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SEND IN THE MARINES

DAWN J WRIGHT REPORTS ON THE NEXT PHASE OF AN UNPRECEDENTED GLOBAL DIGITAL OCEAN PROJECT

In 2016, a team of international scientists led by the United States Geological Survey (USGS) and Esri completed the first phase of a 3D digital ocean project known as the ecological marine units (EMUs). The project was commissioned in 2015 by the 90-member intergovernmental partnership, the Group on Earth Observations (GEO), as a means of developing a standardised and practical global ecosystem classification and a map of the ocean, ultimately to support the wise use of ocean resources and the preservation of environmental resilience.

EMUs are composed of a global point mesh framework, created from over 52 million data points from the authoritative National Oceanic and Atmospheric Administration (NOAA) World Ocean Atlas, with a horizontal spatial resolution of 1ºx1º (approx 27x27km at the equator), at 44 varying depths, and a temporal resolution that is currently decadal. Each point carries attributes of chemical and physical oceanographic structure (temperature, salinity, dissolved oxygen, nitrate, silicate, phosphate) that are likely drivers of many marine ecosystem responses. A k-means statistical clustering of the point mesh framework yielded the identification and mapping of 37 environmentally distinct 3D regions (candidate ecosystems) within the water column worldwide (see Figure 1). These units can then be attributed in GIS according to their productivity, direction and velocity of currents, species abundance, global seafloor geomorphology, and much more.

A major intent of the EMU project is to provide visualisation support for the design of new marine-protected areas, ocean planning and management, marine biodiversity conservation assessments, and economic valuation studies of marine ecosystem goods and services. This project also intends to enable understanding of the impacts of climate change and other disturbances (for example, ocean acidification, pollution, resource exploitation) on ecosystems. As such, the EMUs represent a rich geospatial accounting framework for these types of activities as well as for scientific research on species distribution and their relationship to the marine physical environment.

To further benefit the community and facilitate collaborative knowledge building, a set of free, open data products is available via esri.com/ecological-marine-units. These include the original 3D point mesh as well as the EMU clusters derived from the surface, bottom, and within the water column (best viewed in ArcGIS Pro and ArcGIS Online). In addition, the free Ecological Marine Unit Explorer app (see Figure 2) allows the exploration of the EMUs and the original World Ocean Atlas data on both the web and mobile devices. It should be particularly useful for classroom and laboratory instruction as well as public environmental outreach.

There are also free, downloadable web and mobile apps for exploring the EMUs and the original World Ocean Atlas data.

Although GIS has been a ready tool for mapping the two-dimensional top layer of the ocean and the seafloor, the EMUs provide one of the first means for visualising, characterising, and analysing 3D volumetric inner space between the sea surface and the seafloor on a global scale. The EMU map, unique and unprecedented in its scope and detail, differs from existing maps of marine ecoregions or biogeographic realms in that it is globally comprehensive, quantitatively data driven and truly 3D.

Phase 2: Localising the EMUs

The EMU project was commissioned by GEO at a global scale, but, undoubtedly, there were many requests for help in providing this global framework for local-scale analyses within smaller marine-protected areas; in bays or estuaries; and, ultimately, along coastlines (see Figure 3). Therefore, a major aim of the next phase of the project is to assist the ocean community in moving this research forward by incorporating the EMU framework with the higher-resolution data from NOAA (for example, the World Ocean Database of in situ measurements that the World Ocean Atlas draws from).

Therefore, a new workflow in ArcGIS Pro (using tasks) has been developed to allow the creation of localised EMUs. Given a sample higher-resolution, gridded data within a local region, this workflow (a task bar in ArcGIS Pro) takes the user through a series of steps to create the localised EMUs: downloading and converting World Ocean Database NetCDF files; visualising and summarising the result; building a localised 3D point mesh with the necessary 3D interpolation; performing spatial statistical analyses that will cluster the data; and applying EMU clusters to the point mesh (see Figure 4).

This workflow seeks to remove the impediment of the EMU framework being too coarse spatially and not dynamic enough temporally for smaller regions of interest, thereby providing opportunities for additional analytical scenarios such as creating seasonal versions of the EMUs. It is also meant to encourage users to develop additional GIS algorithms and workflows that scale effectively from global to regional to local. The original EMU project team is currently assisting users with the implementation of this new workflow (including via workshops at the Esri Ocean GIS Forum, a new online discussion forum), as well as the hosting of additional data products as needed in Esri Living Atlas of the World.

A tsunami of interest

The EMU project has generated considerable interest worldwide, ushering another component of the second phase of the project: that of several use cases where researchers are either implementing the EMUs at the original global scale or working toward the development of localised, high-resolution EMUs based on their own data (rather than NOAA's) and on applications of value specific to their own stakeholders (see Figure 5).

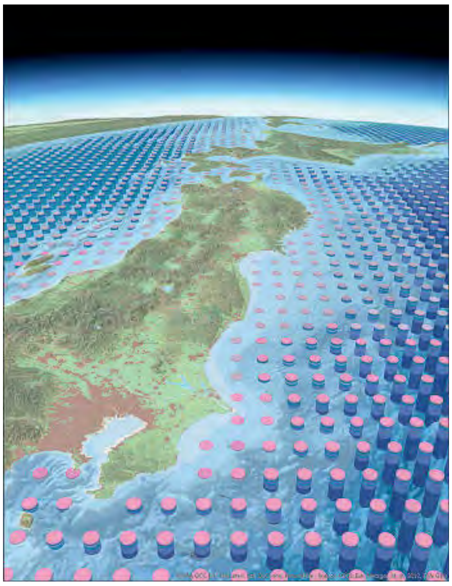

Figure 1. Visualisation of the EMUs off the eastern coast of Japan. Although the EMUs are natively available as a continuous surface, representing them in 3D is facilitated using columnar stacks, allowing visualisation of the 'layering' of EMUs over a point location. Surface temperature gradients are also apparent between the pink EMUs in the south and the blue EMUs in the north

Dr Orhun Aydin and Dr Kevin Butler of the Esri spatial statistics team have developed an integrated GIS and machine learning approach to build a data-driven model of seagrass presence/absence in a changing climate, scaled up to the global ocean using the EMUs (see Figure 6). Seagrass meadows are among the most important habitats for fish species, store up to 100 times more carbon than tropical forests and aid in protecting shorelines from storm damage. Aydin and Butler say that if rising ocean temperatures cause these seagrass ecosystems to fail, the loss will only expedite the global warming that killed it.

Butler has also developed a prototype integration of the NOAA Animal Telemetry Network with EMUs for a better understanding of animal movement (such as elephant seals) throughout the water column (see Figure 7). This will aid in evaluating the full spectrum of a species' behaviour and habitat preferences at depth, not just correlating suitable habitat to surface-measured parameters such as sea surface temperature.

In addition, there are currently 15 other use cases being developed by researchers all over the world. Among them is a study by the EU-funded ATLAS project – an international consortium of 24 institutes and over 100 people from Europe, the US and Canada –undertaking a transatlantic assessment and deepwater ecosystem-based spatial management plan for the North Atlantic Ocean. ATLAS researchers hope to use the EMUs in refining UNESCO's Global Open Oceans and Deep Seabed (GOODS) biogeographic classification tool for the North Atlantic, particularly for deepwater hydrothermal vent communities, cold corals, cold seeps.

"This will enable us to validate the extent that physical proxies for biogeographic boundaries truly reflect species biogeographies, which will have important implications for policy makers and managers of vulnerable marine ecosystems [VMEs] and marine-protected areas [MPAS]," says Dr Lea-Anne Henry of the University of Edinburgh in the UK and the ATLAS project.

THE EMUS REPRESENT A RICH GEOSPATIAL ACCOUNTING FRAMEWORK

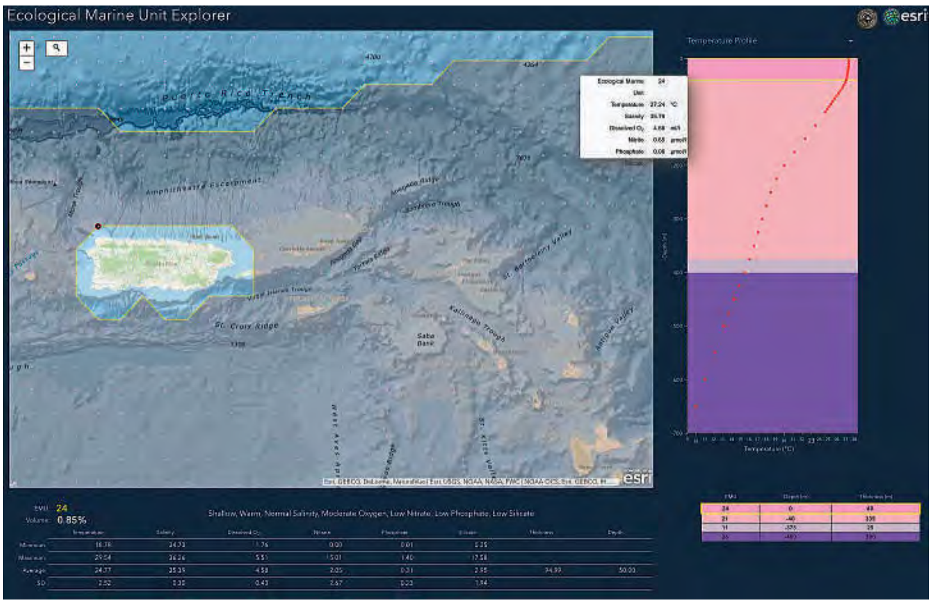

Figure 2. A screen capture of the Ecological Marine Unit Explorer Web App

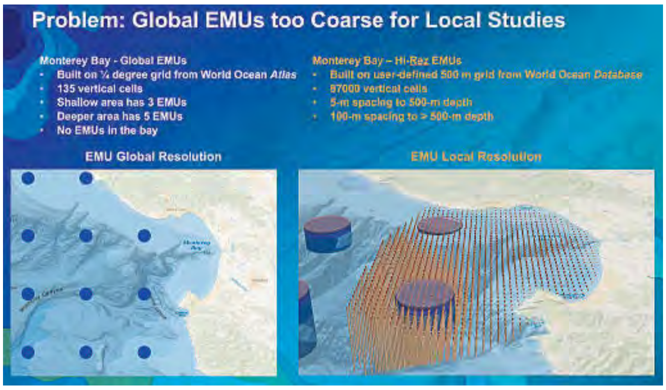

Figure 3. The resolution of global EMUs for a local area such as Monterey Bay, California, is compared to localised EMUs built from higher-resolution data from the region

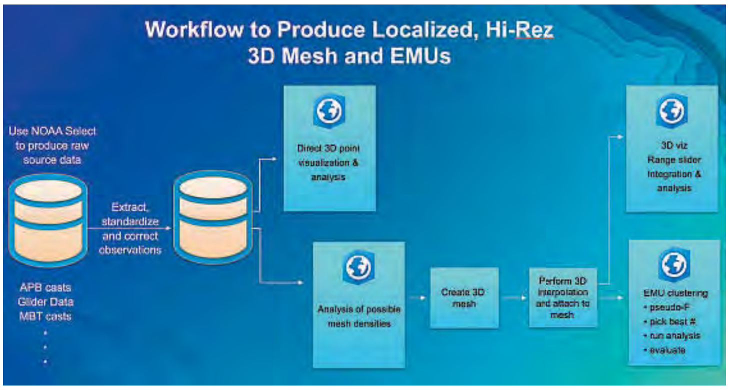

Figure 4. This is the ArcGIS Pro workflow for localising global-scale EMUs (APB – autonomous pinniped bathythermograph; MBT– mechanical bathythermograph)

Figure 5. Ocean scientists, technologists and resource managers participate in the very first Analysis with the Ecological Marine Units half-day workshop, conducted by Dr Kevin Butler and Keith Van Graafeiland of Esri as part of the Esri Ocean GIS Forum, November 2017. © Eric Laycock, Esri

Prof Dr Angelika Brandt and Dr Hanieh Saeedi of the Senckenberg Research Institute and Natural History Museum in Frankfurt, Germany wish to compare and contrast their EMU case study in the NW Pacific with the ATLAS use case in the North Atlantic. They are compiling 6,000–7,000 deep-sea species records from Russian-German and German research expeditions to the Aleutian Trench and the Kuril-Kamchatka Trench (see Figure 8). This region may serve as a potential northward migration point for fauna due to climate change. The researchers seek to create their own localised EMUs to as deep as 9,000m by statistically clustering their own data, which will be an important extension to the current EMU maximum depths of 5,000-6,000m in the Pacific. Saeedi notes, "These data have also never been mobilised to open-access databases and thus never [before] been available to the public, so the study will make an important [open science] contribution in its own right."

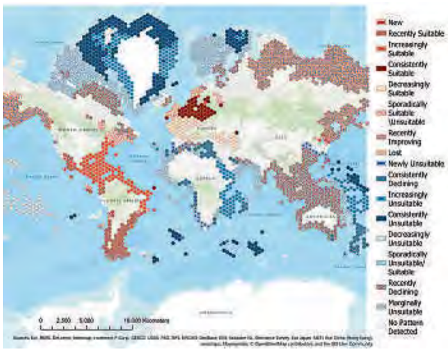

Figure 6. Results of a machine learning classifier (random forest) used to model the relationship between oceanic conditions based on Ecological Marine Units and the occurrence of seagrass. The map shows that with a 2°C increase in sea surface temperature, trends in seagrass habitat suitability via Emerging Hot Spot Analysis. 'Recently' refers to a switch in state – for example, southern South America started off as unsuitable for seagrasses but switched to suitable over the course of the temperature change. 'Declining' indicates locations that are trending toward poor habitat suitability, particularly in the southwest Pacific. © Orhun Aydin, Esri

A call to action

The EMU project is a significant step forward in the quest to comprehensively map the entire ocean. As Dr Suzette Kimball, director of the USGS, states, "While oceans cover about 70 per cent of the earth's surface, the impact of climate change on the oceans, apart from sea level rise, has largely been hidden. This easily accessible map will serve as a fresh resource for improving our understanding of the ocean's structure – its salinity, temperature, oxygen levels, and nutrients – in millions of specific places. This insight will, in turn, help us better understand the rapid changes in ocean ecology that are now happening around the world."

And while the EMUs are appropriate for characterising chemically and physically distinct ocean regions, they are still inadequate for a robust characterisation of coastal ecology, because:

- Coastal features often occur at even finer spatial resolutions
- Coastlines represent the interface between land and water, but EMUs have no terrestrial dimension.
- Humans are densely distributed in coastal environments.

Therefore, in November last year, a group of coastal ecosystem classification and mapping specialists met at Esri headquarters ahead of the Esri Ocean GIS Forum to lay out the conceptual framework and general methodology for delineating a set of robust, standardised, and practical global ecological coastal units (ECU) at a spatial resolution of at least 30m. This is yet another project commissioned by GEO, and initial results should be forthcoming by 2019. The group will also be exploring how to conceptually and spatially connect EMUs at the ECU interface with ecological land units and the forthcoming ecological freshwater units.

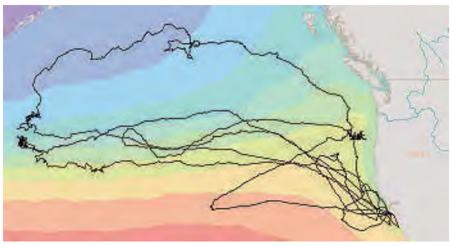

Figure 7. Telemetry track of a northern elephant seal over a raster of sea surface temperatures as interpolated from EMU data. NOAA Animal Telemetry Network data are being integrated with EMUs to better summarise the physical and chemical characteristics of the ocean environment through which animals are moving. © Kevin Butler, Esri

THE STUDY WILL MAKE AN IMPORTANT CONTRIBUTION IN ITS OWN RIGHT

Dawn J Wright is Esri chief scientist (www.esri.com)

Figure 8. The study area in the Northwest Pacific for a proposed EMU use case by Senckenberg Research Institute, Germany