Marine Ecological Classification Standard, Federal Geographic Data Committee.

The partition of the CMEC Standard into separate hierarchies requires that different ecosystem characteristics are scored and mapped in isolation. This flexibility is advantageous, because it allows the full complexity of ecosystems to be described in fine detail, and each character can be described in the complete absence of knowledge of any others. In contrast to a biotope classification (e.g. EUNIS, CBiCS), this approach is particularly useful in the context of a national scheme where the aims are to both provide a classification framework which can be used into the future to map broad and fine scale community level characteristics, and to accommodate historical data that may often only map one component, e.g. biotic characteristics.

There is also a spatial hierarchy implied by the structure of the scheme, moving from broad descriptions of the Biogeographic and Aquatic Settings, to smaller scale Geomorphology classifications, and to finer descriptions of Substratum Type and the Biotic Community associated with the seafloor. This means that the scheme can be easily tailored to the specific needs of a project and the equipment available for mapping, facilitating its use by a variety of end-users.

CMECS provides two broad-based, complementary settings within which to partition the coastal and marine world (Table 1, Table 2).

The Biogeographic Setting (BS) identifies ecological units based on species aggregations and features influencing the distribution of organisms. Coastal and marine waters are organized into regional hierarchies composed of realms (largest), provinces and ecoregions (smallest).

CMECS adopts the approach described by Spalding et al. (2007)[2] in *Marine Ecosystems of the World* (MEOW) to characterize Biogeographic Settings occurring in the Estuarine System and in the Marine Nearshore and Marine Offshore Subsystems. MEOW is worldwide in coverage and identifies five realms, eight provinces, and 24 ecoregions in U.S. waters. Representative units include the Gulf of Maine/Bay of Fundy, Carolinian, and Southern California Bight ecoregions.

Biogeographic Settings for the CMECS Oceanic Subsystem are defined in the *Global Open Ocean and Deep Seabed (GOODS) Biogeographic Classification* (UNESCO 2009). As in MEOW, hierarchies composed of regions, provinces, and ecoregions are identified, but separate suites of terms are applied to benthic and water column habitats.

The Aquatic Settings (AS). CMECS also divides the coastal and marine environment into three Systems: Marine, Estuarine, and Lacustrine. Secondary and tertiary layers of the Aquatic Setting describe Subsystems (e.g., Nearshore, Offshore, and Oceanic within the Marine System) and Tidal Zones within the Estuarine System and Marine Nearshore Subsystem.

[2] Spalding, M. D., H. E. Fox, G. R. Allen, N. Davidson, Z. A. Ferdaña, M. Finlayson, B. S. Halpern, M. A. Jorge, A. Lombana, S. A. Lourie, K. D. Martin, E. McManus, J. Molnar, C. A. Recchia and J. Robertson (2007). "Marine ecroegions of the world: A bioregionalization of coastal and shelf areas." BioScience 57(7): 573-583.

Table 1 CMECS Settings and Components. AS, BS, BC, and SC are internally hierarchical. WC and GC include non-hierarchical subcomponents

Biogeographic Setting (BS)	Aquatic Setting (AS)	Water Column Component (WC)	Geoform Component (GC)	Substrate Component (SC)	Biotic Component (BC)
Realm *Province* *Ecoregion*	*System* *Subsystem* *Tidal Zone*	**Layer Subcomponent**	**Tectonic Setting Subcomponent**	*Substrate Origin* *Substrate Class* *Substrate Subclass* *Substrate Group* *Substrate Subgroup*	*Biotic Setting* *Biotic Class* *Biotic Subclass* *Biotic Group* *Biotic Community*
		Salinity Subcomponent	**Physiographic Setting Subcomponent**		
		Temperature Subcomponent	**Level 1 Geoform Subcomponent** *Geoform Origin* *Level 1 Geoform* *Level 1 Geoform Type*		
		Hydroform Subcomponent *Hydroform Class* *Hydroform* *Hydroform Type*	**Level 2 Geoform Subcomponent** *Geoform Origin* *Level 2 Geoform* *Level 2 Geoform Type*		
		Biogeochemical Feature Subcomponent			

CMECS is organized into four components to record and define the attributes of environmental units and biota within each setting--the Water Column Component (WC), the Geoform Component (GC), the Substrate Component (SC), and the Biotic Component (BC).

The Water Column Component (WC) represents a new approach to the ecological classification of open water settings. The component describes the water column in terms of vertical layering, water temperature and salinity conditions, hydroforms, and biogeochemical features. Modifiers allow users to further subdivide water column units.

The Geoform Component (GC) describes the major geomorphic and structural characteristics of the coast and seafloor. This component is divided into four subcomponents that describe tectonic and physiographic settings and two levels of geoform elements that include geological, biogenic, and anthropogenic geoform features. Representative units include lagoon, ledge, tidal channel/creek, and moraine.

The Substrate Component (SC) describes the composition and size of estuary bottom and seabed materials in all CMECS systems. This component is hierarchical and encompasses substrates of 14 geologic, biogenic, and anthropogenic origin. Particle size classes conform to those developed by Wentworth (1922) and substrate mixes conform to the standard described by Folk (1954). Representative units include sandy mud, coral sand, and construction rubble. See Section 7 for more details.

The Biotic Component (BC) is a hierarchical classification that identifies (a) the composition of floating and suspended biota and (b) the biological composition of coastal and marine benthos. Representative units include *Sargassum* raft, jellyfish aggregation, *Oculina* reef, *Crassostrea* bed, and *Rhizophora mangle* fringe forest.

CMECS incorporates a list of **standard modifiers**—a consistent set of characteristics and definitions— as part of each component to describe the nature and extent of observed variability within ecological units. Modifiers allow users to customize the application of the classification in a standardized manner.

A **biotope** is defined as the combination of abiotic features and associated species. Users can start with non-living physical characteristics from any of the other CMECS settings or components, if there is no benthic survey. As knowledge of biotopes increases, biotope units and descriptions will be added to CMECS.

CMECS units are spatial tessellations, defined on the basis of attributes observed in specific areas of the seafloor (as viewed from above) or specific segments of the water column (in three-dimensional space).

Table 2 A table of main CMECS components

<table>
<tr><th>Component</th><th>Contents</th></tr>
<tr><td>BS</td><td>
<table>
<tr><th>Realm</th><th>Province</th><th>Ecoregion</th></tr>
<tr><td>Arctic</td><td></td><td>Beaufort Sea Continental Coast and Shelf</td></tr>
<tr><td></td><td></td><td>Chukchi Sea</td></tr>
<tr><td></td><td></td><td>Eastern Bering Sea</td></tr>
<tr><td>Temperate Northern Atlantic</td><td>Cold Temperate Northwest Atlantic</td><td>Scotian Shelf</td></tr>
<tr><td></td><td></td><td>Gulf of Maine/Bay of Fundy</td></tr>
<tr><td></td><td></td><td>Virginian</td></tr>
<tr><td></td><td>Warm Temperate Northwest Atlantic</td><td>Carolinian</td></tr>
<tr><td></td><td></td><td>Northern Gulf of Mexico</td></tr>
<tr><td>Temperate Northern Pacific</td><td>Cold Temperate Northeast Pacific</td><td>Aleutian Islands</td></tr>
<tr><td></td><td></td><td>Gulf of Alaska</td></tr>
<tr><td></td><td></td><td>North American Pacific Fijordland</td></tr>
<tr><td></td><td></td><td>Puget Trough/Georgia Basin</td></tr>
<tr><td></td><td></td><td>Oregon, Washington, Vancouver Coast and Shelf</td></tr>
<tr><td></td><td></td><td>Northern California</td></tr>
<tr><td></td><td></td><td>Southern California Bight</td></tr>
<tr><td>Tropical Atlantic</td><td>Tropical Northwestern Atlantic</td><td>Eastern Caribbean</td></tr>
<tr><td></td><td></td><td>Greater Antilles</td></tr>
<tr><td></td><td></td><td>Southwestern Caribbean</td></tr>
<tr><td></td><td></td><td>Floridian</td></tr>
<tr><td>Central Indo-Pacific</td><td>Tropical Northwestern Pacific</td><td>Mariana Islands</td></tr>
<tr><td>Eastern Indo-Pacific</td><td>Hawaii</td><td></td></tr>
<tr><td></td><td>Marshall, Gilbert and Ellis Islands</td><td>Marshall Islands</td></tr>
<tr><td></td><td>Central Polynesia</td><td>Line Islands</td></tr>
<tr><td></td><td></td><td>Phoenix/Tokelau/Northern Cook Islands</td></tr>
<tr><td></td><td></td><td>Samoa Islands</td></tr>
</table>
</td></tr>
<tr><td>AS</td><td>
<table>
<tr><th>System</th><th>Subsystem</th><th>Tidal Zone</th></tr>
<tr><td>Lacustrine</td><td>Lacustrine Littoral</td><td></td></tr>
<tr><td></td><td>Lacustrine Limnetic</td><td></td></tr>
<tr><td>Estuarine</td><td>Estuarine Coastal</td><td>Estuarine Coastal Subtidal</td></tr>
<tr><td></td><td></td><td>Estuarine Coastal Intertidal</td></tr>
<tr><td></td><td></td><td>Estuarine Coastal Supratidal</td></tr>
<tr><td></td><td>Estuarine Open Water</td><td>Estuarine Open Water Subtidal</td></tr>
<tr><td></td><td>Estuarine Tidal Riverine Coastal</td><td>Estuarine Tidal Riverine Coastal Subtidal</td></tr>
<tr><td></td><td></td><td>Estuarine Tidal Riverine Coastal Intertidal</td></tr>
<tr><td></td><td>Estuarine Tidal Riverine Open Water</td><td>Estuarine Tidal Riverine Open Water Subtidal</td></tr>
<tr><td>Marine</td><td>Marine Nearshore</td><td>Marine Nearshore Subtidal</td></tr>
<tr><td></td><td></td><td>Marine Nearshore Intertidal</td></tr>
<tr><td></td><td></td><td>Marine Nearshore Supratidal</td></tr>
<tr><td></td><td>Marine Offshore</td><td>Marine Offshore Subtidal</td></tr>
<tr><td></td><td>Marine Oceanic</td><td>Marine Oceanic Subtidal</td></tr>
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</td></tr>
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WC

Water Column Layer	Salinity Regime	Temperature Regime	Hydroform Class	Hydroform	Hydroform Type	Biogeochemical Featu
Estuarine Coastal Surface Layer	Oligohaline Water	Frozen/Superchilled Water	Current	Boundary Current	Eastern Boundary Current	Benthic Boundary Layer
Estuarine Coastal Upper Water Column	Mesohaline Water	Very Cold Water			Western Boundary Current	Boundary Layer
Estuarine Coastal Pycnocline	Lower Polyhaline Water	Cold Water		Buoyancy Flow	Downwelling	Chlorophyll Maximum
Estuarine Coastal Lower Water Column	Upper Polyhaline Water	Cool Water			Upwelling	Chlorophyll Minimum
Estuarine Open Water Surface Layer	Euhaline Water	Moderate Water		Current Meander		Drifting Fine Woody Debris
Estuarine Open Water Upper Water Column	Hyperhaline Water	Warm Water		Deep Boundary Current		Drifting Herbaceous Debris
Estuarine Open Water Pycnocline		Very Warm Water		Deep Circulation	Abyssal Deep Circulation	Drifting Trees
Estuarine Open Water Lower Water Column		Hot Water			Abyssal Deep Circulation	Drifting Woody Debris
Estuarine Tidal Riverine Coastal Surface Layer		Very Hot Water			Bathyl Deep Circulation	Euphotic Zone
Estuarine Tidal Riverine Coastal Upper Water Column				Deep Convection		Halocline
Estuarine Tidal Riverine Coastal Pycnocline				Density Flow		Lens
Estuarine Tidal Riverine Coastal Lower Water Column				Ekman Flow	Ekman Upwelling	Lysocline
Estuarine Tidal Riverine Open Water Surface Layer					Ekman Downwelling	Marine Snow Aggregation
Estuarine Tidal Riverine Open Water Upper Water Column				Inertial Current		Microlayer
Estuarine Tidal Riverine Open Water Pycnocline				Langmuir Circulation		Nepheloid Layer
Estuarine Tidal Riverine Open Water Lower Water Column				Mean Surface Current	North Equatorial Surface Current	Neustonic Layer
Marine Nearshore Surface Layer					South Equatorial Surface Current	Nutrient Maximum
Marine Nearshore Upper Water Column				Mesoscale Eddy	Cold Core Ring	Nutrient Minimum
Marine Nearshore Pycnocline					Warm Core Ring	Nutricline
Marine Nearshore Lower Water Column				Residual Current	Fjord Circulation	Oxygen Maximum
Marine Offshore Surface Layer					Partially Mixed Domain	Oxygen Minimum
Marine Offshore Upper Water Column					Reverse Estuarine Flow	Oxycline
Marine Offshore Pycnocline					Salt Wedge Domain	Sea Foam
Marine Offshore Lower Water Column					Well-mixed Domain	Seep
Marine Oceanic Surface Layer				Sub-mesoscale Eddy		Surface Film
Marine Oceanic Epipelagic Upper Layer				Thermohaline Eddy		Surface Mixed Layer
Marine Oceanic Epipelagic Pycnocline				Tidal Flow	Diurnal Tidal Flow	Thermocline
Marine Oceanic Epipelagic Lower Layer					Mixed Semi-diurnal Tidal Flow	Turbidity Maximum
Marine Oceanic Mesopelagic Layer					Semi-diurnal Tidal Flow	
Marine Oceanic Bathypelagic Layer				Turbidity Flow		
Marine Oceanic Abyssopelagic Layer				Wave-driven Current	Longshore Current	
Marine Oceanic Hadalpelagic Layer					Rip Current	
					Undertow	
				Wind-driven Current		
			Front	Coastal Upwelling Front		
				Shelf-break Front		
				Tidal Front		
			Water Mass	Background Mesoscale Field		
				Fumarole Plume		
				Hydrothermal Plume	Detached Hydrothermal Plume	
				Ice	Drift Ice	
					Fast Ice	
					Frazil or Grease Ice	
					Ice Field	
					Ice Floe	
					Pack Ice	
					Pancake Ice	
					Polnya	
				Mesoscale Lens	River/Estuary Plume	
					Meddy	
				Microscale Lens	Small Freshwater Plume	
				Winter Water Mass		
			Wave	Anthropogenic Wave		
				Coastally Trapped Wave	Internal Kelvin Wave	
					External Kelvin Wave	
					Shelf Wave	
					Topographic Wave	
				Edge Wave		
				Equatorial Wave		
				Non-Equatorial Wave		
				Internal Wave		
				Seiche		
				Storm Surge		
				Surf Zone		
				Surface Wave		
				Surface Wind Wave		
				Surface Swell		
				Tsunami		

GC

Tectonic Setting	Physiographic Setting	Geoform Origin	Geoform	Level 1	Level 2	Geoform Type	Level 1	Leve
Abyssal Plain	Abyssal/Submarine Fan	Geologic	Apron	x				
Convergent Active Continental Margin	Barrier Reef		Bank	x				
Divergent Active Continental Margin	Bight		Bar	x	x	Bay Mouth Bar	x	
Fracture Zone	Borderland					Longshore Bar	x	
Spreading Center	Continental/Island Rise					Point Bar		x
Mid-Ocean Ridge	Continental/Island Shelf					Relict Longshore Bar		x
Passive Continental Margin	Continental/Island Shore Complex		Basin	x				
Transform Continental Margin	Continental/Island Slope		Beach	x	x	Barrier Beach	x	x
Tectonic Trench	Embayment/Bay					Mainland Beach	x	x
	Fjord					Pocket Beach		x
	Inland/Enclosed Sea					Tide-Modified Beach	x	x
	Lagoonal Estuary					Tide-Dominated Beach	x	x
	Major River Delta					Wave-Dominated Beach	x	x
	Marine Basin Floor		Beach Berm	x	x			
	Ocean Bank/Plateau		Boulder Field	x				
	Riverine Estuary		Cave		x			
	Shelf Basin		Channel	x	x	Pass/Lagoon Channel		x
	Shelf Break					Sand Channel		x
	Sound					Slough	x	
	Submarine Canyon					Tidal Channel/Creek	x	x
	Trench		Cone	x	x			
			Cove	x	x	Barrier Cove	x	x
						Mainland Cove	x	x
			Delta	x	x	Glacial (Kame) Delta	x	
						Ebb Tidal Delta		x
						Flood Tidal Delta		x
						Flood Tidal Delta Slope		x
						Levee Delta	x	x
			Delta Plain	x				
			Depression		x	Scour Depression		x
			Diapir	x	x	Salt Dome	x	x
			Dike		x			
			Drumlin		x			
			Drumlin Field	x				
			Dune Field	x				
			Dune		x			
			Fan	x	x	Alluvial Fan	x	
						Basin Floor Fan	x	
						Shoreline Fan	x	
						Washover Fan	x	x
			Flat	x	x	Back Barrier Flat	x	
						Barrier Flat	x	
						Ebb Tidal Delta Flat		x
						Flood Tidal Delta Flat		x
						Tidal Flat	x	x
						Washover Fan Flat	x	
						Wind Tidal Flat	x	
			Fluvio-Marine Deposit	x	x			
			Fracture	x	x			
			Hole/Pit		x	Scour Hole		x
						Solution Hole/Pit		x
			Hydrothermal Vent Field	x	x			
			Hydrothermal Vent		x			
			Inlet	x	x	Tidal Inlet	x	
						Relict Tidal Inlet	x	
			Island	x	x	Barrier Island	x	x
			Karren		x			
			Knob		x			
			Lagoon	x	x			
			Lava Field/Plain	x				
			Ledge	x	x			
			Marine Lake	x				
			Marsh Platform	x	x			
			Megaripples	x				
			Moraine	x		Disintegration Moraine	x	
						End Moraine	x	
						Ground Moraine	x	
						Kame Moraine	x	
						Lateral Moraine	x	
						Recessional Moraine	x	
						Terminal Moraine	x	
			Mound/Hummock	x	x	Tar Mound		x

SC

Substrate Origin	Substrate Class	Substrate Subclass	Substrate Group	Substrate SubGroup
Geologic Substrate	Rock Substrate	Bedrock		
		Megaclast		
	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel	Boulder
				Cobble
				Pebble
				Granule
			Gravel Mixes	Sandy Gravel
				Muddy Sandy Gravel
				Muddy Gravel
			Gravelly	Gravelly Sand
				Gravelly Muddy Sand
				Gravelly Mud
		Fine Unconsolidated Substrate	Slightly Gravelly	Slightly Gravelly Sand
				Slightly Gravelly Muddy Sand
				Slightly Gravelly Sandy Mud
				Slightly Gravelly Mud
			Sand	Very Coarse Sand
				Coarse Sand
				Medium Sand
				Fine Sand
				Very Fine Sand
			Muddy Sand	Silty Sand
				Silty-Clayey Sand
				Clayey Sand
			Sandy Mud	Sandy Silt
				Sandy Silt-Clay
				Sandy Clay
			Mud	Silt
				Silt-Clay
				Clay
Biogenic Substrate	Algal Substrate	Algal Sand	*Halimeda* Sand	
		Rhodolith Substrate	Rhodolith Rubble	
			Rhodolith Hash	
			Rhodolith Sand	
	Coral Substrate	Coral Reef Substrate		
		Coral Rubble		
		Coral Hash		
		Coral Sand		
	Organic Substrate	Organic Debris	Peat Debris	
			Woody Debris	Fine Woody Debris
				Coarse Woody Debris
				Very Coarse Woody Debris
		Organic Detritus		
		Organic Mud		
	Ooze Substrate	Carbonate Ooze	Coccolithophore Ooze	
			Foraminiferan Ooze	*Globigerina* Ooze
			Pteropod Ooze	
		Siliceous Ooze	Diatomaceous Ooze	
			Radiolarian Ooze	
	Shell Substrate	Shell Reef Substrate	Clam Reef Substrate	*Coquina* Reef Substrate
			Crepidula Reef Substrate	
			Mussel Reef Substrate	
			Oyster Reef Substrate	
		Shell Rubble	Clam Rubble	*Coquina* Rubble
			Crepidula Rubble	
			Mussel Rubble	
			Oyster Rubble	
		Shell Hash	Clam Hash	*Coquina* Hash
			Crepidula Hash	
			Mussel Hash	
			Oyster Hash	
		Shell Sand	*Coquina* Sand	
	Worm Substrate	Sabellariid Substrate	Sabellariid Reef Substrate	
			Sabellariid Rubble	
			Sabellariid Hash	
		Serpulid Substrate	Serpulid Reef Substrate	
			Serpulid Rubble	
			Serpulid Hash	
Anthropogenic Substrate	Anthropogenic Rock	Anthropogenic Rock Reef Substrate		
		Anthropogenic Rock Rubble		
		Anthropogenic Rock Hash		
		Anthropogenic Rock Sand		
		Anthropogenic Rock Mud		
	Anthropogenic Wood	Anthropogenic Wood Reef Substrate		
		Anthropogenic Wood Rubble		
		Anthropogenic Wood Hash		
	Construction Materials	Construction Reef		
		Construction Rubble		
		Construction Hash		
	Metal	Metal Reef Substrate		
		Metal Rubble		
		Metal Hash		
	Trash	Trash Rubble		
		Trash Bits		

	Biotic Setting	Biotic Class	Biotic Subclass	Biotic Group	Biotic Community
BC	Planktonic Biota	Zooplankton	Crustacean Holoplankton	Amphipod Aggregation	*Hyperia* Aggregation
					Caprellid Aggregation
				Copepod Aggregation	*Acartia* Aggregation
					Calanus Aggregation
				Krill Aggregation	*Euphausia* Aggregation
					Thysanoessa Aggregation
			Crustacean Meroplankton	Decapod Larval Aggregation	Brachyuran Crab Larval Aggregation
					Anomuran Crab Larval Aggregation
					Pandalus Larval Aggregation
				Mixed Crustacean Larvae	
			Coral Meroplankton	Coral Spawning and Larval Aggregation	Acroporid Spawning Aggregation
					Montastraea Spawning Aggregation
				Coral Larval Aggregation	Acroporid Larval Aggregation
					Monstastraea Larval Aggregation
			Echinoderm Meroplankton	Mixed Echinoderm Larval Aggregation	Ophiuroid Larval Aggregation
					Asteroidean Larval Aggregation
					Holothurian Larval Aggregation
			Fish Meroplankton	Fish Spawning and Larval Aggregation	Damselfish Spawing and Larval Aggregation
					Grouper Spawning and Larval Aggregation
					Surgeonfish Spawning and Larval Aggregation
				Fish Larval Aggregation	Clupeid Larval Aggregation
					Engraulid Larval Aggregation
					Sciaenid Larval Aggregation
			Gelatinous Zooplankton	Ctenophore Aggregation	*Beroe* Aggregation
					Mnemiopsis Aggregation
					Pleurobrachia Aggregation
				Jellyfish Aggregation	*Aurelia* Aggregation
					Chrysaora Aggregation
				Salp Aggregation	*Thalia* Aggregation
					Pegia Aggregation
				Siphonophore Aggregation	*Bargmannia* Aggregation
					Nanomia Aggregation
					Physalia Aggregation
			Mixed Zooplankton	Mixed Zooplankton Aggregation	Chaetognath, Salp, and Fish Larval Aggregation
					Ctenophore, Worm and Copepod Aggregation
			Molluscan Holoplankton	Pteropod Aggregation	*Carolla* Aggregation
					Clione Aggregation
			Molluscan Meroplankton	Veliger Aggregation	Bivalve Veliger Aggregation
					Gastropod Veliger Aggregation
			Protozoan Holoplankton	Foraminiferan Aggregation	*Globigerina* Aggregation Layer
				Radiolarian Aggregation	*Acantharea* Aggregation
					Polycistina Aggregation
			Worm Holoplankton	Chaetognath Aggregation	*Flaccisagitta* Aggregation
					Sagitta Aggregation
				Polychaete Aggregation	Syllid Aggregation
					Tomopteris Aggregation

2.3 European Union Nature Information System (EUNIS) and Combined Biotope Classification Scheme (CBiCS)

The EUNIS habitat classification scheme is based on recommendations from Davies and Moss [3] and modifications of the Joint Nature Conservation Committee Classification scheme for Britain and Ireland[4]. It was developed to describe terrestrial, freshwater, coastal, and marine habitats in the European region only. It differs from the CMEC Standard in its approach in that the marine section classifies biotopes. The biotopes described by the EUNIS scheme are arranged in a single hierarchy, constituting six levels (environment, broad habitat, habitat complex, biotope complex, biotope and sub-biotope) for the marine habitat branch. The upper levels focus on physical characteristics, while the lower levels describe biotic components of the habitat.

The CBiCS (http://www.cbics.org/) is based on both the CMEC Standard and the EUNIS schema, with a total of seven components: biogeographic setting, aquatic setting, water column component, geoform component, substrate component, biotic component and morphospecies component. Each component has a set of hierarchical classes. The first five components (biogeographic setting, aquatic setting, water column component, geoform component, substrate component) are based on CMECS. The sixth component is the biotic component, which is the central component of CBiCS, classifying biological communities that are in a defined habitat. The biotic component was adapted from EUNIS. The last morphospecies component is a completely new

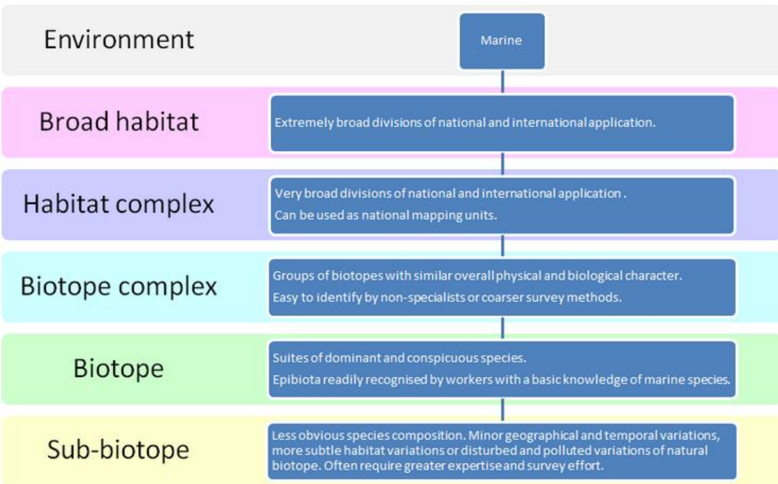
[3] Davies, C. E. and D. Moss (2004). EUNIS habitat classification marine habitat types: Revised classification and criterea European Environment Agency European Topic Centre on Nature Protection and Biodiversity. CO249NEW.
[4] Connor, D. W., J. H. Allen, N. Golding, K. L. Howell, L. M. Lieberknecht, K. O. Northern and J. B. Reker (2004). The Marine Habitat Classification for Britain and Ireland version 04.05. Joint Nature Conservation Comittee. Peterborough

component, provides a scheme for the systematic classification of species and biological groups based on visual characteristics.

The EUNIS and CBiCS are both examples of hierarchical classifications with a shared aim to improve the management and conservation of marine communities. The focus of these schemes is on biotope descriptions – biological communities that consistently occur within a defined set of physical environmental conditions/habitat features. Biotope classifications are advantageous in that they capture the full complexity of biotic communities and how they vary with gradients in environmental conditions, e.g. exposure, salinity, light. They also allow for classes to be described as much by dominant taxa as by frequently occurring but less abundant or rare species, which can be an important consideration for conservation and management of marine environments.

However, the combination of both physical and biological attributes into a single hierarchy in this structure means that it is impossible to reclassify existing data, which often only maps a single habitat characteristic, e.g. biota. Source units get 'stuck' at the higher levels of the hierarchy, resulting in reclassified units with concepts much broader than the original source concept. Furthermore, the ecological meaning of biotope descriptions is not often intuitive, and labels are typically long and complicated, e.g. *sublittoral mud in variable salinity* (estuaries) (EUNIS). To avoid this implicit loss of information, the Seamap Australia scheme, in which CMECS is adopted, has not adopted a biotope approach to the classification of benthic marine habitats.

Figure 2 Six levels of the biotic component of the EUNIS habitat classification scheme



2.4 National Intertidal/Subtidal Benthic classification (NISB)

The National Intertidal Subtidal Benthic (NISB) Classification Scheme developed by Mount and Bricher[5] in 2008 defines broad habitat types in Australia in terms of substratum type (e.g. boulder, rock) and structural biota (e.g. seagrass, coral) with the

[5] Mount, R. and P. Bricher (2008). Estuarine, Coastal and Marine National Habitat Map Series user guide First PAss Coastal Vulnerabiliy Assessment. Australian Government Department of Climate Change, National Land and Water Resources Audit, University of Tasmania, Hobart

option of including a range of environmental attributes (e.g. depth, light availability, exposure) as additional descriptors. The classification range extends from the Highest Astronomical Tide (HAT) to the outer edge of the continental shelf (~200 m depth).

The use of broad habitat types in the NISB scheme makes for clear and intuitive habitat classes. However, a limitation of this scheme is that the classes are not defined at a finer resolution. Many habitat mapping initiatives include data to species level, and the option to include classification at this level is necessary. Furthermore, while the NISB scheme captures the dominant habitat types, many commonly occurring and/or important habitat types are not described within the framework (e.g. rhodolith beds). This leads to an inability to adequately describe the diversity of marine ecosystems.

The classification scheme was designed to be compatible with other schemes employed by mapping groups in Australia, however, it was structured as an attribute-based system and so was not hierarchical. It could therefore not account for the nested scales of different mapping initiatives and this may explain why it was not readily adopted by the Australian seabed mapping community.

2.5 USGS/ESRI Ecological Marine Units

Ecological Marine Units (EMUs)[6]are baseline 3D mapped ecosystems of the ocean that have been classified through statistical clustering. EMUs come from an unprecedented 3D point mesh framework of 52 million global measurements of 6 key ocean variables over a 50-year period at a horizontal resolution of 1/4˚ by 1/4˚, over 102 depth zones. The deterministic parameters are temperature, salinity, dissolved oxygen, nitrate, phosphate, and silicate.

The data used in constructing the EMUs comes from World Ocean Atlas (WOA), which is a compendium of data from a variety of ocean research and monitoring programs over the past five decades. The complete set of variables from the 2013 WOA is used and it contains over 52 million points (ocean mesh).

Temporally, the WOA archive is available in seasonal, annual, and decadal resolutions. Spatially the WOA has a horizontal spatial resolution of 1/4˚ × 1/4˚ for temperature and salinity, and 1˚ × 1˚ for oxygen, nitrate, phosphate, and silicate. Resolution 1˚ × 1˚ were downscaled to the 1/4˚ resolution to reconcile all data to a common working horizontal resolution. In the vertical dimension, points are located at variable depth intervals, ranging from 5 m increments near the surface to 100 m increments at depth. A total of 102 depth zones extend to 5500 m.

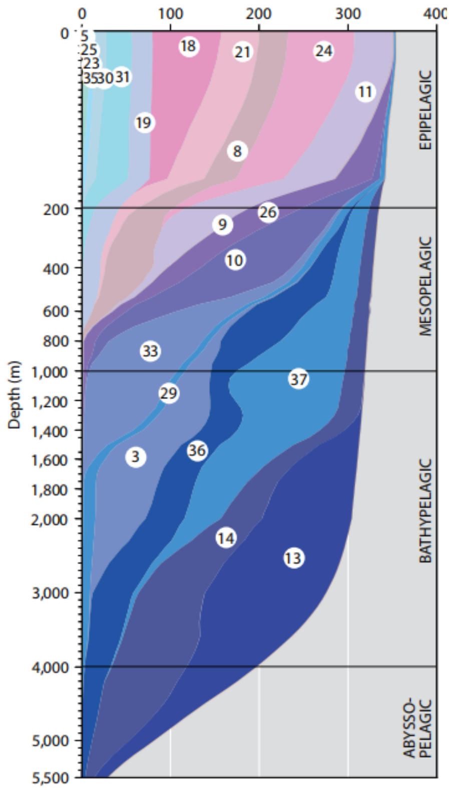
The procedure for defining an EMU are as follows: Firstly, constructing an “empty” ocean point mesh using the 52,487,233 WOA point locations, and then constructing the water column by attaching the WOA attribute data to those points. Secondly,

[6] Sayre, R.G., D.J. Wright, S.P. Breyer, K.A. Butler, K. Van Graafeiland, M.J. Costello, P.T. Harris, K.L. Goodin, J.M. Guinotte, Z. Basher, M.T. Kavanaugh, P.N. Halpin, M.E. Monaco, N. Cressie, P. Aniello, C.E. Frye, and D. Stephens (2017). A three- dimensional mapping of the ocean based on environmental data. Oceanography 30(1): 90-103.

statistically clustering the points in the mesh in order to identify environmentally distinct regions in the water column. The clustering was blind to both the depth of the point and the thickness of the depth interval at that point's vertical position in the water column. The clustering was implemented using SAS (Statistical Analysis System) software, the optimum cluster number 37 was determined by inspection of the behavior of the pseudo F-statistic. Finally, the clusters were labeled using the naming criteria of the CMECS. The labels begin with depth zone assignments, followed by a concatenation of the CMECS descriptors for temperature, salinity, and dissolved oxygen.

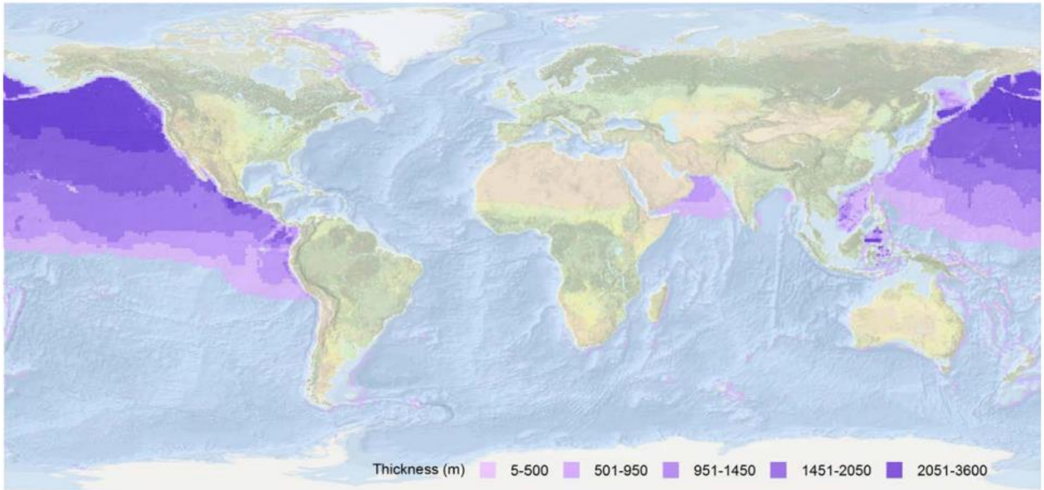
Global ocean is divided into 37 EMUs in 3D space. Twenty-two of the EMUs are large, with essentially global or large regional distributions, while the 15 others are small, shallow, and coastal, and collectively represent only about 1% of the ocean volume. The distribution of EMUs is shown in the figure3 and figure4.

Figure 3 Vertical distribution of the 37 EMUs



EMU may be used to map the global ocean ecosystem in a 3D form. The biggest challenge in marine mapping is that the ocean is a three-dimensional space, different species distribute in different depths. The "land cover map for the ocean" can't express all kinds of ocean data very well. The proposal of EMU provides a new way of ocean three-dimensional mapping. EMUs embody open, accessible data and serve as the basis for a variety of marine spatial research such as ocean conservation and resource management.

Figure 4 Global distribution of one EMU (named Bathypelagic, Very Cold, Euhaline, Severely Hypoxic, High Nitrate, Medium Phosphate, High Silicate)



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However, limitations in EMUs are related to both temporal scaling dimensions and parameters selected for the clustering. First, the 57-year mean values for the six parameters were used to map EMU, and it prohibits the assessment of temporal variability and trends. Second, the clustering of oceanic data to derive EMUs was based on the six variables in the WOA data set. The addition of other variables would likely influence the oceanic partitioning. The inclusion of data on particulate organic carbon (POC), carbonate contents, and ocean current patterns might influence the clustering results. Furthermore, while calling these 37 volumetric regions EMUs, we can find that their true ecological character has not yet been established.

3 Data Considerations

3.1 Overview

As we know, there are some specialized maps for individual ecosystem types (coral, mangrove, seagrass, etc.), bathymetry, ocean chemistry, species ranges, etc. There are also several comprehensive maps for continental ocean regions, countries and sub-national areas. Our aim is to create a comprehensive map for the global ocean ecosystem, that is, coastal and marine areas. For mapping global ocean ecosystem, it is a necessity to create a collection of standardized spatial ocean data with regular production, quality control and update mechanisms.

We have reviewed some of existing global ocean ecosystem datasets in accordance with a general ocean ecosystem classification framework. Some of the datasets are introduced in the following section.

3.2 **World Ocean Database 2018 and World Ocean Atlas 2013**

The World Ocean Database (WOD) (https://www.nodc.noaa.gov/OC5/WOD/prwod.html) is a collection of scientifically quality-controlled ocean profile and plankton data that includes measurements of temperature, salinity, oxygen, phosphate, nitrate, silicate, chlorophyll, alkalinity, pH, pCO2, TCO2, Tritium, Δ13Carbon, Δ14Carbon, Δ18Oxygen, Freon, Helium, Δ3Helium, Neon, and plankton.

WOD incorporates 20,547 different datasets received and archived at NCEI (National Center of Environment Information). The data represent the results of 216,845 oceanographic cruises on 8,215 different platforms from 798 institutes around the world and 553 separate projects.

There are 3.56 billion individual profile measurements (depth/pressure vs. measured variable) in the WOD. Of these 1.95 billion are temperature, 1.13 billion salinity, 260 million oxygen, and 4.5 million plankton measurements. There are an additional 22 million meteorological/sea state observations. These measurements make up the 15.7 million oceanographic casts in the WOD.

The WOD data are available online presorted by 10° geographic squares, by year, or user-specified via WOD select data selection tool at standard or observed depth levels. All the WOD ASCII output files are in GZIP compressed format as “.gz” files and can be uncompressed to “.csv” files. The data of WOD shows as the formats of excel csv or grid, which can be analyzed and visualized in GIS platforms. All data are downloadable from the WOD website (https://www.nodc.noaa.gov/OC5/WOD/readwod.html) or ftp (ftp.nodc.noaa.gov)

Table 3 The main sub-datasets in WOD

Dataset	Content
OSD	Bottle, low resolution CTD (Conductivity, Temperature and Depth), and plankton data
MBT	Mechanical Bathythermograph data
XBT	Expendable Bathythermograph data
CTD	High resolution CTD data
APB	Autonomous Pinniped Bathythermograph data
DRB	Drifting Buoy data
MRB	Moored Buoy data
PFL	Profiling Float data
UOR	Undulating Oceanographic Recorder data
GLD	Glider data

WOA13 (https://odv.awi.de/en/data/ocean/world-ocean-atlas-2013/) is an atlas describing climatological mean fields on both a quarter- and on a one-degree longitude/latitude grids. It is provided by the U.S. National Oceanographic Data Center (NODC). Statistical fields used in quality control (but not objectively analyzed climatological means) are available on a five-degree longitude/latitude grid.

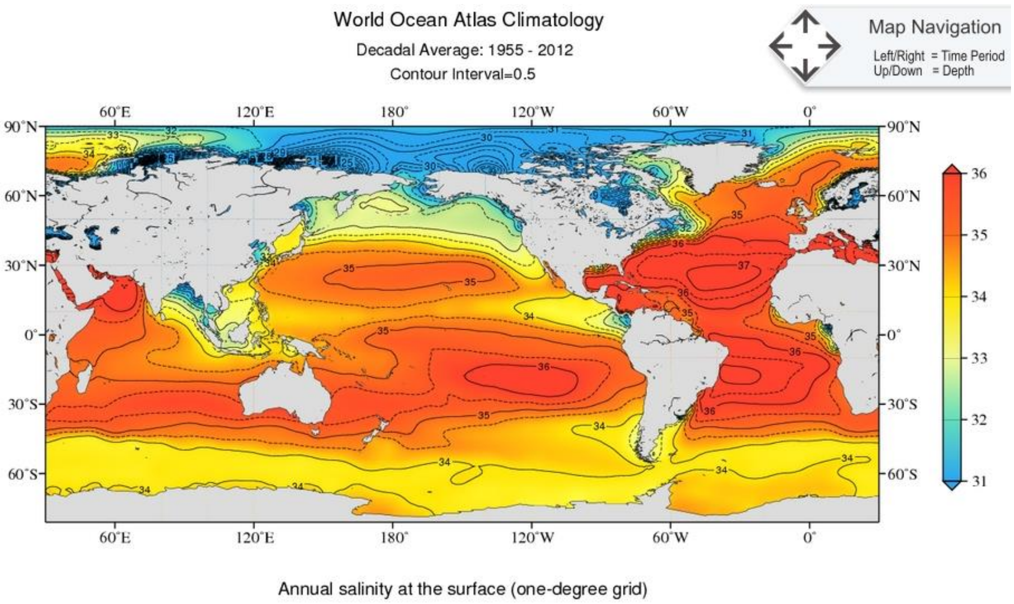
The data files in WOA13 are available in four formats: Climate and Forecast (CF) compliant netCDF, comma-separated value (csv) format, ArcGIS-compatible shapefiles, and compact grid format (a legacy WOA ASCII format). The time periods are annual, seasonal (by three-month periods; Winter = January, February, and March; Spring, Summer, and Fall are the sequentially following three-month periods), and monthly. Time spans are mostly decadal (10 years) spans.

The online version of World Ocean Atlas 2013 Figures V2 (WOA013FV2) contains a collection of "JPEG" images of objectively analyzed fields and statistics generated from the World Ocean Atlas 2013 V2. The images of the features in 33 depth levels can be viewed on the website of WOA13.

Table 4 The images in World Ocean Atlas 2013 V2

Temperature (°C)
Salinity (unitless)
Density (kg/m3) beta version
Conductivity (S/m)
Dissolved Oxygen (ml/l)
Percent Oxygen Saturation (%)
Apparent Oxygen Utilization (ml/l)
Silicate (µmol/l)
Phosphate (µmol/l)
Nitrate (µmol/l)

Figure 5 Sample map of WOA



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Each individual data value and each profile in WOD18 has quality control flags associated with it. A description of these flags and general documentation describing the software for reading and using the WOD18 database are found in Garcia et al. (2018)[7]. WOD also includes quality control flags assigned by data submitters. It is clear that there are both Type I and Type II statistical errors (for normal distributions) associated with these flags. There are some data that have been flagged as being questionable or unrepresentative when in fact they are not. There are some data that have been flagged as being "acceptable" based on our tests, which in fact may not be the case. In addition, the scarcity of data, non-normal frequency distributions, and the presence of different water masses in close proximity result in the incorrect assignment of flags. Oguma et al. (2003; 2004)[8] discuss the skewness of oceanographic data. The WOD flags represent data values used or not used in the calculation of the WOA climatological mean fields.

3.3 **Ocean+ Habitat Atlas by UNEP-WCMC**

The Ocean+ Habitat Atlas was originally curated by UNEP-WCMC (United Nations Environment World Conservation Monitoring Centre) (http://data.unep-wcmc.org/) in collaboration with hundreds of data contributors, ranging from governments to individual researchers. The aim of Ocean+ Habitat Atlas is to produce the first online, authoritative database on the known extent of ecologically-important ocean habitats, such as seagrasses, warm- and cold-water corals, mangroves and salt marshes, and to update this database consistently over time.

As of January 2018, the atlas consists of several datasets that include global distribution of seagrasses, warm- and cold-water corals, mangroves and saltmarshes (Figure 6).

Data types: raster or 1-2 shapefiles, one with polygons and one with points, and both including associated spatial and tabular information on key attributes; one source table identifying the sources of the data (provider, date and metadata *etc.*).

The data are also available for download from the Ocean Data Viewer in file geodatabase, KML, ESRI Web Map Service (WMS) and CSV formats. The atlas is based on the Geographic Coordinate System: World Geodetic Survey (WGS) 1984.

Data update: the data providers are required to update country-level data at least every five years.

The Atlas will only store one version of a given habitat and all records should be verified by an authoritative source. The 'Verification' (VERIF) field allows two values: Government Verified and Expert Verified.

Quality assurance: three indicators are calculated for every release, which will be reviewed at each release: percentage of records with boundaries in polygon format (where relevant), percentage of data attributes reported, and percentage of records

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[7] Garcia, H. A., C. Y. Rodriguez, R. Silva, E. Mendoza, and L. A. Vega (2018). Determination of the potential thermal gradient for the mexican pacific ocean. Journal of Marine Science and Engineering, 6(1): 20.

[8] Oguma, S., and Y. .Nagata (2002). Skewed water temperature occurrence frequency in the sea off sanriku, japan, and intrusion of the pure kuroshio water. Journal of Oceanography, 58(6): 787-796.

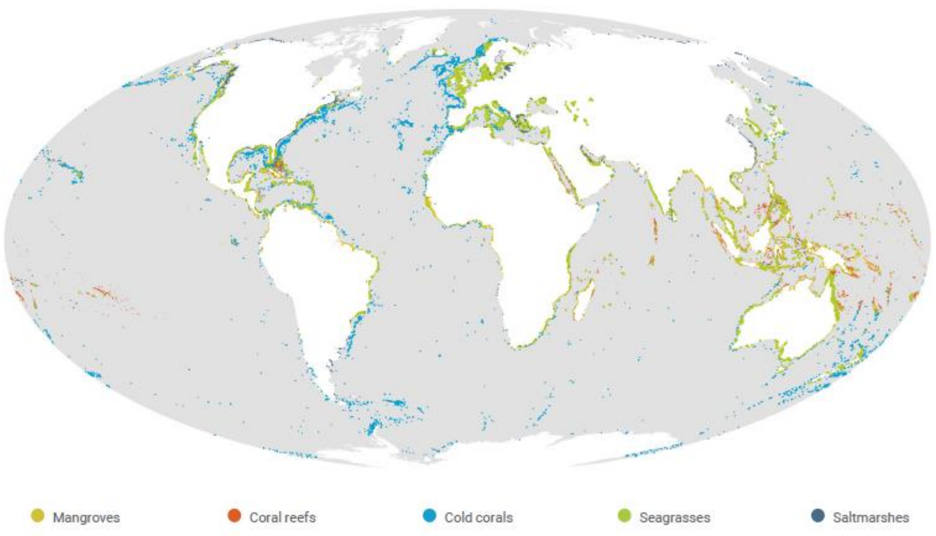
updated, or confirmed without change, by the data provider in the last 5 years.

Table 5 Dataset description for Ocean+ Habitat Atlas by UNEP-WCMC

Dataset	Sub-dataset	Geometry type	Timespan	Data type	Publication date
Coral reefs	Global Distribution of Coral Reefs	Polygon, point	1954-2018	Empirical observation	2018
	Global Distribution of Coral Reefs (cold water)	Polygon, point, other	1915-2014		2018
	Global Distribution of Coral Reefs (warm water)	Polygon, point			
	Reefs at Risk Revisited	Polygon	2011-2011	Modelled data	2011
	Global Distributions of Habitat Suitability for Cold-Water Octocorals		2012-2012	Modelled data	2012
Mangrove	Global Mangrove Watch	Polygon	1996-2016		2018
	Global Distribution of Modelled Mangrove Biomass	Polygon	2014-2014	Modelled data	2018
	World Atlas of Mangroves	Polygon	1999-2003	Empirical observation	2010
	Global Distribution of Mangroves USGS	Polygon	1997-2000	Empirical observation	2011
Seagrass	Global Distribution of Seagrasses	Polygon, point	1934-2015	Empirical observation	2017
	Global Seagrass Species Richness	Polygon		Metric	
	A Modelled Global Distribution of the Seagrass Biome	Polygon		Modelled data	
Saltmarsh	Global distribution of Saltmarshes	Polygon, point	1973-2015	Empirical observation	2017
Sea surface	Mean Sea Surface Productivity in June	Raster	2003-2007	Modelled data	2008
	Mean Sea Surface Productivity in December	Raster	2003-2007	Modelled data	2008
	Mean Annual Sea Surface Chlorophyll-a Concentration	Raster	2009-2013		2015
	Mean Annual Sea Surface Temperature	Raster	2003-2007	Empirical observation	2008
Sea animals	Global Distribution of Sperm Whales	Raster	2013-2013	Modelled data	2013

Dataset	Sub-dataset	Geometry type	Timespan	Data type	Publication date
	Global Distribution of Sei Whales	Point	2013-2013	Modelled data	2013
	Global Distribution of Bowhead Whales	Point	2013-2013	Modelled data	2013
	Global Distribution of Northern Bottlenose Whales	Point	2013-2013	Modelled data	2013
	Global Distribution of Atlantic Spotted Dolphins	Point	2013-2013	Modelled data	2013
	Global Distribution of Melon-Headed Whales	Point	2013-2013	Modelled data	2013
	Global Distribution of Hector's Dolphins	Point	2013-2013	Modelled data	2013
	Global Distribution of Grey Seals	Point	2013-2013	Modelled data	2013
	Global Distribution of Hawaiian Monk Seals	Point	2013-2013	Modelled data	2013
	Global Distribution of Northern Fur Seals	Point	2013-2013	Modelled data	2013
	Global Distribution of Sea Turtle Feeding Sites	polygon	1993-1993	Empirical observation	1999
	Global Distribution of Sea Turtle Nesting Sites	other	1949-1993	Empirical observation	1999
Others	Global Distribution of Seamounts and Knolls	Polygon, point	2011-2011	Modelled data	2011
	Global Estuary Database	polygon	2003-2003	Empirical observation	2003
	Global Patterns of Marine Biodiversity	polygon	1900-2009	Metric	2010
	Global Distribution of Dive Centres	Point		Empirical observation	2001
	Global Critical Habitat Screening Layer (Published) (Area of biodiversity importance)	Raster	2017-2017	Classification	2017
	Marine Ecoregions and Pelagic Provinces of the World (2007, 2012)	polygon	2007-2012	Classification	2015
	World Database on Protected Areas(Area of biodiversity importance)	Polygon, point			2016

Figure 6 Mapping major ecosystem datasets of Ocean+ Habitat Atlas



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3.4 **AquaMaps (08/2016)**

AquaMaps (https://www.aquamaps.org/) is a joint project of **FishBase** and **SealifeBase**. AquaMaps includes standardized distribution maps for over 25,000 species of fishes, marine mammals and invertebrates. These estimates of species preferences, called environmental envelopes, are derived from large sets of occurrence data available from online collection databases such as GBIF (Global Biodiversity Information Facility, www.gbif.org) and OBIS (Ocean Biogeographic Information System, www.obis.org), and from independent knowledge from the literature about the distribution of a given species and its habitat usage that are available in FishBase (and in SeaLifeBase and AlgaeBase for non-fish).

Six major environmental parameters are included in the dataset: depth, temperature, salinity, primary production, sea ice concentration and distance to land.

Depth: refers to the minimum and maximum cell bathymetry derived from ETOPO 2min negative bathymetry elevation; in meters.

Temperature:

- Observed mean annual surface and bottom sea temperature derived from NCEP SST Climatology (1982-1999); in degrees Celsius.
- Modeled current mean annual surface and bottom sea temperature from the IPSL Climate model SRES A2 (2001-2010); in degrees Celsius.
- Modeled 2100 mean annual surface and bottom sea temperature from the IPSL Climate model SRES A2 (2090-2099); in degrees Celsius.

Salinity:

- Observed mean annual surface salinity provided by the World Ocean Atlas (1982-1999); in PSU.
- Observed mean annual bottom salinity provided by the World Ocean Atlas Bottom Source Information (1990-1999); in PSU.
- Modeled current mean annual surface and bottom salinity from the IPSL Climate model SRES A2 (2001-2010); in PSU.
- Modeled year 2100 mean annual surface and bottom salinity from the IPSL Climate model SRES A2 (2090-2099); in PSU.

Primary Production:

- Proportion of annual primary production in a cell from http://seaaroundus.org/PrimaryProduction/Interpolation_method.htm ; in $mgC \cdot m^{-2} \cdot day^{-1}$.
- Modeled proportion of annual primary production in a cell from the IPSL Climate model SRES A2 (2001-2010); in $mgC \cdot m^{-2} \cdot day^{-1}$.
- Modeled year 2100 proportion of annual primary production in a cell from the IPSL Climate model SRES A2 (2090-2099); in $mgC \cdot m^{-2} \cdot day^{-1}$.

Sea Ice Concentration:

- Observed mean annual ice cover as derived from the National Snow and Ice Data Centre (1979-2002), http://nsidc.org/data/nsidc-0051.html ; in percent.
- Modeled current mean annual ice cover from the IPSL Climate model SRES A2 (2001-2010); in percent.
- Modeled year 2100 mean annual ice cover from the IPSL Climate model SRES A2 (2090-2099); in percent.

AquaMaps predictions of species distributions are generated in a two-step process. In the first step, maps are computer-generated using algorithm-derived input parameter settings based on occurrence data filtered with information on the distribution and habitat usage of a species (e.g., depth range, geographic range limits, environment occupied according to adult feeding or breeding behavior). In the second step, experts can review, edit and approve the computer-generated AquaMaps: Algorithm and Data Sources for Aquatic Organisms 2 maps. These expert-reviewed maps can, from then on, only be updated by experts. The computer-generated maps are updated every 1-2 years.

Both observed and modelled data are used in AquaMaps. All data can be downloaded as .csv files.

Figure 7 Marine AquaMaps Statistics

Marine AquaMaps Statistics

As of August 2015 we have:

- 22889 total maps for marine species
- 12068 marine fishes
- 118 marine mammals
- 10159 other marine metazoans (=Kingdom Animalia and not Fish and not Class Mammalia)
- 116 biodiversity maps by pre-defined phylogenetic groups
- 66 checklists by LMEs
- 240 checklists by country or island/territory

3.5 COPEPOD, the global plankton database

COPEPOD's global plankton database component (https://www.st.nmfs.noaa.gov/plankton/about/databases.html) provides an integrated data set of quality-reviewed, globally distributed plankton abundance, biomass and composition data. COPEPOD works closely with NOAA programs (e.g., the Fisheries And The Environment (FATE) and Integrated Ecosystem Assessment (IEA) programs) and a variety of international scientific organizations.

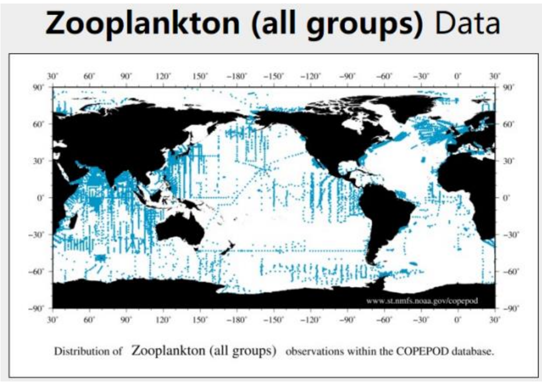
Three levels of data can be found in the database: (1) Raw Data Compilation, with many different methods and units; (2) Standardized Spatial Field, in-situ fields without interpolation or modelling, without missing-data or gap-filling; (3) Analyzed Spatial Field, modelled or interpolated gap filling.

All the data can be downloaded as ".csv" files with longitude and latitude coordinates, and they can be converted to Esri shapefiles. COPEPOD first went online in August of 2004. Full database content and method summaries are released roughly every few years (e.g. COPEPOD-2014, COPEPOD-2010, COPEPOD-2007, COPEPOD-2005), with new data content added each month.

Figure 8 Example of Zooplankton data from COPEPOD

Quick-Links to key COPEPOD elements:

- Access/Search the Database
  - search by geographic region
  - search by ship or cruise
  - search by project or program
  - search by institute or agency
  - search by country
  - search by investigator
  - see *Master Listing* of all data sets
- Interactive Plankton Atlas
  - Total Plankton Biomass (no speciation)
  - Zooplankton Taxa
  - Phytoplankton Taxa
  - *see also* COPEPEDIA for species distribution maps
- Global Biomass Fields
  - COPEPOD-2012 biomass fields
  - Moriarty & O'Brien 2013 biomass fields
  - Stromberg fields (*coming soon*)
  - *see also the* Spatial Fields *master topic*



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The Time Series Metabase is an information (i.e., "metadata") database providing details and graphical results from over 350 marine ecological time series. The Metabase contains investigator and project contact information, sampling and methods details, and a collection of standardized summary graphics for each time program.

3.6 OBIS (Ocean Biographic Information System)

OBIS (https://www.obis.org/) emanates from the Census of Marine Life (2000-2010) and was adopted as a project under IOC-UNESCO's International Oceanographic Data and Information (IODE) programme in 2009. More than 20 OBIS nodes around the world connect 500 institutions from 56 countries. Collectively, they have provided over 45 million observations of nearly 120 000 marine species, from Bacteria to Whales, from the surface to 10 900 meters depth, and from the Tropics to the Poles. The datasets are integrated so you can search and map them all seamlessly by species name, higher taxonomic level, geographic area, depth, time and environmental parameters.

3.7 BODC (British Oceanographic Data Centre)

As part of the UK's National Oceanography Centre, British Oceanographic Data Centre (BODC) provides instant access to over 130,000 unique data sets (https://www.bodc.ac.uk/data/bodc_database/nodb/search/). It provides International sea level, Historical BPR (bottom pressure recorder data) data, Argo floats, GEBCO's (see below) gridded bathymetric data, AMT CTD and underway, UK tide Gauge Network and Historical UK tide gauge data.

GEBCO's gridded bathymetric data sets are global terrain models for ocean and land. They are maintained and distributed by BODC on behalf of GEBCO. The GEBCO_2019 Grid is GEBCO's latest global terrain model at 15 arc-second intervals. The Grid is available to download as a global file in netCDF format, or for user-defined areas in netCDF, Esri ASCII raster or GeoTiff formats. (https://www.bodc.ac.uk/data/hosted_data_systems/gebco_gridded_bathymetry_data/)

3.8 GEBCO (General Bathymetric Chart of the Oceans)

GEBCO (General Bathymetric Chart of the Oceans) (https://www.gebco.net/) produces and makes available a range of bathymetric data sets and products. The dataset includes global gridded bathymetric data sets; the GEBCO Gazetteer of Undersea Feature Names; the GEBCO world map.

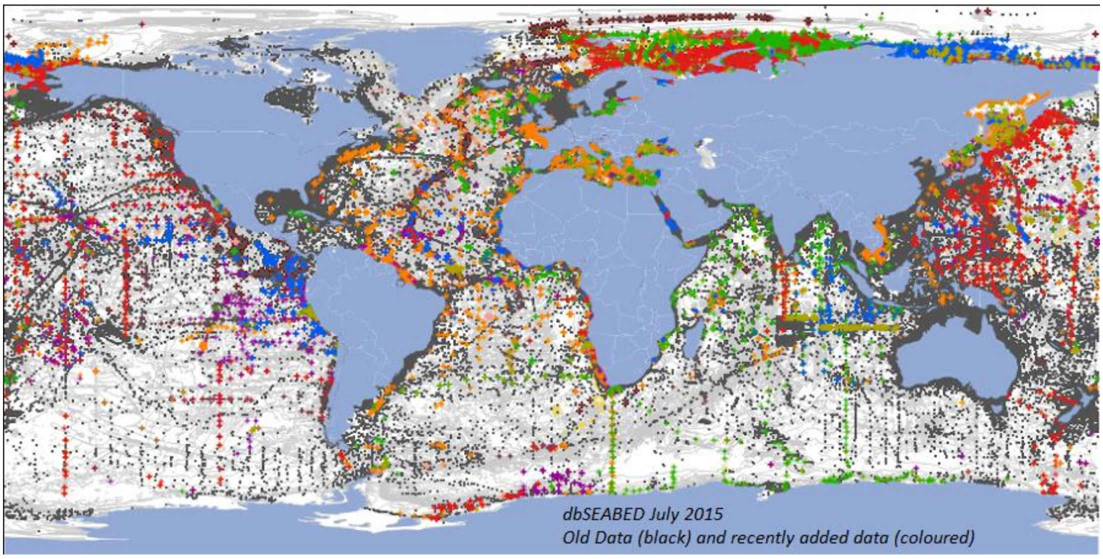
The gazetteer is available to view and download via a web map application, hosted by the International Hydrographic Organization Data Centre for Digital Bathymetry (IHO DCDB) co-located with the US National Centers for Environmental Information (NCEI). The data are available in a number of formats including spreadsheets, shapefile, KML, WMS and ArcGIS layer and can be accessed as a REST-style API.

Seabed 2030 is a collaborative project between the Nippon Foundation and GEBCO. It aims to bring together all available bathymetric data to produce the definitive map of the world ocean floor by 2030 and make it available to all.

3.9 **dbSEABED: Information Integration System for Marine Substrates**

dbSEABED (https://instaar.colorado.edu/~jenkinsc/dbseabed/) creates unified, detailed mappings of the materials that make the seafloor by efficiently integrating thousands of individual datasets. The goal is to bring decades of seabed information - and today's information - from marine geology, biology, engineering and surveys into one seabed mapping that can fulfill the community needs for ocean-bottom information on many spatial scales. The system deals with seabed texture, composition, acoustic properties, colour, geology and biology.

Figure 9 Point data distribution in dbSEABED 2015



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Huge data entry efficiencies come from programs that prepare the data for use in standard databases. As evidence of its efficiency, the US, Australian and global coverages together hold integrated data for over 3,000 datasets and 5 million described seafloor sites.

The scale of operation is local, national and global: shorelines, bays, seaways, national EEZ's, ocean basins, and worldwide. The database deals with coastal, estuarine, inshore, continental shelf, continental slope and very deep-sea environments.

dbSEABED is point-data based, so spatial resolution improves as more datasets are added. Gridded and vector mappings of the seafloor materials are computed from the point-data coverages. Accuracies are the same as for the original survey data; system precision is 1m; datum is WGS84.

The data is presented in the organization of a multidimensional cube, one dimension per parameter. Every parameter, not just the spatial data, can then be a dimension for query, retrieval, plotting. The hypercube structure has other benefits. It is not software-specific and can be imported into many analysis packages including Matlab, ArcGIS, ArcView, MS Access, GMT, OceanDataView. Access to the complete data is full and direct through the hypercube, or per-core through KML Google Earth.

Quality assurance is achieved by checks on data at data entry, by error-trapping in the data-processing software, and by working the data intensively in various collaborative research programs. dbSEABED was devised to be robust in an inexact and incomplete information environment - marine geosciences. An uncertainty budget is calculated with map outputs.

4 Findings and Recommendations

In summary, mapping global ocean ecosystem is feasible concerning the ocean ecosystem classification and data availability. For the classification system, CMECS is recommended to map global ocean ecosystem. For the datasets, coupling multiple datasets is practicable in creating the map. However, it is a very complicated and tough task partly due to the fluidity of most of the components in ocean ecosystem.

4.1 Recommendations on ocean ecosystem classification

4.1.1 Recommendations

CMECS is recommended to map global ocean ecosystem. CMECS is applicable to mapping global ocean ecosystem given that CMECS provides a means for classifying ecological units using a simple, standard format and common terminology. It has the following advantages.

(1) CMECS is compatible with relevant standards and based on most recent publications. CMECS is compatible with relevant U.S. FGDC-endorsed national standards. This compatibility is intended to facilitate studies across the transition between terrestrial and coastal aquatic ecosystems. Furthermore, CMECS draws from some of the most recent publications and studies. The three hierarchical categories of the Biogeographic Setting (BS) are based on the *Marine Ecoregions of the World* (MEOW) technique (Spalding et al., 2007). Water column and benthic environments are addressed in the classification. The principles guiding the MEOW approach were applied to oceanic benthic and water column settings and published as the *Global Open Oceans and Deep Seabed Biogeographic Classification* (GOODS) by scientists working under the aegis of UNESCO (United Nations Educational, Scientific and Cultural Organization) (UNESCO 2009).

(2) CMECS has a systematic and flexible framework composed of four components, two settings and multiple modifiers, which cover most of the water conditions, seafloor condition and biotic status. Furthermore, both the Biogeographic and Aquatic Settings and components can be extended according to the application areas.

(3) CMECS shows data-friendly features. CMECS allows investigators to determine the types of data to be collected. Its structure accommodates data from multiple disciplines at multiple spatial and temporal scales, and its use is not limited to

specific gear types or to observations made at specific spatial or temporal resolutions. Traditionally, spatial data have been organized and represented in four general formats: points, lines, polygons, and grids. Although CMECS has been focused on biological communities, CMECS units are very amenable to each of the major spatial data types.

(4) CMECS has been applied successfully in both U.S. coastal study and Australia after extension on the original structure. These application cases have approved CMECS's validity and extensibility.

4.1.2 **Challenges**

(1) Dynamic water column and biotic components at multiple temporal scales ranging from daytime to nighttime, month, season and climate change etc. CMECS recognizes that the seafloor and water column are dynamic. A given area of seafloor may be characterized differently over time. Users of CMECS are encouraged to identify all CMECS units present during an observation—regardless of their likely longevity. Any CMECS observation should be considered a "snapshot in time," in order to provide the most information.

(2) It is hard for collecting data at multiple time points or periods. It is hard for collecting data at one-time point or period given that very few or no fixed water columns maintain over time due to the fluidity of water, an ever-present transfer between ocean surface and atmosphere, etc.

(3) More application tests should be carried out and the results needing an assessment before global mapping. The application tests should be implemented both in coastal regions all around the world and at multiple scales with progressive details requirements. The necessary extensions should be clarified before global use.

4.2 **Recommendations on global datasets for integration**

On the one aspect, in most cases, one feature of ocean conditions (such as temperature, depth, etc.) is contained in multiple datasets. On the other aspect, an ocean dataset covers limited ecosystem components. Coupling multiple datasets are practicable in creating a global ocean ecosystem map.

(1) For data describing the water column, **WOA** is recommended as a reference. WOA is a relatively comprehensive global ocean dataset which is composed of multi formats: points, lines, polygons, and grids. Both observed data and modelled data are included in the datasets, both of which have passed quality control by the government or the experts. The data of multi-points in time can be downloaded from its website. The data contents focus on biochemical features of the ocean conditions that can be used with other databases, such as **Ocean+ by UNEP-WCMC** covering major ocean and coastal ecosystem distributions and conditions.

(2) For data related to the global ocean ecosystem, **Ocean+ by UNEP-WCMC** can be used. Ocean+ Habitat Atlas is to produce the first online, authoritative database on

the known extent of ecologically-important ocean habitats, such as seagrasses, warm- and cold-water corals, mangroves and salt marshes, and to update this database consistently over time.

(3) For data describing the geoform, GSHHG (Global Self-consistent, Hierarchical, High- resolution Geography Database) is recommended as a reference. GSHHG can provide data for mapping Beach, Beach Berm, Boulder Field, Bank, Shore and Shelf.

(4) For mapping the biotic, CMECS divided the biotic into Planktonic Biota Benthic/Attached Biota. The COPEPOD's global plankton database component and WOD Ocean Station Data (OSD) can provide Plankton data. NOAA's Deep Sea Coral Research and Technology Program (DSCRTP) CoRIS: Coral Reef Information System can provide reef biota data.

(5) For data describing the substrate, the dbSEABED, Information Integration System for Marine Substrates are suggested. dbSEABED is based on point data. This database includes seabed texture, composition, acoustic properties, color, geology and biology.

The distributions of many marine species (such as fish and plankton) are dynamic in space and time, and some movements made by individuals are regularly, while others are erratic. Mapping such mobile species is challenging. To solve this problem, we can use the relative probability of occurrence to show the range of the species. For example, the AquaMaps is a tool for generating model-based, large-scale predictions of natural occurrences of mobile species. The AquaMaps provides standardized range maps for marine species using available information on species occurrence.

The Ocean+ Habitat Atlas included some species range datasets, an example of global distribution of Sei Whales is shown in Figure 10. The dataset contains continuous probabilities of occurrence of Sei Whale as a global grid of 0.5° resolution.

Mapping marine conditions require a lot of data, which comes from different websites. Some of the recommended datasets can be found in Table 5. Furthermore, NOAA National Centers for Environmental Information provides lots of regional datasets, which can be used after a detailed review.

Table 6 shows an initial idea on linking CMECS and available global ocean ecosystem data, more detail should be discussed when creating a draft map. Table 7 shows the list for available datasets reviewed for mapping global ocean ecosystem.

An example of a global coral reef distribution map using CMECS and coral reef data from NCEI (https://www.ncei.noaa.gov/maps/deep-sea-corals/mapSites.htm) is shown in Figure 11.

Figure 10 Examples of expression methods for mobile species

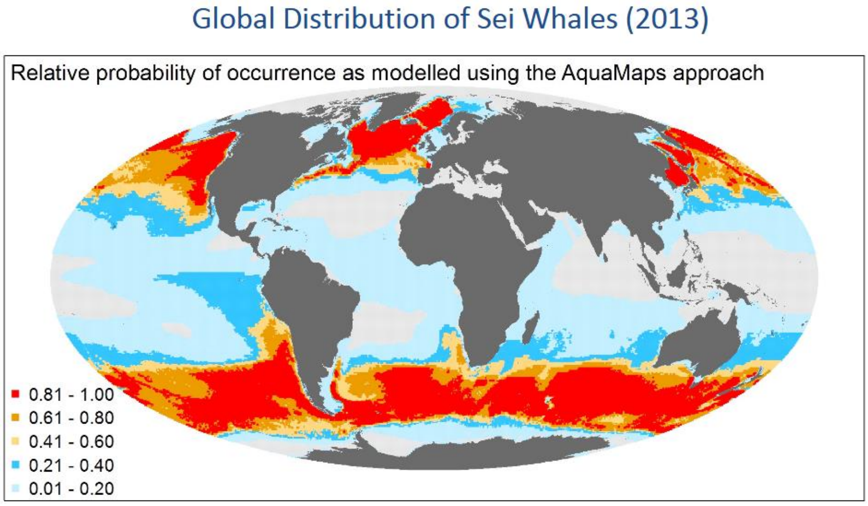

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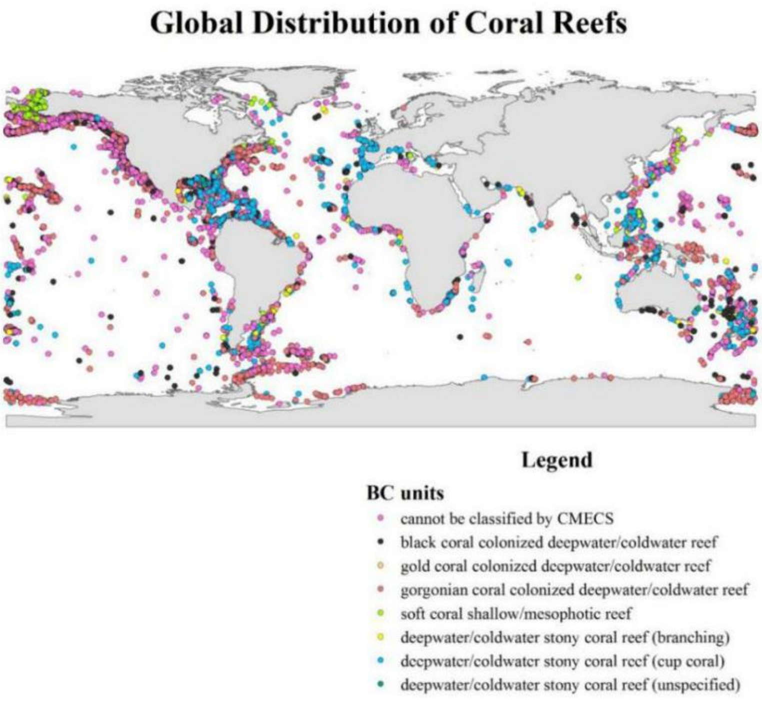
Figure 11 Example of global coral reef distribution using CMECS



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5 **Initial Work Plan**

(1) It is a must to determine the spatial and temporal scale and granularity when creating a draft map for the global ocean ecosystem. Thus, the primary issues should

be addressed, including minimum mapping unit, CMECS units used and date/time and duration of the study (to address temporal issues), etc. To some extent, it is determined by datasets. In turn, it will give requirements and guidance for datasets selection and coupling. This may need 1 person-month.

(2) Then, the potentially available datasets should be analyzed in detail and then some datasets at a certain spatial scale and time point are adopted. Ancillary data used to support the analysis also need to be determined (e.g. a bathymetric grid used to determine tidal zones). In this process, the example data need to be downloaded to clarify the quality of these data. This may take 1 person-month.

(3) Due to the gaps in the data format, spatial and temporal resolutions of various datasets, some preprocessing steps are needed to unify the datasets so that they can be combined to map land cover for the global ocean. Preprocessing steps include but not limited to format conversion, projection conversion, data correction and validation. It may take 1 person-month.

(4) To define a crosswalk from an existing system into CMECS is the best way to preserve the original data information and also support standard mapping, once the datasets are determined. It is important to note that successful crosswalking is dependent on an understanding of the parameters behind the original data development and equivalency between classification systems—not only at the unit definition level, but also in hierarchical context. 2 person-months are suggested.

(5) The last process should be linking CMECS and data at needed spatial and temporal scale. CMECS can organize data of different levels and scales. Using CMECS to classify all kinds of data, for integrated mapping. It may take 1 person-month.

Totally, six person-months are suggested for creating an initial test map. Furthermore, workshops on CMECS training and major datasets introduction are essential for research team to achieve the goal of mapping global ocean ecosystem. And Pilot studies of the application of CMECS and the existing data for mapping typical regional ocean ecosystem are encouraged. For the workshop on CMECS training, researchers of CMECS development and application, experts in the field of the ocean ecosystem and ocean science should be invited. For the workshop on major ocean ecosystem data requirement and provision discussion, researchers from ocean science, ocean ecosystem data providers and managers in coastal regions (e.g. Asian Pacific, EU, etc.) are needed.

Table 6 A table of major CMECS components and suitable datasets

CMECS Setting/Component	Class	Subclass	Datasets	Datasets description
BS Biogeographic Setting	Arctic Temperate Northern Atlantic Temperate Northern Pacific Tropical Atlantic Central Indo-Pacific Eastern Indo-Pacific			
AS Aquatic Setting	Lacustrine Estuarine Marine			
WC Water Geoform	Water Column Layer			
	Salinity Regime	Oligohaline Water Mesohaline Water Lower Polyhaline Water Upper Polyhaline Water Euhaline Water Hyperhaline Water	The Global Temperature and Salinity Profile Programme (GTSPP)	ASCII,netCDF,Best Copy Data Sets; update at least once a month; 1990-Present; global

CMECS Setting/Component	Class	Subclass	Datasets	Datasets description
	Temperature Regime	Frozen/Superchilled Water Very Cold Water Cold Water Cool Water Moderate Water Warm Water Very Warm Water Hot Water Very Hot Water	Group for High Resolution SST (GHRSST) AVHRR Pathfinder Satellite Data	netCDF (netCDF-4 classic),PNG ; update twice a day; 1981-Present ; resolution:4km; global
	Hydroform Class	current	Global Ocean Currents Database (GOCD)	generated by NCEI, sufficient quality control , spans 1962 to 2013 NetCDF) format
		wave	NOAA Marine Environmental Buoy Database	F291, netCDF format contains wave height, wave period and wave spectrum data, originate from National Data Buoy Center (NDBC) real-time data(Last updated July 16, 2019)
		Front, Water		

CMECS Setting/Component	Class	Subclass	Datasets	Datasets description
	Biogeochemical Feature	nutrition chlorophyll oxygen .etc	World Ocean Dataset(WOD)	WOD native ASCII format、CSV、netCDF; update per 3-5 years;
GC Geoform Component	Tectonic Setting			
	Physiographic Setting			
	Geoform	Beach Beach Berm Boulder Field Bank Shore Shelf	GSHHG(Global Self-consistent, Hierarchical, High-resolution Geography Database)	amalgamated from two databases: World Vector Shorelines (WVS) and CIA World Data Bank II (WDBII) Shapefiles (polygons,lines) ,Native binary files; Uncertain update interval ; five resolutions: crude(c), low(l), intermediate(i), high(h), and full(f)
		Shallow/Mesophotic Coral Reef	NOAA Global Distribution of Coral Reefs	Vector (polygon; .shp),KML,WMS 1954-2009,global ;
		Deep/Cold-Water Coral Reef	NOAA's Deep Sea Coral Research and Technology Program (DSCRTP) CoRIS: Coral Reef Information System	point data with species and depth .etc information of coral reef ; provided format : html, csv, json, kml ;
		.etc		
	Geologic Substrate		dbSEABED	

CMECS Setting/Component	Class	Subclass	Datasets	Datasets description
SC Substrate Component	Biogenic Substrate			tables which can be imported into practically any GIS, Continuous updating Point-data based
	Anthropogenic Substrate			
BC Biotic Component	Planktonic Biota	Zooplankton, Floating/Suspended Plants and Macroalgae, Phytoplankton, Floating/Suspended Microbes.	WOD Ocean Station Data(OSD) Plankton	WOD native ASCII format、CSV、netCDF; 1800,1900-2017;
			COPEPOD's global plankton database component	globally distributed plankton abundance, biomass and composition data ; Full databaseare released roughly every few years new data content added each month.
	Benthic/Attached Biota	Reef Biota	NOAA's Deep Sea Coral Research and Technology Program (DSCRTP) CoRIS: Coral Reef Information System	point data with species and depth .etc information of coral reef ; provided format : html, csv, json, kml ;
		Aquatic Vegetation Bed	UNEP WCMC Ocean+ seagrass	1:1000000;1934-2015;Vector (polygon，point; .shp),Uncertain update interval
		Forested Wetland	Global Distribution of Mangroves USGS;	1999-2003 , global , 30m
			World Atlas of Mangroves	1997-2017 , global , 1:1000000

Table 7 A brief list for available datasets reviewed for mapping global ocean ecosystem

Class	Dataset	Website	Organization	Metadata	Format	Version	Update	Time span	Resolution/ scale	Extent
Mangroves	Global Distribution of Mangroves USGS	http://data.unep-wcmc.org/datasets/4	UNEP-WCMC	TRUE	Vector (polygon; .shp)	Version 1.3 (June 2015)	not being updated	1997-2000	30 m	global
	World Atlas of Mangroves	http://data.unep-wcmc.org/datasets/5	UNEP-WCMC	TRUE	Vector (polygon; .shp),KML,WMS	Version 3.0 (June 2018)	not being updated.	1999-2003	1:1,000,000	global
	Global Mangrove Watch	http://www.eorc.jaxa.jp/ALOS/en/kyoto/mangrovewatch.htm	UNEP-WCMC	TRUE	Vector (polygon; .shp),WMS	Version 2.0	updated on a yearly basis	1997-2017	0.8 arc seconds	global
Seagrasses	Global Distribution of Seagrasses	http://data.unep-wcmc.org/datasets/7	UNEP-WCMC	TRUE	Vector (polygon,point; .shp),KML,WMS	Version 6.0 (June 2018)	updated in intervals that are uneven in duration	1934-2015	1:1,000,000	global

Class	Dataset	Website	Organization	Metadata	Format	Version	Update	Time span	Resolution/ scale	Extent
Coral Reefs	Global Distribution of Coral Reefs	http://data.unep-wcmc.org/datasets/1	UNEP-WCMC	TRUE	Vector (polygon; .shp),KML,WMS	Version 3.0 (June 2018)	Corrections are made on an ad-hoc basis	1954-2009	Variable	global
Coral	Global Distribution of Cold-water Corals	http://data.unep-wcmc.org/datasets/3	UNEP-WCMC	TRUE	Vector (polygon,point ; .shp) , KML,WMS	Version 5.0 (June 2018)	Data are updated in intervals that are uneven in duration	1915-2014	Variable	global
Plankton	WOD OSD dataset	https://www.nodc.noaa.gov/cgi-bin/OC5/SELECT/dbextract.pl	NOAA	TRUE	WOD native ASCII format,CSV,netCDF	WOD18	Updating with WOD	1963-1998		global
Sealife	AquaMaps 45 million observations of nearly 120	https://www.aquamaps.org/								

Class	Dataset	Website	Organization	Metadata	Format	Version	Update	Time span	Resolution/ scale	Extent
	000 marine species									
Shoreline	GSHHG(Global Self-consistent, Hierarchical, High-resolution Geography Database)	https://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html	NOAA NCEI	FALSE	Shapefiles (polygons,lines) ,Native binary files.	version 2.3.7 (June 15, 2017)	being updated	Unknown	five resolutions: crude(c), low(l), intermediate(i), high(h), and full(f)	global
	NOAA Medium Resolution Shoreline	https://shoreline.noaa.gov/data/datasheets/medres.html	NOAA	FALSE	Shapefiles (polygons,lines)				Average scale of 1:70,000	Regional:Continental U.S.
	Prototype Global Shoreline	https://dnc.nga.mil/PrototypeGSD.php	NGA	\	ESRI shapefiles.(seamless polyline files)				1:75,000 and smaller	Global . except the polar regions
Temperature	AVHRR Pathfinder SatelliteData	https://www.ghrsst.org/	NOAA NCEI GHRSST	FALSE	netCDF (Version: netCDF-4 classic) PNG	version 5.3	daily update(twice)	1981-Present	4km	Global

Class	Dataset	Website	Organization	Metadata	Format	Version	Update	Time span	Resolution/ scale	Extent
Salinity	The Global Temperature and Salinity Profile Programme (GTSPP)	https://www.nodc.noaa.gov/GTSPP/	NOAA NCEI	FALSE	ASCII ; netCDF;Best Copy Data Sets		three times a week ; every Sunday ; about the 7th of each month	1990-Present	Unknown	global
	Argo data	https://www.nodc.noaa.gov/argo	The U.S. NODC	FALSE	netCDF,GADR-3.0		being updated	2000-Present		global
Bathymetry	GEBCO, global gridded bathymetric data sets; the GEBCO Gazetteer of Undersea Feature Names; the GEBCO world map	https://www.gebco.net/	IHO DCDB co-located with theNCEI.	FALSE	spreadsheet, shapefile, KML, WMS ,netCDF , Esri ASCII raster or GeoTiff formats	latest version: GEBCO _2019	being updated	Unknown	grid intervals:15 arc-second	global

Class	Dataset	Website	Organization	Metadata	Format	Version	Update	Time span	Resolution/ scale	Extent
	Global Relief Model, ETOPO1	https://www.ngdc.noaa.gov/mgg/global/global.html	NOAA	FALSE	netCDF, georeferenced tiff		Unknown	Unknown	grid intervals:1 arc-minute	global
Substrate	dbSEABED,Information Integration System for Marine Substrates	https://instaar.colorado.edu/~jenkinsc/dbseabed/		FALSE	Point-data based		keep updating	Unknown	spatial resolution improves as more datasets are added	global