Ocean Accounts

Feasibility Study

for Mapping Global Ocean Ecosystems

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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 Standard¹ (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.

Biogeographic Setting (BS)	Aquatic Setting (AS)	Water Column Component (WC)	Geoform Component (GC)	Substrate Component (SC)	Biotic Component (BC)
()		Layer Subcomponent	Tectonic Setting Subcomponent	Substrate Origin Substrate Class Substrate Subclass Substrate Group	Biotic Setting Biotic Class Biotic Subclass Biotic Group
		Salinity Subcomponent	Physiographic Setting Subcomponent	Substrate Subgroup	Biotic Community
Realm Province Ecoregion	System Subsystem Tidal Zone	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			

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

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).

•	Contents					
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				Eastern Bering Sea		
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				Gulf of Maine/Bay of Fundy		
				Virginian		
			Warm Temperate Northwest Atlan	tic Carolinian		
	Tana anta M	ath any Decific	Cold Torresta North and David	Northern Gulf of Mexico		
	Temperate No		Cold Temperate Northeast Facilit	Gulf of Alaska		
				North American Pacific Fijordland		
DC				Puget Trough/Georgia Basin		
82				Oregon, Washington, Vancouver Coast and Shelf Northern California		
				Southern California Bight		
	Tropical Atlan	tic	Tropical Northwestern Atlantic	Eastern Caribbean		
				Greater Antilles		
				Southwestern Caribbean		
	Central Indo F	Pacific	Tropical Northwestern Pacific	Mariana Jelande		
	Central Indo-Pacific		Hawaji	Manana Islands		
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Table 2 A table of main CMECS components

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	Water Column Layer		Salinity Regime	Temperature Reg	jime	Hydroform Class		Hydroforn	n	Hydroform Type	Bioge	eochemica	al Feat
	Estuarine Coastal Surface Layer Estuarine Coastal Linner Water Column		Oligohaline Water Mesohaline Water	Frozen/Superchilled Wat	ter	Current	Boundary	/ Current		Eastern Boundary Current Western Boundary Current	Benthio	Boundary La	iyer
	Estuarine Coastal Upper Water Column Estuarine Coastal Pycnocline		Lower Polyhaline Water	Cold Water			Buoyano	y Flow		Downwelling	Chloroo	iy Layer hyll Maximur	n
	Estuarine Coastal Lower Water Column		Upper Polyhaline Water	Cool Water				teres?		Upwelling	Chlorop	hyll Minimum	i na i i
	Estuarine Open Water Surface Layer Estuarine Open Water Upper Water Column		cunaine Water Hyperhaline Water	Woderate Water			Deep Bo	weander undary Current			Urifting	Herbaceous	Debris
	Estuarine Open Water Pycnocline			Very Warm Water			Deep Cir	culation		Abyssal Deep Circulation	Drifting	Trees	_
	Estuarine Open water Lower Water Column Estuarine Tidal Riverine Coastal Surface Layer			Very Hot Water						Bathyl Deep Circulation	Euphoti	viocay Deb c Zone	<u>a</u>
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	Estuarine Tidal Riverine Coastal Lower Water Colum	10					Ekman F	low		Ekman Upwelling	Lysoch	ne	_
	Estuarine Tidal Riverine Open Water Surface Layer Estuarine Tidal Riverine Open Water Upper Water C	olumn					Inertial C	urrent		Ekman Downwelling	Marine 3 Microlay	Snow Aggreg /er	ation
	Estuarine Tidal Riverine Open Water Pycnocline						Langmuir	Circulation		Nanth Freestanded Roch	Nephelo	oid Layer	
	Estuarine Tidal Riverine Open Water Lower Water C Marine Nearshore Surface Layer	olumn					Mean Su	rface Current		North Equatorial Surface Current South Equatorial Surface Current	Neustor	nic Layer t Maximum	
	Marine Nearshore Upper Water Column						Mesosca	le Eddy		Cold Core Ring	Nutrient	t Minimum	
	Marine Nearshore Pychooline Marine Nearshore Lower Water Column						Residual	Current		Warm Core Ring Fiord Circulation	Oxygen	Maximum	
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	Marine Offshore Lower Water Column									Well-mixed Domain	Seep	_	_
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	Marine Oceanic Epipelagic Pychocline				_		Tidal Flov	w		Diurnal Tidal Flow	Thermo	cline	
	Marine Oceanic Epipelagic Lower Layer Marine Oceanic Mesopelagic Layer				_					Mixed Semi-diurnal Tidal Flow Semi-diurnal Tidal Flow	Turbidity	y Maximum	
	Marine Oceanic Bathypelagic Layer				_		Turbidity	Flow					_
	Marine Oceanic Abyssopelagic Layer Marine Oceanic Hadalnelagic Layer		-				Wave-dri	iven Current		Longshore Current Rin Current			
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	Fradure Zone Spreading Center M4-Ocean Ridge Passike Contental Margin Transform Continental Margin Tectonic Trench	Borderla Continer Continer Continer Continer Embaym Fjord Inland/EL Lagoona Major Ri Marine B Ocean B Riverine Shelf Ba Shelf Bre	nd talifsland Rise talifsland Shorf talifsland Shore Comple: talifsland Shore Comple: talifsland Slope ent/Bay nclosed Sea Estuary er Delta asin Floor ank/Plateau Estuary sin ak		Basin Beac Beac Bould Cave Chan	h Berm Jer Field Inel		X X X X X X	x x x x	Bay Mount Bai Longahore Bar Point Bar Relict Longshore Bar Barrier Beach Mainland Beach Pocket Beach Tide-Modified Beach Wave-Dominated Beach Wave-Dominated Beach Wave-Dominated Beach Pass/Lagoon Channel Pass/Lagoon Channel		x x x x x x	
	Fracture Zone Spreading Center Md-Ocean Ridge Passive Continental Margin Transform Continental Margin Tectonic Trench	Borderla Borderla Continer Continer Embaym Fjord Inland/E Lagoona Major Ri Marine B Ocean B Riverine Shelf Ba Shelf Bre Sound	nd ttal/lisent Rise ttal/siend Shorf ttal/siend Shore Comple: ttal/siend Slope ent/Day hclosed Sea I Estuary er Delta asin Floor ank/Piateau Estuary sin ak		Basin Bead Bead Bould Cave Chan	n h Berm Jer Field Inel		X X X X X X	x x x x x x	ear action East Longahote Bar Point Bar Reitel Longahote Bar Reitel Longahote Bar Reitel Longahote Bar Marinand Beach Pocket Beach Tide-Modified Beach Tide-Modified Beach Tide-Modified Beach Tide-Modified Beach Pass Lagoon Channel Sand Channel Sand Channel		x x x x x x	
	Fradure Zone Spreading Center Md-Ocean Ridge Passive Continental Margin Transform Continental Margin Tectonic Trench	Borden Borden Continer Continer Continer Embaym Fjord Inland/Ei Lagoona Major Ri Marine B Ocean B Riverine Shelf Ba Shelf Bre Sound Submari Trench	nd tablistand Rise tablistand Sheff tablistand Shoref tablistand Shoree Complex tablistand Slope enWBay Licstuary en Costed Sea Licstuary en Delta asin Floor ank/Plateau Estuary estuary ak ne Canyon		Basin Beac Beac Bould Cave Chan	n h h Berm fer Field nnel		X X X X X X	x x x x x	Bay Mould Bal Longshore Bar Point Bar Relict Longshore Bar Relict Longshore Bar Barter Beach Point Beach Point Beach Point Beach Point Beach Waiv-Dominated Beach Waiv-Dominated Beach Waiv-Dominated Beach Sand Channel Sand Channel Sand Channel Creek		x x x x x x x x x x	
	Fradrite Zone Spreading Center Md-Ocean Ridge Passve Continental Margin Transform Continental Margin Tectonic Trench	Borden Borden Continer Continer Continer Embaym Fjord Inland/En Lagoona Major Ri Marine B Ocean B Riverine Sheff Bra Sound Submari Trench	nd MalvBland Rise MalvBland Shef Nature Complex HalvBland Shore Complex HalvBland Shope envtBay Inclosed Sea Estuary exr Delta asin Floor ank/Flateau Estuary sin Ak Ancomplex Estuary sin Ak		Bar Basin Beac Beac Bould Cave Chan Cone Cove	n h b Berm der Field nel		x x x x x x x x x x	x x x x x x	Elongabilitation Elongabilitation Control Bar Relict Longabore Bar Barrier Deach Mainfand Beach Pocket Beach Tide-Dominated Beach Tide-Dominated Beach Wave-Dominated Beach Wave-Dominated Beach Pase Lagoon Channel Stough		x x x x x x x x x x x x x	
	Fracture Zone Spreading Center Md-Ocean Ridge Passive Continental Margin Transform Confinental Margin Tectonic Trench	Borderta Continer Continer Continer Embayn Fjord Inland/Ei Lagoona Major Riv Marine B Ocean B Riverine Shelf Ba Shelf Ba Shelf Ba Sound Submari Trench	nd Haldsland Rise Haldsland Sheff Haldsland Shore Complet Haldsland Slope ent/Bay Lifethary Estuary er Detta asin Floor ank/Plateau Estuary ak he Catyon		Bar Basin Bead Bead Cave Chan Cone Cove	n h b Berm der Field nel		X X X X X X X X X	x x x x x x x x	Ear Addit Ear Form Bar Reid Longhhore Bar Reid Longhhore Bar Reid Longhhore Bar Barrier Beach Marinard Beach Poolet Beach Tide-Modified Beach Tide-Modified Beach Tide-Modified Beach Tide-Modified Beach Pass IL agoon Channel Sand Channel Sand Channel Sand Channel Barrier Cove Mainland Cove		x x x x x x x x x x x x x x x x x	
	Fradrie Zone Spreading Center Md-Ocean Ridge Passive Continental Margin Transform Continental Margin Tectonic Trench	Borderla Borderla Continer Continer Embaym Fjord Inland/E Lagoona Major Ri Marine B Ocean B Riverine Shelf Ba Shelf Bre Sound Submari Trench	nd tablistind Rise tablistind Sheff tablistind Sheff tablistind Sheff tablistind Shop tablistind Shop tablistind Shop tablistind Debata and Debata and Deb		Basin Beac Beac Boulc Cave Chan Cone Cove	n h Berm Ser Field inel		X X X X X X X X X X	x x x x x x x x	eary adduit self Longshore Bar Point Bar Relict Longshore Bar Relict Longshore Bar Maintand Beach Potet Beach Potet Beach Tide-Modified Beach Wave-Dominated Beach Wave-Dominated Beach Wave-Dominated Beach Wave-Dominated Beach Wave-Dominated Beach Maintand Cove Stough Maintand Cove Gascal (Kame) Detta		x x x x x x x x x x x x x x x x x	
	Fracture Zone Spreading Center Md-Ocean Ridge Passive Continental Margin Transform Continental Margin Tectonic Trench	Borderta Borderta Continer Continer Embaym Fjord Inland/E Lagoona Major Ri- Marine B Ocean B Riverine Sheff Bre Sound Submari Trench	nd Italistand Rise Italistand Sheff Italistand Shore Completion Italistand Slope em/Bay Indosed Sea I E stuary I E stuary ex Detta asin Floor ank/Plateau E stuary ak ne Canyon		Basin Beacl Beacl Boulc Cave Cave Cave Cone Cove	h Berm h Berm Jer Field h		x x x x x x x x x x x x	x x x x x x x x x	eary account ease and account ease prover Bar Relicit Longshore Bar Relicit Longshore Bar Relicit Longshore Bar Barner Deach Pocket Beach Tide-Modified Beach Tide-Modified Beach Tide-Modified Beach Wave-Dominated Beach Wave-Dominated Beach Pass Alagoon Channel Sand Channel Sand Channel Sand Channel Sand Channel Sand Channel Sand Channel Sand Channel Barter Coce Matriand Core Colegiat (Kinne) Delta Ebb Tida Delta Ebb Tida Delta		x x x x x x x x x x x x x x x	
	Fradrie Zone Spreading Center Md-Ocean Ridge Passive Continental Margin Transform Confinental Margin Tectoric Trench	Borderic Borderic Continer Continer Continer Embaym Fjord Inland/E Lagoona Major Ri- Marine B Ocean B Riverine Shelf Bre Sound Submari Trench	nd tablistand Rise tablistand Sheff tablistand Shero Complex tablistand Shoro Complex tablistand Shoro Complex tertore tablistand Shoro tertore ter		Basin Beacl Beacl Boulc Cave Chan Cone Cove	h h Berm der Field innel		x x x x x x x x x	x x x x x x x x	Ear Audon East Longshote Bar Point Bar Relict Longshote Bar Relict Longshote Bar Relict Longshote Bar Maniard Beach Postet Beach Tide-Modified Beach Tide-Modified Beach Tide-Modified Beach Wave-Dominated Beach Wave-Dominated Beach Pass/Lagoon Channel Sand Channel Sand Channel Sand Channel Channel/Creek Barrier Cove Miariand Cove Glacati (Karne) Delta Ebb Tridal Delta Flood Tridal Delta Flood Tridal Delta Flood Tridal Delta Flood Tridal Delta		x x x x x x x x x x x x x	
	Pradruž Zone Spreading Center Md-Ocean Ridge Passve Continental Margin Transform Continental Margin Tectonic Trench	Borderic Borderic Continer Continer Continer Embaym Fjord Inlander Lagoona Major Ri Marine B Ocean B Riverine Sheff Ba Sheff Ba Sheff Ba Sheff Ba Shuff Ba	nd Italisland Rise Italisland Sheff Italisland Shefe Complex Italisland Slope emBay Inclosed Sea I Estuary er Cetta asin Floor ani/Fulseau Estuary asin ne Canyon		Bar Basir Bead Bould Cave Chan Cove	n h Berm Ger Field nei		x x x x x x x x x x	x x x x x x x x x	ear oroxin East Chrom Bar Relict Longshore Bar Relict Longshore Bar Barner Deach Mainland Beach Pooket Beach Tide-Dominated Beach Tide-Dominated Beach Wave-Dominated Beach Wave-Dominated Beach Bart (Lagoon Channel Sand Channel Sand Channel Sand Channel Sand Channel Cladat (Kame) Delta Ebb Tidat Delta Flood Tidat Delta Flood Tidat Delta Flood Tidat Delta Flood Tidat Delta		x x x x x x x x x x x x x x x x x x x	X X X X X X X X X X X X X X X X X X X
	Fracture Zone Spreading Center Md-Ocean Ridge Passive Continental Margin Transform Continental Margin Tectonic Trench	Borderia Borderia Continer Continer Continer Embaym Fjord Inland/E Lagoona Major Ri Nearine B Ocean B Riverine Sheff Bra Sound Submari Trench	nd Hallsland Rise Hallsland Sheff Hallsland Shore Complet Hallsland Slope em/Bay I Estuary Estuary ex Detta asin Floor ank/Plateau Estuary ak ne Canyon		Bar Basin Bead Bould Cave Chan Core Core Delta	n h Berm der Field annel		x x x x x x x x x x x x x x x x x	x x x x x x x x	ear Addit Bar Hong Bor Relici Long hore Bar Relici Long hore Bar Relici Long hore Bar Barrier Beach Marinard Beach Pockel Beach Tide-Modified Beach Tide-Modified Beach Tide-Modified Beach Wave-Dominated Beach Wave-Dominated Beach Pass Lagoon Channel Sand Channel Sand Channel Sand Channel Barrier Cove Giacali (Kamo Detta Flood Tida Detta Speet Beats		x x x x x x x x x x x x x x x x	
	Practure Zone Spreading Center IM4-Ocean Ridge Passive Continental Margin Transform Continental Margin Tectonic Trench	Borderia Borderia Continer Continer Continer Continer Embaym Fjord Inland/E Lagoona Major Rix Mairne B Ocean B Riverine Sould B Submari Trench	nd tablistand Rise tablistand Sheff tablistand Shere Complex tablistand Shore Complex tablistand Shore Complex tablistand Shope entBay LiEstuary exc Detta asin Piorr and/Piateau Estuary exc Detta asin Piorr and/Piateau Estuary exc Detta asin ne Canyon		Bar Basin Beacl Boulc Cave Cave Cave Cave Cave Cave Cave Cave	n h der Field anel Plain r Flain ession ir		x x x x x x x x x x x x x x	x x x x x x x x x x x	Bay addition Bai Longshote Bar Point Bar Relicit Longshote Bar Relicit Longshote Bar Relicit Longshote Bar Marinard Basch Trode Modified Basch Tide-Dominated Beach Tide-Dominated Beach Wave-Dominated Beach Wave-Dominated Beach Wave-Dominated Beach Wave-Dominated Beach Pass/Lagoon Channel Sand Channel/Creek Barnier Cove Miarinard Cove Gladati (Karne) Delta Ebb Tidal Delta Flood Tidal Delta Flood Tidal Delta Flood Tidal Delta Flood Tidal Delta Flood Tidal Delta Scour Depression Scatt Depression		x x x x x x x x x x x x x x x x x	x x x x x x x x x x x x x x x x x x x
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	Pradruž Zone Spreading Center Md-Ocean Ridge Passve Continental Margin Transform Continental Margin Tectonic Trench	Borderla Borderla Continer Continer Continer Continer Figrd Inland/E Lagoona Major Ri Marine B Ocean B Riverine Sheff Bra Sheff Bra Sheff Bra Sheff Bra Sheff Bra	nd Italisland Rise Italisland Sheff Italisland Sheff Italisland Slope emBay Inclosed Sea IEstuary er Oetla asin Floor ani/Fulstau Estuary en Catyon ne Canyon		Bar Basir Bead Bead Bead Cave Chan Cone Cone Cone Delta Delta Depri Dike Drum Dune	h h Berm Jer Field Plain ession r vin Field Field		x x x x x x x x x x x x x x x x x x x	X X X X X X X X X X X X X	Bar octobil Bale Control Bar Relict Longshore Bar Relict Longshore Bar Barrier Geach Mainland Beach Pocket Beach Tide-Dominated Beach Tide-Dominated Beach Wave-Dominated Beach Wave-Dominated Beach Pass (Lagoon Channel Sand Channel Sand Channel Sand Channel Sand Channel Creek Barrier Cove Mainland Cove Glacati (Kame Joella Ebb Tidal Delta Flood Tidal Delta Flood Tidal Delta Scour Depression Salt Dome		x x x x x x x x x x x x x x x x x	
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cologic Substrate	Rock Substrate	Bedrock	συροτιατα στουρ	Substrate SubGroup
		Megaclast		
	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel	Boulder
				Cobble
				Pebble
				Granule
			Gravel Mixes	Sandy Gravel
				Muddy Sandy Gravel
				Muddy Gravel
			Gravelly	Gravely Sand
				Gravely Muddy Sand
				Gravely 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	Sity Sand
				Sity-Clayey Sand
				Clavey Sand
			Sandy Mud	Sandy Silt
				Sandy Silt-Clay
				Sandy Clay
			Mud	Sit
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		naiouoliur Suosu ale	Dhodolith Hash	
			Dhadalih Sand	
	Coral Substrate	Coral Paaf Substrate	Rinddollan Sand	
	Coral Substrate	Corel Rubble		
		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		
	Onze Substrate	Carbonate Onze	Concerning the second second	
			Foraminiferan Ooze	Globigerina Ooze
		Siliceous Ooze	Pteropod Ooze Diatomaceous Ooze Diatomaceous Ooze Diatomaceous Ooze Diatomaceous Ooze	Globigerina Ooze
		Siliceous Ooze	Peropod Ooze Patomaceous Ooze Diatomaceous Ooze Radiolarian Ooze	Globigerina Ooze
	Shell Substrate	Siliceous Ooze Siliceous Ooze Shell Reef Substrate	Foraminiferan Ooze Foraminiferan Ooze Pteropod Ooze Diatomaceous Ooze Radiolarian Ooze Clam Reef Substrate	Globigerina Osze
	Shell Substrate	Siliceous Ooze Shell Reef Substrate	Foraminiferan Ooze Peraminiferan Ooze Peropod Ooze Radolarian Ooze Clam Reef Substrate Crepidula Reef Substrate	Globigerina Ooze
	Shell Substrate	Siliceous Ooze	Peraminiferan Oze Peraminiferan Oze Peraminiferan Oze Peropod Oze Datamaceous Oze Radiolarian Oze Cam Reef Substrate Crepidula Reef Substrate Mussel Reef Substrate	Globiperina Ocze
	Shell Substrate	Siliceous Ooze Shell Reef Substrate	Peropol Ooze Peropol Ooze Peropol Ooze Distomaceous Ooze Clam Reef Substrate Crepidula Reef Substrate Ususer Reef Substrate Ususer Reef Substrate Ususer Reef Substrate	Globigerina Ooze
	Shell Substrate	Siliceous Ooze Shell Reef Substrate	Peraminiferan Oze Peraminiferan Oze Peraminiferan Oze Peropod Oze Datomaceous Oze Radiolarian Oze Clam Reef Substrate Usussel Reef Substrate Usussel Reef Substrate Usussel Reef Substrate Usussel Reef Substrate	Globigerina Ooze
	Shell Substrate	Siliceous Ooze Shell Reef Substrate	Peraminiferan Ooze     Peraminiferan Ooze     Peropod Ooze     Radiolarian Ooze     Cam Reef Substrate     Crepidua Reef Substrate     Oyster Reef Substrate     Oyster Reef Substrate     Cam Rubble     Cam Rubble	Globiperina Osze
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	Shell Substrate	Siliceous Ooze Shell Reef Substrate	Peraminiferan Oze Peraminiferan Oze Peraminiferan Oze Peropod Oze Datomaceous Oze Radiolarian Oze Cam Reef Substrate Oyster Reef Substrate Oyster Reef Substrate Clam Rubble Crepidula Rubble Crepidula Rubble	Globiperina Ocze
	Shel Substrate	Siliceous Ooze Shell Reef Substrate	Foraminiferan Ooze     Foraminiferan Ooze     Peropod Ooze     Diatomaceous Ooze     Clam Reef Substrate     Creptulua Reef Substrate     Mussel Reef Substrate     Clam Rubbie     Creptulua Rubbie     Mussel Rubbie     Mussel Rubbie	Globiperina Osze
	Shell Substrate	Siliceous Ooze Shell Reef Substrate Shell Rubble	Peraminiferan Oze     Peraminiferan Oze     Peraminiferan Oze     Peropod Oze     Datomaceous Oze     Radiolarian Oze     Cam Red Substrate     Orster Red Substrate     Oyster Red Substrate     Oyster Red Substrate     Clam Rubble     Crepiziula Rubble     Mussel Red Subbrate     Oyster Rubble     Oyster Rubble     Oyster Rubble     Care Rubble     Oyster Rubble	Globigerina Ooze Coquina Reef Substrate Coquina Rubble Coquina Hash
	Shell Substrate	Siliceous Ooze Shell Reef Substrate Shell Rubble Shell Hash	Peraminiferan Ooze     Peraminiferan Ooze     Peraminiferan Ooze     Peropod Ooze     Radiolarian Ooze     Cam Reef Substrate     Crepidua Reef Substrate     Oyster Reef Substrate     Oyster Reef Substrate     Cam Rubble     Crepidua Rubble     Oyster Rubble	Globiperina Ocze Coquina Reef Substrate Coquina Rubble Coquina Rubble Coquina Hash
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	Shell Substrate	Siliceous Ooze Shell Reef Substrate Shell Rubble Shell Hash	Peraminiferan Oze Foraminiferan Oze Foraminiferan Oze Peropod Oze Distomeceous Oze Radiolarian Oze Cam Reef Substrate Crepidula Reef Substrate Oyster Reef Substrate Clam Rubble Crepidula Rubble Oyster Rubble Oyster Rubble Clam Hash Clam Hash Mussel Hash	Globiperina Ocze
	Shell Substrate	Silceous Ooze Shel Reef Substrate Shel Rubble Shel Hash	Concentration of the code     Forminiferan Ooze     Forminiferan Ooze     Peropod Ooze     Datomaceous Ooze     Radiolarian Ooze     Clam Reef Substrate     Mussel Reef Substrate     Mussel Reef Substrate     Crepidul Reef Substrate     Crepidul Reef Substrate     Crepidul Reef Substrate     Crepidul Reef Substrate     Control Control     Control Control     Control     Mussel Rubble     Crepidul Rash     Mussel Hash     Mussel Hash     Mussel Hash	Globigerina Ooze
	Shell Substrate	Shell Rash Shell Rash Shell Rash Shell Rash Shell Rash	Coloring the Voze     Foraminiferan Ooze     Foraminiferan Ooze     Peropod Ooze     Datomaceous Ooze     Radiolarian Ooze     Clam Reof Substrate     Oyster Reof Substrate     Oyster Reof Substrate     Oyster Reof Substrate     Clam Rubble     Crepicula Rubble     Carpital Rubble	Globigerina Coze
	Shell Substrate	Shell Rubble Shell Rubble Shell Rubble Shell Rubble Shell Rubble Shell Agand	Peraminiferan Ooze     Foraminiferan Ooze     Peropod Ooze     Diatomaccous Ooze     Radiokrain Ooze     Cam Reef Substrate     Orster Reef Substrate     Oyster Reef Substrate     Oyster Reef Substrate     Cam Rubble     Crepidula Rubble     Oyster Rubble     Oyster Rubble     Oyster Rubble     Oyster Rubble     Oyster Rubble     Clam Hash     Mussel Rash     Oyster Hash     Coguine Sand     Sand     Sand	Globigerina Ooze
	Shell Substrate	Shell Rubble Shell Sand Shell Sand	Concentingthere use     Foraminiferan Osze     Foraminiferan Osze     Peropod Osze     Radiolarian Osze     Radiolarian Osze     Clam Reef Substrate     Crepidua Heef Substrate     Crepidua Heef Substrate     Clam Rubble     Crepidua Heef Substrate     Crepidua Heash     Mussel Rubble     Crepidua Heash     Crepidula Hash     Crepidula Hash     Crepidula Hash     Cyster Hash     Coquina Sand     Sabellanid Reef Substrate     Capalina Sand     Sabellanid Reef Substrate	Globiperina Ooze
	Shell Substrate Worm Substrate	Shell Rubble Shell	Peraminiferan Oze     Foraminiferan Oze     Peropol Oze     Peraminiferan Oze     Paropol Oze     Radiolarian Oze     Radiolarian Oze     Clam Reef Substrate     Oyster Reef Substrate     Oyster Reef Substrate     Clam Rubble     Crepidula Rubble     Oyster Rubble     Oyster Rubble     Oyster Rubble     Oyster Hash     Mussel Hash     Mussel Hash     Coquina Sand     Sabelarid Reef Substrate     Sabelarid Reef Substrate	Globiperina Ocze
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Δnthronopenic Sub-trata	Vice Substrate Shell Substrate Worm Substrate Anthropogenic Reck	Siliceous Ooze Siliceous Ooze Shell Reef Substrate Shell Rubble Shell Rubble Shell Hash Shell Sand Sabellarid Substrate Serpuid Substrate Anthronopenio Bov/ Deaf Substrate	Coordination of the code     Foraminiferan Ooze     Foraminiferan Ooze     Peropod Ooze     Distomeceous Ooze     Radiolarian Ooze     Clam Reef Substrate     Crepidula Reef Substrate     Oyster Reef Substrate     Oyster Reef Substrate     Clam Rubble     Crepidula Rubble     Oyster Rubble     Clam Hash     Mussel Hash     Mussel Hash     Oyster Fash     Sabelarid Reef Substrate     Sabelarid Hash     Sabelarid Hash     Sapelarid Hash     Sapelarid Reef Substrate     Serpuid Rubble	Globiperina Ocze
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Anthropogenic Substrate	Vice Substrate Shell Substrate Worm Substrate Anthropogenic Rock Anthropogenic Wood	Shell Rubble Shell Rash Shell Rubble Shell Rubble Shell Rubble Shell Rubble Shell Sand Sabellariid Substrate Anthropogenic Rock Reef Substrate Anthropogenic Rock Rubble Anthropogenic Rock Sand Anthropogenic Rock Sand Anthropogenic Rock Sand Anthropogenic Rock Sand Anthropogenic Wood Rubble	Coccontribution oze Ferraminiferan Ooze Ferraminiferan Ooze Perraminiferan Ooze Radiolarian Ooze Radiolarian Ooze Claim Reef Substrate Crepidual Reef Substrate Calm Rubble Crepidual Reef Substrate Claim Rubble Claim Hash Crepidual Reash Mussel Flash Coquina Sand Sabelarid Rueb Del Sabelarid Rubble Sabelarid Ruash Serpuld Reaf Substrate Serpuld Rubble Serpuld Reash Serpuld Reash	Slobigerina Ooze  Coquina Reef Substrate  Coquina Rubble  Coquina Hash  Coquina Hash
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Biotic Setting	Biotic Class	Biotic Subclass	Biotic Group	Biotic Commun
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 Appregation
		Fish Meroplankton	Fish Spawning and Larval Aggregation	Damselfish Spawing and Larval Aggregation
				Grouper Spawning and Larval Appregation
				Surgeonfish Snawning and Larval Apprena
			Eish Larval Appreciation	Clupeid Larval Appreciation
				Engraulid Larval Apprenation
				Scieenid Larval Apprenation
		Gelatinous Zooplankton	Ctenophore Appreciation	Beroe Appregation
				Mnemiopsis Aggregation
				Pleurobrachia Appregation
			Jellyfish Aggregation	Aurelia Aggregation
				Chrysaora Apprenation
			Salp Appreciation	Thalia Aggregation
				Pegia Appreciation
			Siphonophore Appreciation	Baramannia Appregation
				Nanomia Angregation
				Physalia Appreciation
		Mixed Zooplankton	Mixed Zooplankton Aggregation	Chaetoonath Salo and Fish Larval Angrega
				Ctenophore Worm and Copepod Apprenatic
		Molluscan Holoplankton	Pteropod Appregation	Carolla Aggregation
				Clione Apprenation
		Molluscan Meroplankton	Veliger Aggregation	Bivalve Veliger Aggregation
				Gastropod Veliger Appregation
		Protozoan Holoplankton	Foraminiferan Appregation	Globigering Appregation Laver
			Radiolarian Appregation	Acantharea Appregation
				Polycistina A ggregation
		Worm Holoplankton	Chaetognath Appreciation	Elaccisagitta Aggregation
				Sagitta Aggregation
			Rolychaete Aggregation	Svilid 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 Ireland⁴. 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 (<u>http://www.cbics.org/</u>) 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 Bricher⁵ 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 attributebased 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)⁶are 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  $1/4^{\circ} \times 1/4^{\circ}$  for temperature and salinity, and  $1^{\circ} \times 1^{\circ}$  for oxygen, nitrate, phosphate, and silicate. Resolution  $1^{\circ} \times 1^{\circ}$  were downscaled to the  $1/4^{\circ}$  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.





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)** (<u>https://www.nodc.noaa.gov/OC5/WOD/pr</u>wod.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,  $\Delta$ 13Carbon,  $\Delta$ 14Carbon,  $\Delta$ 18Oxygen, Freon, Helium,  $\Delta$ 3Helium, 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 (<u>https://www.nodc.noaa.gov/OC5/WOD/</u>readwod.html) or ftp (<u>ftp.nodc.noaa.gov</u>)

Dataset	Content
080	Bottle, low resolution CTD (Conductivity, Temperature and Depth), and
030	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

Table 3	The main	sub-datasets	in WOD
---------	----------	--------------	--------

**WOA13** (<u>https://odv.awi.de/en/data/ocean/world-ocean-atlas-2013/</u>) 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.

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)

Table 4 The images in World Ocean Atlas 2013 V2

Figure 5 Sample map of WOA



Annual salinity at the surface (one-degree grid)

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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) (<u>http://data.unep-wcmc.org/</u>) 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

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.

Defeed	Out-defeed	0	<b>T</b> :	Dete fame	Public
Dataset	Sub-dataset	Geometry type	Timespan	Data type	date
	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
Coral reefs	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
	Global Mangrove Watch	Polygon	1996-2016		2018
	Global Distribution of Modelled Mangrove Biomass	Polygon	2014-2014	Modelled data	2018
Mangrove	World Atlas of Mangroves	Polygon	1999-2003	Empirical observation	2010
	Global Distribution of Mangroves USGS	Polygon	1997-2000	Empirical observation	2011
	Global Distribution of Seagrasses	Polygon, point	1934-2015	Empirical observation	2017
Seagrass	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
	Mean Sea Surface Productivity in June	Raster	2003-2007	Modelled data	2008
Sea	Mean Sea Surface Productivity in December	Raster	2003-2007	Modelled data	2008
surface	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

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

					Public
Dataset	Sub-dataset	Geometry type	Timespan	Data type	ation
	Clobal Distribution of Sai				date
	Whales	Point	2013-2013	Modelled data	2013
	Global Distribution of				
	Bowhead Whales	Point	2013-2013	Modelled data	2013
	Global Distribution of	Doint	2012 2012	Madallad data	2012
	Northern Bottlenose Whales	Point	2013-2013	modelled data	2013
	Global Distribution of Atlantic	Point	2013-2013	Modelled data	2013
	Spotted Dolphins	1 on R	2010 2010		2010
	Global Distribution of Melon-	Point	2013-2013	Modelled data	2013
	Headed Whales				
	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	Point	2013-2013	Modelled data	2013
	Northern Fur Seals				
	Global Distribution of Sea	polygon	1993-1993	Empirical observation	1999
	Global Distribution of Sea Turtle Nesting Sites	other	1949-1993	Empirical observation	1999
	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
Others	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 (<u>https://www.aquamaps.org/</u>) 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, <u>www.gbif.org</u>) and OBIS (Ocean Biogeographic Information System, <u>www.obis.org</u>), 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 <u>http://seaaroundus.org</u> /<u>PrimaryProduction/Interpolation_method.htm</u>; in mgC·m-²·day -1.
- Modeled proportion of annual primary production in a cell from the IPSL Climate model SRES A2 (2001-2010); in mgC·m-²·day -1.
- Modeled year 2100 proportion of annual primary production in a cell from the IPSL Climate model SRES A2 (2090-2099); in mgC·m-²·day -1.

Sea Ice Concentration:

- Observed mean annual ice cover as derived from the National Snow and Ice Data Centre (1979-2002), <u>http://nsidc.org/data/nsidc-0051.html</u>; 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 (<u>https://www.st.nmfs.noaa.gov</u>/<u>plankton/about/databases.html</u>) 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.





Disclaimer: The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries 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 (<u>https://www.bodc.ac.uk/data/bodc_database/nodb/search/</u>). 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. (<u>https://</u> 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) (<u>https://www.gebco.net/</u>) 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 (<u>https://instaar.colorado.edu/~jenkinsc/dbseabed/</u>) 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 softwarespecific 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 (<u>https://www.ncei.noaa.gov/maps/deep-sea-corals/mapSites.htm</u>) is shown in Figure 11.

#### Figure 10 Examples of expression methods for mobile species



Global Distribution of Sei Whales (2013)

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#### Figure 11 Example of global coral reef distribution using CMECS



#### **Global Distribution of Coral Reefs**

Legend



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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 personmonth.

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.

CMECS				
Setting/Comp	Class	Subclass	Datasets	Datasets description
onent				
	Arctic			
	Temperate Northern			
PC	Atlantic			
Do Diogoographia	Temperate Northern			
Sotting	Pacific			
Setting	Tropical Atlantic			
	Central Indo-Pacific			
	Eastern Indo-Pacific			
AS Aquatio	Lacustrine			
AS Aqualic	Estuarine			
Setting	Marine			
	Water Column Layer			
		Oligohaline Water		
MC Motor		Mesohaline Water	The Clobel Temperature	ASCII,netCDF,Best Copy Data Sets;
	Colinity Degime	Lower Polyhaline Water	and Solinity Drofile	update at least once a month;
Geolom	Salinity Regime	Upper Polyhaline Water		1990-Present;
		Euhaline Water	Programme (GTSPP)	global
		Hyperhaline Water		-

### Table 6 A table of major CMECS components and suitable datasets

Setting/Comp onent         Class         Subclass         Datasets         Datasets         Datasets description           onent	CMECS						
onent         Frozen/Superchilled Water         Very Cold Water         Cool Water         Cool Water         Cool Water         Cool Water         Moderate Water         Warm Water         Very Warm Water         Very Hot Water	Setting/Comp	Class	Subclass	Datasets	Datasets description		
Frozen/Superchilled Water Very Cold Water Cold Water Cold Water 	onent						
current       Global Ocean Currents Database (GOCD)       generated by NCEI, sufficient quality control , spans 1962 to 2013 NetCDF) format         Hydroform Class       NOAA Marine       F291, netCDF format contains wave height, wave period and wave         wave       Environmental Buoy Database       originate from National Data Buoy Center (NDBC) real-time data(Last updated July 16,		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 Wave Wave Hydroform Class Hydroform C		Hydroform Class	current	Global Ocean Currents Database (GOCD)	generated by NCEI, sufficient quality control , spans 1962 to 2013 NetCDF) format		
2019)			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)		

CMECS Setting/Comp onent	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;
	Tectonic Setting			
	Physiographic Setting			
GC 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)
Component	Geoform	Shallow/Mesophotic Coral Reef	NOAA Global Distribution of Coral Reefs	Vector (polygon; .shp),KML,WMS 1954-2009,global ;
		Deep/Cold-Water Coral Reef .etc	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 ;
	Geologic Substrate		dbSEABED	

CMECS Setting/Comp onent	Class	Subclass	Datasets	Datasets description
	Biogenic Substrate			tables which can be imported into
SC Substrate Component	Anthropogenic Substrate			practically any GIS, Continuous updating Point-data based
		Zooplankton, Floating/Suspended	WOD Ocean Station Data(OSD) Plankton	WOD native ASCII format、CSV、 netCDF; 1800,1900-2017;
	Planktonic Biota	Plants and Macroalgae, Phytoplankton, Floating/Suspended Microbes.	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.
BC Biotic Component	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

Class	Datasot	Website	Organizatio Metada		Format	Vorsion	Undato	Time	<b>Resolution/</b>	Extont
01033	Dataset		n	ta	Tornat	1011	opuale	span	scale	LAtent
Mangrove s	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/ALO S/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
Seagrasse s	Global Distribution of Seagrasses	http://data.unep- wcmc.org/datasets/7	UNEP- WCMC	TRUE	Vector (polygon,point ; .shp),KML,W MS	Version 6.0 (June 2018)	updated in intervals that are uneven in duration	1934- 2015	1:1,000,000	global

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

Class Datasot		Wabsita	Organizatio Metada		Format	Version	ion Undate	Time	<b>Resolution/</b>	Extont
CIdSS	Dalasel	Website	n	ta	Format	Version	Opuale	span	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)	Correcti ons 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/c gi- bin/OC5/SELECT/dbextract. pl	NOAA	TRUE	WOD native ASCII format,CSV,n etCDF	WOD18	Updatin g with WOD	1963- 1998		global
Sealife	AquaMaps 45 million observations of nearly 120	https://www.aquamaps.org/								

Class	Dataset	Website	Organizatio	Metada	Format	Version	Update	Time	Resolution/	Extent
	Dataoot		n	ta			opaaro	span	scale	
	000 marine									
	species									
	GSHHG(Glob								fivo	
	al Self-					vorsion			rosolutions:	
	consistent,				Shapefiles					
	Hierarchical,	https://www.ngdc.noaa.gov/			(polygons,line	2.3.7 ( luno	being	Unkno		alahal
	High-	mgg/shorelines/gshhs.html	NOAA NCEI	FALSE	s) ,Native	(June 15	updated	wn	IOW(I),	giobai
	resolution				binary files.	15,			intermediate(	
	Geography					2017)			i), nign(n),	
	Database)								and rull(I)	
Snoreline	NOAA								A	Regiona
	Medium	https://shoreline.noaa.gov/d			Snapefiles				Average	I:Contin
	Resolution	ata/datasheets/medres.html	NOAA	FALSE	(polygons,line				scale of	ental
	Shoreline				S)				1:70,000	U.S.
	Ductoture				ESRI					Global .
	Prototype	https://dnc.nga.mil/Prototype		,	shapefiles.(se				1:75,000 and	except
	Global	GSD.php	NGA	١	amless				smaller	the polar
	Snoreline				polyline files)					regions
Temperatu re					netCDF	version da 5.3 wi				
	AVHRR	R nder <u>https://www.ghrsst.org/</u> teData	NOAA NCEI		(Version:		daily	1981-	4km G	
	Pathfinder			FALSE	netCDF-4		update(t	Prese		Global
	SatelliteData		GHK221		classic)		wice)	nt		
					PNG					

Class	Dataset	Website	Organizatio n	Metada ta	Format	Version	Update	Time span	Resolution/ scale	Extent
Salinity	The Global Temperature and Salinity Profile Programme (GTSPP)	<u>https://www.nodc.noaa.gov/</u> <u>GTSPP/</u>	NOAA NCEI	FALSE	ASCII ; netCDF;Best Copy Data Sets		three times a week ; every Sunday ; about the 7th of each month	1990- Prese nt	Unknown	global
	Argo data	https://www.nodc.noaa.gov/ argo	The U.S. NODC	FALSE	netCDF,GAD R-3.0		being updated	2000- Prese nt		global
Bathymetr y	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	Unkno wn	grid intervals:15 arc-second	global

Class	Detect	Wabaita	Organizatio Metada		Format	Varaian	Undata	Time	<b>Resolution/</b>	Extont
Class	Dalasel	website	n	ta	Format	version	Opuale	span	scale	Extent
	Global Relief				netCDF,		Unknow	Linkno	grid	global
	Model,	mtps://www.ngdc.noaa.gov/	NOAA	FALSE	georeferenced		UNKNOW	Unkno	intervals:1	
	ETOPO1 mgg/global/global.ntml			tiff		Π	WII	arc-minute		
	dbSEABED,In								spatial	
	formation			FALSE			keep	Unkno	resolution	
Substrate	Integration	https://instaar.colorado.edu/ ~jenkinsc/dbseabed/_	F		Point-data				improves as	alahal
Substrate	System for				based	updatin	wn	more	giobai	
	Marine						g		datasets are	
	Substrates								added	