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Sommario

Session 1 – Shelf and Deep Sea habitats

KEYNOTE

BENEFITS OF HABITAT MAPPING IN AN URBAN SEA – THE NE PACIFIC MARGINAL SALISH SEA

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Urban seas are heavily populated, industrialized coastal, estuarine, and/or inland marginal seas that are hot spots for pollution and disturbances, both natural and anthropogenic. They are generally situated at the nexus of terrestrial and maritime transportation hubs that support significant economic activities and global trade. Examples of differing types of urban seas consist of the Baltic, Venice, Shanghai, Sydney, Tokyo, and the Salish, to mention only a few. These locals have been historically attractive to various cultures throughout the occupation of humans on Earth and often host or hosted diverse ecological environments. They are particularly significant in the present day of globalization and turmoil as they are critical to the sustainability of resources delivery and processing.

Urban seas are natural laboratories for the study of environmental changes such as global warming, sea level rise, and the decline or expansion of species. They also contain both human and natural resources that can be brought into play to monitor and predict changes to the physical and ecological environments. Academic, government, and industrial resources that advance technologies and the understanding of Earth's processes are generally readily available for use in these natural laboratories to investigate changes. The Salish Sea is one such marginal sea.

We present an example of how geologic and marine benthic habitat mapping of the central Salish Sea – the Gulf and San Juan Islands archipelago of southern British Columbia, Canada and Washington State, USA – has become a focal point in evaluating potential for renewable energy along with the protection of the sub-tidal habitats in cases of oil spills and other accidents. Under the umbrella of the *UN Decade of Ocean Science Sustainable Development 2021-2030* (Ocean Decade) the US and Canada are viewing urban seas for an initiative to address the problem of global warming and its associated impacts. The Salish Sea has tremendous potential for continuous, predictable tidal power that can securely provide localized off grid electricity to communities within the region. Through past and present day marine benthic habitat mapping the most ideal sites for tidal energy turbines can be selected, not only to take advantage of the greatest power generating locals, but to select the best substrate for emplacement of turbines and least impactable habitats. In addition, the Salish Sea, like other urban seas around the globe, is experiencing a tremendous increase in shipping with the potential to spill oil, contaminants, and containers that all can sink to the seafloor. Up to this time sub-tidal habitats have been "out-of-mind" because they are "out-of-sight" when oil spill mitigation activity takes place. However, within the Salish Sea benthic habitat maps have been re-interpreted to show those habitats most prone to impacts from sunken oil such as diluted bitumen, thus providing very visible seafloor conditions that can be evaluated during mitigation of any spill in the region. Lessons learned, and being learned in the Salish are exportable to other urban seas around the globe.

BENTHIC HABITAT IN CALIFORNIA STATE WATERS OFFSHORE OF MORRO BAY

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Motivated by the desire to develop offshore wind energy capacity and infrastructure, Coastal and Marine Ecological Classification Standard (CMECS) geoform, substrate, and biotic component GIS products were developed in the U.S. Exclusive Economic Zone of South-Central California. The project was funded by the U.S. Bureau of Ocean Energy Management to assess potential impacts on the environment. Wind-energy developers have interest in specific sites further offshore at depths of 500 to 1200 meters to access higher wind potential, minimize fishing conflicts that occur closer to shore, and are also near onshore electric grid infrastructure. Multibeam echosounder (MBES) data were collected by Fugro Inc., processed by The California State University Monterey Bay Seafloor Mapping Lab. Analysis of the data was a collaboration between the USGS and the UCSC Center for Integrated Spatial Research. The data release published by the U.S. Geological Survey (USGS) has, in addition to CMECS polygons, seafloor character (a three-class induration-ruggedness integer raster), backscatter intensity, and bathymetry rasters.

Derivatives of the MBES used in this analysis include seafloor character (from bathymetric ruggedness and backscatter intensity), slope, bathymetric position index, and CMECS depth zone. A CMECS modifier value was generated for each polygon which includes the Substrate Induration, Slope Class, and Depth Zone. There are 25 unique combinations of these variables. Polygons with unique combinations of induration, slope, and BPI were grouped into 9 geoforms. Geologic unit names and codes were also created for the geoforms.

In all, 400.22 km^2 of seafloor was classified. The study area substrate is predominantly soft sediment (mud and fine sand) covering 231.56 km^2 (57.9% of the area). Mixed substrate areas are found predominantly in scour depressions and comprise 55.50 km^2 (13.9%) of the study area. Hard substrate areas are outcrops of Miocene sedimentary bedrock. Hard substrates comprise 113.16 km2 of the study area (28.3%), a significantly larger area than State waters areas to the south with greater sediment supply. Differential erosion of the folded and tilted sedimentary rocks has produced excellent habitat for benthic organisms of concern such as Rockfish (Sebastes sp.). Holocene asphalt (tar), weathered and biodegraded oil derived from underlying or nearby natural hydrocarbon seeps, and pockmarks cover a small percentage (0.02%) of the mapped area.

MAPPING AND MORPHOLOGICALLY CHARACTERIZING COLD-WATER CORAL MOUNDS ACROSS THE ATLANTIC OCEAN

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Cold-water corals form substantial biogenic habitats on continental margins and in deep-sea areas with topographic highs, such as banks and seamounts. In the Atlantic Ocean, many reef and mound complexes are engineered by the stony corals *Desmophyllum pertusum* (previously known as *Lophelia pertusa*) and *Madrepora oculata*. These corals can be defined as 'ecosystem engineers' as their reefs alter the local hydrodynamics and sediment deposition and provide complex three-dimensional habitat for many other species, including commercially important fish and communities of suspension-feeding invertebrates such as sponges and other corals. These reefs and mounds form under specific environmental conditions that are not yet fully understood but which are known to be controlled by a complex interplay of physical, chemical and biological factors.

As part of the Horizon 2020 iAtlantic project (www.iatlantic.eu), a variety of semi-automatic mapping tools, such as the BRESS (Bathymetry and Reflectivity Based Estimator of Seafloor Segments, www.hydroffice.org) and ArcGIS based seabed mapping toolboxes, were used to map the spatial distribution of cold-water coral mounds in different regions across the north and south Atlantic ocean (i.e. Norway, Scotland, Iceland, US and Brazil).

The complexity of the underlying seabed on which the mounds occur varied greatly, and ranged from relatively flat and sandy (e.g. Darwin Mounds) to more complex terrains with for example ridge features (e.g. Lónsdjúp trough). Bathymetric datasets ranging from 5x5 m to 100x100 m resolution were used and morphometric information on their width, length, area, orientation, height, shape, and connectivity was extracted and compared. By comparing the variability in the morphology of cold-water coral mounds across the Atlantic Ocean, our understanding of how their history and environment might affect their current morphology can be improved.

SEABED MAPPING USING 3D SEISMIC DATA TO INVESTIGATE CONTINENTAL SLOPE MORPHOLOGY AT THE BRAZILIAN EQUATORIAL MARGIN

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The Brazilian Equatorial Margin (BEM) is a transform passive margin formed by the Gondwana break-up during the Early Cretaceous (Aptian-Albian) (Matos, 1999). Rifting created a series of rift sedimentary basins including the Potiguar Basin (POT) (Fig.1a)-NE Brazil. Despite the continental shelf of the POT had been extensively investigated, studies on the continental slope are still scarce, while they are essential to identify instabilities and their related mechanisms. These investigations can also provide information necessary to map possible geological risk areas and prevent accidents regarding submarine installations.

The dataset, conceded by the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP) is composed of a 3D high-resolution seismic cube of ~1850 Km² and a velocity analysis cube. The software used to conduct seismic interpretation was Petrel E&P, licensed by Schlumberger. Here we report the very first results of this research which is the seabed mapping and morphological descriptions. The seabed horizon (SBH) was mapped by picking the first reflector with positive amplitude using a combination of manual tracking with 3D automatic tracking. Then, the SBH was used to create a surface (Fig.1b) by the convergent interpolation method. Finally, a velocity model was created using the velocity cube to provide a time-depth converted dataset.

Our results (Fig.1b) show that the slope is characterized by canyons/channels, landslides, sediment wave marks, and depressions organized in trails. The presence of these elements indicates that different processes may be shaping the slope. The slope is generally steep and characterized by erosional and depositional features indicating processes that can be related to slope instabilities (e.g., landslides). In addition, we observed trails of elliptical depressions similar to those observed at the Ceará basin (also a BEM basin) by Maestrelli et al., 2020 described as the result of upslope migration of sediment waves supplied by turbiditic flow. These features indicate how gravity-driven processes shape the slope's morphology. Submarine channels formed between the two walls of some of the canyons (Fig.1b) have different morphologies: some are sinuous (C;J;K;P), other meanderings (D;E), and others rectilinear (F;O). Factors that influence the different shapes of the course of the channels will be fully understood during the next step of this research, which will be supported by sub-bottom seismic interpretation.

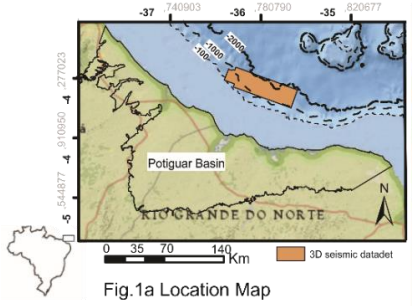

Fig.1a Location Map

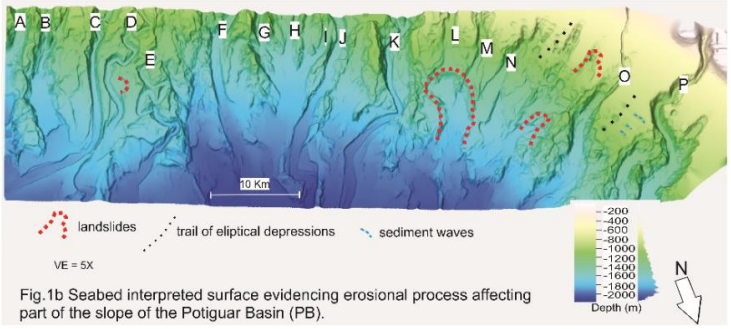

Fig.1b Seabed interpreted surface evidencing erosional process affecting part of the slope of the Potiguar Basin (PB).

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DEEP SEA HABITAT MAPPING AND CHARACTERIZATION OF A SEEPAGE COMPLEX USING MULTIBEAM DATA, AUV AND ROV SURVEYS AT THE PALMAHIM DISTURBANCE, ISRAEL

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Deep-Sea habitats are commonly mapped using multibeam and backscatter data. However, the biological characterization of the habitat cannot be achieved using multibeam data alone. We present a multi-stage mapping and habitat characterization methodology for the deep-sea geological complex of the Palmahim Disturbance (Eastern Mediterranean) at water depths of 1200-1500 m. Analysis of multibeam bathymetry and backscatter data was followed by an AUV survey and by ROV dives. These dives were aimed to sample, document, and provide visual documentation, as well as sedimentological and chemical sampling for this habitat. Multibeam data and AUV surveys revealed complex seafloor morphology and potential rare deep-sea biota. The analysis of the AUV Synthetic Aperture Sonar (SAS) data, revealing pockmarks, carbonate rocks, and bioturbation, led to target further ROV surveys, revealing seafloor gas seeps, brine pools, deep-sea corals, and carbonate rocks, as well as unique deep-sea biota like sharks and chemosynthetic worms.

The discoveries in these surveys resulted in an update to the habitat map of Israel, adding over 200 sq. km. to the Palmahim Disturbance deep-sea habitat. Additionally, this update to the habitat map included detailed characterization of biological and ecological features and geochemical properties and an addition of a newly defined brine-pool complex habitat.

The use of multibeam and AUV survey abilities is now under development to create predictive methods based on multibeam and AUV SAS data to identify and map rare habitats in the deep sea, targeted at increasing our capabilities for extensive area habitat mapping.

MAPPING VULNERABLE MARINE ECOSYSTEMS IN THE SOUTH-WEST ATLANTIC DEEP-SEA

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Deep-sea environments are under increasing anthropogenic pressure. Marine spatial planning is central to applying ecosystem-based management and area-based conservation strategies, which have been called for by the UN 2030 sustainable development agenda goal 14. Marine spatial planning relies on accurate mapping of biodiversity and habitats in relation to anthropogenic activities. However, deep-sea environments remain poorly mapped, especially in the South-West Atlantic due in part to remoteness and being a funding limited location.

In the Falkland Islands, no full coverage deep-sea habitat maps exist, despite it being increasingly recognised as a biodiverse region. The main anthropogenic activity occurring in the deep-sea is a Marine Stewardship Council Certified seabed static longline fishery operating in water depths > 600 m. Understanding the distribution of habitats and vulnerable marine ecosystems (VMEs) is needed to assess the wider ecosystem impact of the fishery.

Legacy data compiling imagery, bathymetry, oceanography and fisheries bycatch data were combined with data collected from a specially adapted longline camera, to characterize and map the megafauna including VME indicator taxa. A suite of terrain derivatives calculated from the bathymetry and ocean chemistry extracted from global models were combined with megafauna location data (compiled from image analysis), and fisheries invertebrate bycatch data. Random Forest and MaxEnt ensemble models of VME indicator taxa distribution were built and compared with Kernel density estimated biomass maps of VME indicator taxa, which were derived from fisheries bycatch data. Areas of congruence indicative of potential VMEs were identified, and the reliability of the two methods to identify VMEs is discussed in the context of marine spatial planning.

THE ATLANTIC MARINE LANDSCAPE:

A BASIN-WIDE CLUSTER ANALYSIS OF NEAR-SEAFLOOR PHYSICO-CHEMICAL CONDITIONS

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Classifications of the marine environment aim to produce a comprehensive and objective sub-division into regions of similar characteristics and can hence provide important input to sustainable ocean resource handling and protection planning. There have been many efforts to categorise the marine realm into seascapes or hydro-morphological provinces, using different approaches and applied at a wide range of scales. Some of the categorisations are based on hierarchical classification schemes with often arbitrary thresholds between categories, or they use simple algorithms which do not fully account for the high complexity of the data. This study presents a basin-wide automated classification of the Atlantic seafloor environment, based on nine global datasets and their derivatives. They contain bathymetry, slope, terrain ruggedness index, topographic position index, sediment thickness, POC flux, salinity, dissolved oxygen, temperature, current velocity, and phytoplankton abundance in surface waters along with seasonal changes.

The results classify the Atlantic seafloor realm into nine seabed areas (SBA). Some are clearly defined by geological and geomorphological properties, while others are dominated by hydrographic properties, or by a mixture of both seafloor terrain and water column characteristics. Larger SBAs cover the deep abyssal plain with low hydrographic and seasonal variation – in contrast to smaller SBAs, including coastal waters, that are subject to high seasonal variability. There are also differences in geographical distributions. A comparison of our SBAs to existing classifications (e.g., Global Ocean Seascapes, GOODS, EMU) and supplementary data (e.g., seamount locations) shows that there are huge discrepancies between the classifications but also some similarities. Additionally, a landscape analysis will be presented that highlights areas of high diversity, pointing out the use of such cluster maps to define regions for potential protection.

MAPPING SEASCAPE SPATIAL HETEROGENEITY AS DRIVER OF SEAMOUNT-ASSOCIATED FISH - A CASE STUDY FROM THE SOUTHWEST INDIAN RIDGE SEAMOUNTS

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The Southwest Indian Ridge (SWIR) seamounts remain poorly studied, yet have been subject to intense deep-sea fishing activity over the past 40 years. Taxa as orange roughly (Hoplostethus atlanticus), pelagic armourhead (Pentacerotidae), oreos (Oreosomatidae) and alfonsino (Beryx spp.) have become particularly well known for their commercial importance, leading to global calls for sustainable management. Although SWIR seamounts are known aggregation spots for commercially important fish species, little is known about the physical habitat characteristics that support them, crucial for informing conservation and ecosystem-based management.

This study examines the influence of multiscale seabed spatial heterogeneity on 15 commercially important fish families at three SWIR seamounts (Coral Seamount, Melville Bank and Atlantis Bank). We integrated fish video survey data from an underwater vehicle with benthic seascape structure surveyed with multibeam sonar. Taking a landscape ecology approach, we quantified seascape heterogeneity from bathymetry and geomorphological habitat maps and identified 15 focal fish families from video data. Fish-habitat associations were assessed using spatial pattern metrics from landscape ecology that measured continuous terrain structure, seascape composition (the variety and relative abundance of patch types), and seascape configuration (the spatial arrangement of patch types). Multivariate regression trees and random forests were used to model the associations of demersal fish families and assemblage characteristics with seabed spatial heterogeneity.

Demersal fish were strongly dependent on geographic location and depth, and at finer scales seascape composition and configuration helped explain fish-habitat associations. A high abundance and diversity of commercially important demersal fish were associated with spatially continuous summit habitat and complex shaped ridge features. Metrics of seascape composition and configuration (i.e., habitat size, shape and structural connectivity) had higher predictive power than terrain derivatives commonly used in developing proxies for deep water fish biodiversity.

These outcomes indicate that patch mosaic metrics, proven to be ecologically relevant on land and in shallow-water marine environments are also relevant for identifying environmental predictors of fish distributions in remote deep-sea environments. We highlight strong context dependency and depth-specific associations that hinder attempts to draw generalizations on fish-seascape linkages for seamounts.

HABITAT MAPPING OF SOUTHWESTERN AUSTRALIAN SUBMARINE CANYON SYSTEMS

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The south-western margin of Australia is incised by numerous submarine canyons that extend from the continental shelf-margin down to the bathyal plains. These differ from many submarine canyons around the world by showing no present connectivity to continental river systems. Essentially unexplored, the Australian submarine canyons host an incredibly diverse benthic fauna, which is only now being recognized.

In the austral summer of 2020, the first Remotely Operated Vehicle (ROV) expedition was conducted along the southwestern Australian margin within the Australian sector of the Southern Ocean. Deployed from RV *Falkor* of the philanthropic Schmidt Ocean Institute, the ROV *SuBastian* explored benthic communities inhabiting several canyons within in the large Bremer Canyon System, located within the Bremer Marine Park offshore Albany. It also explored further west around the Mount Gabi seamount, north of the Leeuwin Canyon, then revisited the Perth Canyon to supplement the first observations undertaken in 2015.

We have characterized the complex seascape from high-resolution bathymetric mapping, geology, as well as physical and chemical oceanography, to provide an overview of the benthic habitats observed between 180-3300 m, with a particular focus on the charismatic cold-water corals (CWC). Our research reveals a considerable richness in diversity and abundance of megabenthos. Especially notable are distinct ecological zones on hard substrata including spectacular coral gardens, bryozoan-sponge animal forests, with the local predominance of CWC, including solitary and colonial scleractinians. Extensive subfossil coral deposits discovered across all three study sites indicate periodic waxing and waning of CWC communities throughout this region, with Mount Gabi having been a major hot-spot but is now predominantly a coral ‘dead zone’. The comprehensive habitat mapping of the SW Australian margin reveals that the Bremer Canyon System currently hosts rich and diverse benthic communities which contrasts to the more depauperate fauna observed in the Perth Canyon, likely due to different oceanographic conditions.

BENTHIC COMMUNITY RESILIENCE TO HABITAT ALTERATION CAUSED BY AN EARTHQUAKE-TRIGGERED TURBIDITY FLOW IN KAIKŌURA CANYON, AOTEAROA NEW ZEALAND

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Turbidity flows (underwater avalanches) transport massive amounts of sediment across large distances and can have dramatic, long-lasting impacts on deep-sea benthic communities. A turbidity flow in Kaikōura Canyon triggered by a 7.8 (Mw) earthquake in 2016 provides a unique opportunity to examine the response of deep-sea benthic communities to a large-scale habitat-altering disturbance.

This presentation will provide an update on initial findings reported at GeoHab 2021 on the impact of the turbidity flow on the mega-epibenthic community. Fauna, lebensspuren (feeding and other life traces on the seafloor) and sediment characteristics were annotated in photographic transects from a towed camera system that were collected at the same sites 10 years before the event as well as 10 weeks, 10 months, and 4 years afterwards. Variation in the faunal and lebensspuren data were separately compared to the variation in the substrate data as well as habitat topographic variables (depth, roughness, aspect, slope etc.) extracted from multibeam bathymetry data acquired before and after the turbidity flow. Results of these analyses revealed that immediately after the event there was little evidence of a living mega-epibenthic community. However, ephemeral patches of bacterial mat, like those seen in chemosynthetic environments, were observed. Four years after the turbidity flow, the visual surveys indicated a benthic community similar in structure to that seen before the event. This recovery was correlated with a change in the physical characteristics of the habitat, specifically the standard deviation of the slope, that have occurred since the turbidity flow drastically altered the habitat in the canyon. The turbidity flow smoothed out the seafloor topography as sediment was both deposited into and removed from the canyon, an alteration that has persisted four years after the event; the change would have had both direct and indirect effects on the structure of the faunal communities. In addition to discussing these results, preliminary analyses for macro- and meio-infauna from sediment cores taken at the same time as the photographic transects will be presented. Overall, these datasets form the basis of a wider project which aims to build models predicting rates of benthic community recovery from large disturbances in the deep sea. These models will contribute to better understanding of natural disturbances from turbidity flows, and will be useable as proxies for anthropogenic disturbance such as seabed mining.

INTERMEDIATE AND DEEP WATER MASSES AND CIRCULATION IN THE TASMAN AND CORAL SEAS USING CTD AND MULTIBEAM DATA FROM R/V FALKOR VOYAGES 2020-21

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This study uses CTD and multibeam bathymetry data collected by the R/V *Falkor* offshore northeastern Australia during two voyages in late 2020 and early 2021 (austral summer period). By identifying the water masses and geomorphic features of the seafloor, we reveal the interaction of the intermediate and deep water masses within the narrow (~20 km wide) Cato Trough which links the Tasman Sea and Cato Basin in the southern Coral Sea.

Several water masses were identified in the CTD data including Antarctic Intermediate Water (AAIW; 600-1200 m), Upper Circumpolar Deep Water/Pacific Deep Water (UCDW/PDW; 1200-2600 m) and Lower Circumpolar Deep Water (LCDW; >2600 m). The CTD data show clear trends in the water masses that reveal clues to the circulation and flow in the region. For example, different AAIW types flow north and south with mixing in this region. LCDW and UCDW flow northward in the Tasman Sea, with some flowing through the Cato Trough. Most of the LCDW turns to flow southward along the base of the Chesterfield Plateau, on the eastern side of the Tasman Basin. PDW flows south in the northern Cato Trough but is blocked from flowing into the Tasman Sea by north-flowing water masses, resulting in a mixing of deep water masses observed in the northern Cato Trough and the southern Coral Sea.

The R/V *Falkor* mapped >76,000 km^2 of the seafloor in the Coral Sea Marine Park and the northern Tasman Sea basin. The geomorphic features (sandwaves, dunes and scours) identified in the high-resolution Kongsberg EM302 multibeam data vary on a range of scales, from 100s m to km-long. The geomorphic features in the northern Tasman Sea basin at depths of 3000-4000 m suggest there is a southward flow with localised accelerated flows, forming channels and scours around the base of the Tasmantid Seamounts. Dunes and sandwaves were also identified on the shallower (1000-2000 m) Chesterfield Plateau, Tasman Sea basin slopes and the abyssal plain at 4000 m. The geomorphic evidence indicates significant localised flows at depths of 600-4000 m in the Tasman and Coral seas.

INCREASING SITUATIONAL AWARENESS IN SEAFLOOR RESEARCH FROM SURVEYING TO VISUALIZATION – AN UPDATE OF THREE PROJECTS

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Complex biogeochemical studies on the seafloor ranging from bathymetry to habitat mapping may suffer from a lack of situational awareness, especially when it comes to the assessment of morphologically complex areas such as hydrothermal vent sites or (sub-) vertical volcanic outcrops. Such sites are generally surveyed using remotely operated vehicles, with their camera system providing only limited field of view, limiting productivity compared to on-land studies. We briefly report advances of three interlinked projects to improve on this situation:

The Schmidt Ocean Institute funded cruise FK160320 visited the Niua South volcanic field in Tongan waters, photogrammetrically mapping an area 500m x 500m x 80m at “industrial” scales. We comment on the challenges of photogrammetrically processing and visualizing a data set of 220.000 images resulting in billions of 3D points, including the lessons learned regarding survey design.

The consequence of this expedition was the LIGHTHOUSE technology validation project, in which a highly integrated suite of acoustic sensors, cameras and laser scanners are fused to create a real-time 360° model of the seafloor surroundings. This project sported the development of the world’s first commercially available native underwater, deep-ocean capable survey lens in cooperation with Carl Zeiss Jena.

Lastly, we will touch on our efforts to visualize the seafloor in the spatially immersive ARENA2 visualization dome at GEOMAR, facilitating quantitative visualization and virtual fieldwork on the seafloor in small groups of researchers.

BACKSCATTER IMAGERY REVEALS FEATURE RICH CONTINENTAL SLOPES OF CENTRAL WESTERN CONTINENTAL MARGIN OF INDIA

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Multibeam echosounder systems have gained large popularity in mapping and charting the depths of the seabed. Given to the advancement in technology during the last few decades, these MBES systems are capable of producing secondary data sets such as backscatter strengths of the seafloor. This has enabled such swath mapping system to produce sediment classification maps. Though it largely depends on the frequency of operation, it provides decent remote surficial sediment estimation coverage map. In the present study, extensive continental slope region around a submerged bank have been mapped on the Western Continental Margin of India. The mapping was carried out using Kongsberg's EM302 system, having the capability to record and analyze the backscatter strength data of the swath mapping system. Apart from gently sloping seabed topography the survey region demonstrates feature rich backscatter imagery map. Such findings initiated further investigation of the region for the sediment grain-size prospective and some spot sounding analysis datasets. Largely, the region presents high backscatter strengths seafloor along the continental edge as well as continental rise regions, whereas all along the continental slope regions it demonstrates weaker returns and will be a point of discussion here.

The present study revolves around exploiting the limits of the MBES system in remote classification of the seabed sediments. An attempt has been made here to augmented the interpretation with the angular response (AR) based on spot sounding seabed backscatter strength analysis.

MAPPING POTENTIAL MARINE HABITATS ON THE RIO GRANDE RISE

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Located in the Southwestern Atlantic Ocean, Rio Grande Rise (RGR) has aroused the scientific community's interest due to the occurrence of ferromanganese crusts on the top of its plateaus. Multibeam data acquired over the central area of RGR enabled the creation of a bathymetry grid with 50 m resolution, between depths of 550 to 3,000 m. Geomorphic types were determined using spatial classification tools in ArcGIS, based on a number of morphometric parameters (e.g. ruggedness, aspect, slope, BPI). Six geomorphological classes were determined: plateaus, valley bottoms, edges, gentle slopes, steep slopes and flanks. A scarce group of sediment samples and dredged rocks collected during different cruises served as an indication of the substrate type. Nevertheless, in order to improve the insight about the seabed composition, video recordings obtained by a ROV were used to classify distinct substrates. The seabed descriptions of the 13 dives and the sediment samples were the main source of information for correlating the locations to the classes of RSOBIA, defined as mud, foraminifera sand, calcarenitic mounds, outcrops and ferromanganese crusts. Deposits of pteropods have also been visualized in great part of the central area of the RGR, indicating that there is possibly a delay in the deposition of these particles.

The potential benthic habitat map was a combination of geomorphic classes and substrate types, sectioning the area in: deep muddy basins; foraminifera sands on gentle slopes; ferromanganese crusts on plateaus; calcarenitic terraces; contourites and outcrops.

THE ABC CELTIC SEA PROJECT – ACOUSTIC SEABED CHARACTERISATION AND BENTHIC HABITAT ASSOCIATIONS IN THE CELTIC SEA

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The Acoustic Seabed Characterisation and Benthic Habitat Associations in the Celtic Sea PhD project (ABC Celtic Sea) aims to develop our understanding of the interplay between seabed characteristics and its inhabiting marine life. Using novel machine learning techniques, acoustic data assets from Ireland's INFOMAR programme will be processed and analysed to identify sedimentary and geomorphological facies that influence benthic habitats and species distributions. Ground-truthing information will be analysed to assess the relationships between acoustic data, sedimentary and geomorphological facies as well as biological communities. This will advance our capacity to create accurate models and maps of the seabed habitat and further our conceptual understanding of what seabed habitats are. To do so, the project will address two primary research questions:

1. What are the key geomorphological and sedimentary facies in the Celtic Sea and how can advances in acoustic data processing and machine learning be leveraged to identify these effectively and efficiently?
2. What is the relationship between species distribution and the derived geomorphological/sedimentary facies zonation, and what does this tell us about the concept of seabed habitat?

The project will capitalize on data assets collected through the INFOMAR programme, build capacity to analyse the wealth of bathymetric data amassed internationally as part of the Seabed 2030 initiative, and tie into large-scale regional seabed mapping efforts and integrated ecosystem assessments such as Atlantic and Mission Atlantic.

HABITAT SUITABILITY MODEL OF THE BREMER CANYON SYSTEM (AUSTRALIA) COLD-WATER-CORAL GROUNDS

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The Bremer Canyon System (BCS), which constitutes a series of deep submarine canyons that incise the south-western Australian margin, was explored during the austral summer in 2020 duringthe Schmidt Ocean Institute cruise FK200126. During this mission, the RV Falkor collected bathymetric and oceanographic data, and remotely operated vehicle (ROV) recordings of the benthic fauna inhabiting the seabed. The study area is included within the Bremer Marine Park, known for the seasonal presence of large populations of cetaceans.

Our study considered a set of three ROV videos that were analyzed for taxonomic identification of mega epifauna. The ROV footage documented diverse benthic habitats in the BCS, often dominated by cnidarians, including cold-water-corals (CWC). We provide a first quantitative description of CWC-bearing habitats and map their distribution in the area. Our exercise focuses on one specific CWC category, i.e. solitary scleractinians (or cup corals) as the main descriptors of the habitats.

Occurrence points of cup corals and geomorphological indices derived from bathymetry were used as input for a Habitat Suitability Model (HSM), with the aim of identifying areas suitable for the presence of CWC in the BCS. Our results show that the BCS hosts highly diverse deep-sea habitats in which CWC represent a dominant component. The predicted area with conditions suitable for cup coral colonisation within the BCS is 3.67 Km2, with canyons heads and slopes showing the highest suitability index. This approach widens considerably the potential area inhabited by CWC in the BCS, well beyond the sites explored by the three ROV dives.

CWC habitats are distributed worldwide and represent hotspots of biodiversity, which are under threat by natural and anthropogenic causes. Spatial information on their distribution is therefore essential to effectively manage and conserve these important ecosystems. Such information and approaches as described here, may also prove useful tools to support broader conservation and natural resource management programs within marine protected areas especially, and help guide future exploration of these habitats.

BENTHIC BIOTOPE IDENTIFICATION AND CLASSIFICATION IN THE CHALLENGING ENVIRONMENTS: SE BALTIC SEA REEFS AND ARCTIC BAYS IN SVALBARD

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Identification of benthic habitats in shallow sublittoral areas can be a challenging task in different environments, for example, hard accessibility with ship due to floating ice and steep slopes in Arctic bays, while in SE Baltic Sea reefs heterogenous hard and mixed bottoms hinder traditional sampling approaches (grab, trawl, box corers, etc.). Remote sensing techniques (satellites, LIDAR) routinely used to characterize the seabed in clear water bodies cannot be applied in places with higher turbidity caused by eutrophication (e.g., Baltic Sea) or melting glaciers in Svalbard. One of the options here is underwater visual technology, which has grown in popularity in recent decades based on its effectiveness in hard-to-reach places. Depending on the properties of the seabed, underwater imagery can be utilized for benthic biotope identification and classification in such challenging environments as we show in our study.

During the 2021 summer-autumn sampling season we filmed 289 video transects in offshore reefs and 66 in coastal reefs in Lithuanian marine area. Underwater video from Svalbard was collected during the 2018 - 2019 summer expeditions in 4 bays at 2-65 m depths. Data acquired was used for the extraction of video frames and the creation of 2D video mosaics. Visual features in frames and 2D mosaics were annotated using labelbox tool. Annotated imagery was then used to train deep learning models for automatic detection and quantification of biotope features.

Analysis of imagery from Svalbard revealed dominant benthic macrofaunal assemblages in glaciated and ice-free arctic fjords, most common were: tube dwelling polychaetes, Ophiurida, bryozoans and bioturbating worms. In SE Baltic several reef associated species were quantified: *Mytilus edulis trossulus* and *Amphibalanus improvisus* in offshore, perennial red algae *Furcellaria lumbricalis*, red algae *Vertebrata fucoides* and green algae *Cladophora* spp. in coastal area. Furthermore, the composition and the coverage of substrate types (boulders, pebble, coble, sand) were also estimated.

The results from underwater imagery analysis are further used for the assessment of sea-floor integrity descriptor under MSFD, while the development of deep learning models for automated quantification of biotope defining visual features can lead to faster, more effective and extensive video data analysis.

Session 2 – Coastal and shallow water habitats

NATIONWIDE MONITORING OF SUBMERGED AQUATIC VEGETATION IN SWEDEN USING A COMBINATION OF DRONE AND SATELLITE IMAGERY

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According to the EU Habitats directive, the Water Framework Directive, and the Marine Strategy Framework Directive, member states are required to map, monitor, and evaluate changes in quality and areal distribution of different marine habitats and biotopes to protect the marine environment more effectively. Submerged aquatic vegetation (SAV) is a key indicator of the ecological status of coastal ecosystems and is therefore widely used in reporting related to these directives.

Environmental monitoring of the spatial distribution of SAV is lacking in Sweden due to the challenges of large-scale monitoring using small-scale methods, such as traditional ground surveys or novel drone imagery. To address this gap, in 2020, we started a project to combine Copernicus Sentinel-2 satellite imagery, novel machine learning (ML) techniques, and advanced data processing in a cloud-based web application that enables users to create up-to-date SAV classifications. Simultaneously, a widespread field inventory program was initiated to collect aerial drone images from shallow soft bottom areas with SAV. Data from drone images are used as independent data to train or validate the analysis of satellite images, and at the same time small scale changes in individual seagrass meadows can be monitored.

The approach has been used to derive the first high-resolution SAV map for the entire coastline of Sweden, where an area of 1550 km^2 have been mapped as SAV. Quantitative evaluation of the accuracy of the satellite derived classification from three different regions along the Swedish coast demonstrate relative high accuracy within shallower areas, particularly where water transparency is high, as on the Swedish west coast (on average 77%; range 64%–89% accuracy). However, in deeper areas and in areas with poorer water quality, the classification misses large proportions of vegetation (on average 31%–50%).

We will present the results of the first satellite-derived SAV classification for the entire Swedish coast and show the implementation of a scalable cloud-based SAV mapping application (prototype) developed within the frame of the project, which could serve as a tool used across countries.

OPTIMIZING THE OBSERVATION SCALE FOR COASTAL HABITAT MAPPING

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Salt marshes, mudflats, and eastern oyster (*Crassostrea virginica*) reefs line much of Florida's Gulf of Mexico coastline. These systems offer services such as water filtration, shoreline erosion control, and habitat provision for recreationally valuable fish. Monitoring these habitats is becoming more of a priority, especially in the case of oyster reefs that are declining due to stressors like overharvest and the increasing frequency of low freshwater flow events. However, monitoring intertidal habitats is logistically challenging and often time-intensive as the tides limit sampling time and accessibility to survey areas. Unoccupied aircraft system (UAS) imagery presents a solution to address these difficulties by allowing an expedient mapping method that is low cost and mitigates accessibility limitations. Despite the advantages of UAS imagery, there is limited understanding of the best methods to ensure efficient mapping and monitoring of these resources.

This study aims to explore one of these gaps – the optimal spatial resolution, or observation scale, at which to collect imagery for habitat mapping of intertidal habitats. Multispectral (red-green-blue) imagery was collected in an intertidal area with mudflats, oyster reefs, and salt marshes near Cedar Key, Florida, USA. The imagery was processed to produce an orthomosaic and digital surface model (DSM), which were both resampled to spatial resolutions ranging from 1 cm to 31 cm in increments of 2 cm. This range of resolutions allowed for observations of any increase or decrease in classification accuracy at a given scale. The upper limit of resolutions was selected to be consistent with what is typical of aerial imagery or commercially-available satellite data. Geographic object-based image analysis (GEOBIA) was used to classify each orthomosaic and DSM into the respective habitat covers (*i.e.*, mudflat, oyster reef, salt marsh, water) using the SegOptim package in R. SegOptim allows for the optimization of segmentation parameters, limiting bias of random parametrization. A random forest classifier was used following segmentation.

Classification accuracies were statistically comparable across the resolutions, with overall accuracies ranging from 75% to 82%. The mean and standard deviation of the DSM were consistently the two most influential variables in the random forest classification. The elevation and heterogeneity of the surface drove the classifications, indicating the importance of the inclusion of terrain characteristics in classification workflows to complement spectral information. These findings also suggest that very-fine resolution may not add discriminative power to the classification algorithm. As a result, monitoring efforts need not target excessively fine spatial resolutions for classification purposes, which also means that they can fly UASs higher, resulting in an increased mapping coverage per battery charge and more efficient efforts. Implementing these findings will further streamline mapping and monitoring without sacrificing the quality of habitat maps.

The classification performances also highlighted that the four cover types achieved the highest user's accuracy at different spatial resolutions, confirming that no single scale is optimal for the observation of all habitat types. Marsh and oyster habitats (96% and 84% user's accuracies, respectively) were best captured at coarser resolutions (23 and 17 cm, respectively), while water and mudflats (86% and 82%) were best captured at finer resolutions (5 and 9 cm). While the classifications performed well overall, this result suggests that the habitat targeted should be considered when planning surveys, or that multiscale approaches are necessary. The results of this study provide guidance on best practices for UAS imagery collection and processing for intertidal

habitat mapping. While useful for estimating habitat coverages, these methods do not assess the health of the surveyed habitats. Future work will further explore the terrain characteristics of oyster reefs to better assess reef status, as healthy oysters are more likely to be vertically oriented.

3D UNDERWATER PHOTOGRAMMETRIC INVESTIGATION OF PECULIAR COLUMNAR CORALLIGENOUS BIOCONSTRUCTIONS OFFSHORE MARZAMEMI (SOUTHEASTERN SICILY, IONIAN SEA)

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Coralligenous bioconstructions include calcareous build-ups of biogenic origin that typify selected regions of the Mediterranean Sea. These habitats thrive from shallow waters (15-20 m of w.d.) up to the limit of the mesophotic zone, and they formed since the Holocene transgression. They are from a few to tens of meters large, displaying variable lateral continuity and thickness. Offshore Marzamemi village (southeastern Sicily, Ionian Sea), peculiar Coralligenous outcrops grow in columnar-shaped forms, partially isolated on the seafloor. Their distribution across the shelf was investigated within the project CRESCIBLUREEF - Grown in the blue: new technologies for knowledge and conservation of Mediterranean reefs, using seafloor mapping data ground-truthed by ROV video inspections. The high-resolution digital terrain models provided by the acoustic survey allowed us to map the extension of well-developed sub-horizontal and deep coralligenous reefs over the entire surveyed area. However, the obtained models cannot provide community-level information associated to these complex habitats, especially when reefs form sub-vertical and/or overhanging walls (as in the case of columnar-shaped build-ups).

To overcome this limitation, multibeam bathymetric data were combined with a high-precision survey, obtained through the implementation of underwater photogrammetry techniques in an area characterized by a high density of coralligenous pillars located at 35/40 meters of water depth. The perfect spot was identified from the analysis of the multibeam map together with ROV videos. Surveys were carried out using a Sony Alpha 7, a full-frame mirrorless camera with an underwater housing (Leo3 EasyDive), equipped with two powerful led lamps. Divers swam at low speed, following parallel transects over a 6x6 m area of the seafloor, delimited by a metric tape. Photos were acquired continuously with a nadiral orientation at a regular distance, to allow optimal images overlap. Then, all the photos were processed using Agisoft Metashape, following the well-established photogrammetric workflow.

The high-resolution outputs, such as 3D meshes, digital terrain models and orthomosaics result to be instrumental for the in situ study of the structural complexity of coralligenous bioconstructions. The integration of the multiscale data obtained from our work aims to propose an innovative approach for the definition of eco-geomorphological indexes throughout the whole monitored area

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INTEGRATING SEDIMENT DYNAMICS INTO HABITAT MAPPING APPROACHES USING SEDIMENT MOBILITY INDICES AND SEABED CLASSIFICATION IN GALWAY BAY, IRELAND

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Sediment dynamics information provide vital insights into the important role of oceanographic forcing factors on habitat distribution; yet remains an under-utilized physical surrogate in marine habitat mapping studies. An integrated oceanographic and geophysical analyses of dynamic processes combining sediment mobility indices, obtained from coupled-hydrodynamic-wave sediment transport models; with seabed classification has been made at Galway Bay, Ireland.

Maerl or rhodolith coralline red algae beds are abundant in Galway Bay and these beds represent more than 65% - 70% of the maerl habitats in Ireland (De Grave and Whitaker, 1999). Maerl beds are particularly affected by hydrodynamics and increased storminess resulting in recurrent disturbance of the benthic habitat patch during winter storms. Live maerl beds are biodiversity rich coastal habitats and form subtidal and intertidal banks and open marine beds. Dead maerl beds of the branched maerl morphotype are considered to be biogenic sediment with form dense biogenic gravel debris beaches.

Sediment mobility modelling is of importance to a range of disciplines including sediment dynamics, marine conservation, coastal engineering, and renewable energy (Harris and Coleman, 1998; Idier et al., 2010; Li et al., 2015, Joshi et al, 2017a, Coughlan et al. 2021). It is based on the fundamental quantity of bed shear stress and the impact of pure currents, wave-only, wave-induced currents or combined wave-current flow on surficial sediments.

Multibeam backscatter from the INFOMAR national seabed mapping program of Ireland have been utilized for seabed classification using the new machine learning and deep learning libraries in ArcGIS Pro and Python.

An integrated interpretation of the dynamic processes happening at the seafloor is made as a result of the combined wave-current induced disturbance regime during storm conditions. Implications for future conservation management of maerl beds impacted by increased storminess and anthropogenic activity are discussed.

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SEAGRASS MAPPING USING SPECIES DISTRIBUTION MODELING AND MULTIBEAM ECHOSOUNDER AROUND REDANG ARCHIPELAGO

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Climate change and anthropogenic activity have harmed the seagrass environment. As a result, a systematic habitat mapping and identification process is essential to ensure that seagrass is conserved and regularly monitored. The research aims to create a seagrass seascape map of the Redang archipelago using Multibeam Echosounder (MBES) technology and machine learning algorithms (i.e., maximum entropy, random forest, and support vector machine).

As predictors, a bathymetric map, a backscatter mosaic, and their associated predictors (slope, eastness, northness, curvature), Gray-Level Co-Occurrence Matrix (GLCM) texture feature (homogeneity, entropy, correlation), and Angular Range Analysis (ARA) parameters (phi and characterization) were used. Seagrass occurrence data was utilized to train and test the SHSM, whereas seascape feature data was used to classify and validate the seafloor classification map.

The findings show that models with high accuracy (>90%) were produced using fine (1 m) and coarse spatial resolution (50 m) datasets. The findings also show that backscatter predictors such as ARA characterization, ARA phi, Gray-Level Co-Occurrence (GLCM) texture features, and backscatter mosaic 32-bit were more important in developing SHSM for coarse resolution models. Bathymetry was discovered to be the most significant predictor for all models. However, for different analysis window widths (3 × 3, 9 × 9, 21 × 21), the models developed from the coarser geographical resolution dataset produced inconsistent habitat suitability maps compared to the models derived from the finer spatial resolution dataset. The RF and MaxEnt models had the highest predictive accuracy (>90%), while the SVM model had the lowest predictive accuracy (<90%). Overall, this research produced a detailed seagrass habitat suitability map and precise information about seagrass habitat distribution in Malaysia.

The enhanced habitat model was presented by using a seabed habitat map, which combined the seagrass habitat suitability index with seafloor features (i.e., coral, seagrass on fine sand, seagrass on coarse sand, fine sand, and coarse sand). A detailed seascape seagrass map was generated using the proposed integration method. The information obtained from the seascape seagrass map will aid decision-makers, such as the marine park authority, in managing seagrass habitats.

ADVANCES IN THE STUDY OF GEOHABITATS ON THE BRAZILIAN CONTINENTAL SHELF: IMPORTANCE OF INCT AMBTROPIC*

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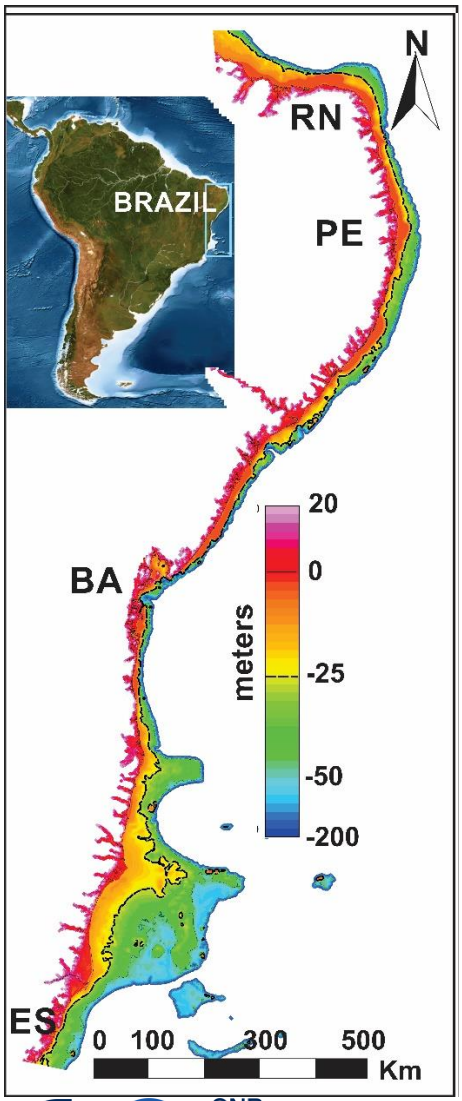
Brazilian participation in GEOHAB conferences started in 2012 and has remained constant since then, including the holding of GEOHAB 2015 in Salvador, Bahia, at the initiative of INCT AmbTropic. The participation and interaction of researchers and students in the workshops and technical presentations made it possible to carry out the first habitat mapping works in Brazil. The second edition of the book Seafloor Geomorphology as Benthic Habitat (HARRIS & BAKER, 2020) includes several case studies on the coast of Brazil, all in the east-northeast region, mostly directly linked to the INCT AmbTropic. While in the first edition there was no case study on the Brazilian coast.



Here we present a brief overview of the main geomorphic features observed in the Brazilian tropical margin between the states of Rio Grande do Norte and Espirito Santo (Fig. 1). The shelf under study ranges from the narrowest portion (8-9 km) of Brazil, attributed to strong structural control, to one of the widest (200 km), as a result of intrusive volcanic activity. Although the narrower portions of this shelf are almost completely covered by carbonate sediments (essentially bioclastic), wider areas show mixed sedimentation, with siliciclastics predominating on the inner shelf and carbonate ones on the outer shelf, generally from 25-30 m in depth until the shelf breaks. Figure 1 shows the study area, where the red color represents the land-ocean interface (emphasizing the connection with mainland rivers). The orange tones correspond to the inner shelf (composed predominantly of siliciclastics), and the yellow ones to the middle shelf (different mixtures between siliciclastics and bioclastics); shades of green and blue, in turn, represent the external shelf.

Incised valleys, beachrocks, subaquose dunes and coral reefs (both shallow and mesophotic) are the main features present. There is still no single geohabitat map for this area. The habitat maps already generated and published have different methodologies and the case studies presented here are examples of these differences.

Figure 1. Location map (source: planetary vision) and Study area. Tropical shelf. GEBCO database

MORPHOLOGY AND MIGRATION CHARACTERISTICS OF ESTUARINE BEDFORMS: CASE OF BOUREGREG ESTUARY, MOROCCO

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The lower reach of the Oued Bouregreg, located on the Atlantic coast of Morocco between the large urban centers of Rabat and Salé, is a microtidal riverine estuary that receives little sediment input from the hinterlands of the Bouregreg catch basin. The main channel is filled with medium sand to muddy sediments.

A field study was conducted in the Oued Bouregreg estuary with the overall objective to improve knowledge about the morphology and sediment dynamics of bedforms in the main estuarine channel. The suite of measurement techniques included: CTD, bottom videography, side-scan sonar, sub-bottom profiler and a Van Veen bottom grab sampler. Morphometric parameters and temporal variability were stratified according to dune type, and analyzed to estimate the sediment dynamics. The integrated data sets were acquired during October 2016 and March 2017. The acoustic measurements of the seabed were made within a few hours either side of high tide.

The main groups of bedforms that were identified in the area were: 2D dunes, 3D dunes, scours and flat bottom. The dunes exhibited different morphological configurations, which are differentiated into straight, sinuous and barchan dunes. The dunes were mostly asymmetrical in cross-section and had a downstream NNW-SSE orientation. The equilibrium relationships obtained from this estuarine morphological analysis were compared with previously published results. Across the estuary, the dune field configurations and distributions of diverse types of bedforms appear to be highly dynamic.

The results have wide implications in terms of modelling hydrodynamics and sediment transport from the superimposed effects of human interventions and climate change.

INNOVATIONS ON GLOBAL CORAL REEF GEOMORPHIC AND BENTHIC HABITAT MAPS: THE ALLEN CORAL ATLAS

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In 2021 the first globally consistent, high thematic and spatial resolution geomorphic and benthic maps with complete coverage of shallow coral reefs were made accessible through the Allen Coral Atlas. The Allen Coral Atlas maps increase the ability to understand the composition of our reefs, design marine protected areas, model ecosystems in space and time and support field site selection.

This talk will provide a short overview of the habitat mapping process, followed by improvements on the 2021 mapping process as a result of ongoing research and expert feedback. On region by region basis the mapping process was applied include includes: a) input data: over 2 million satellite scenes, physical properties (depth, slope, waves) and over 500 reference field data sets received from the community and expert knowledge, b) a classification scheme, c) an machine learning and object based editing routine to create the maps and d) validation routine.

We then present improvements of the 2021 global habitat maps using the Pacific Region as an example, utilising both technical innovations to the mapping process, as well as integration of local and global expert feedback.

We discuss some examples of these changes, contrast it to other global maps, and review some of the limitations of the geomorphic and benthic habitat maps. The new version of the habitat maps will be accessible and freely downloadable by the end of 2022 from www.allencoralatlas.org.

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UTILIZATION OF HIGH-RESOLUTION AIRBORNE LIDAR BATHYMETRY FOR AUTOMATIC MAPPING OF SHALLOW SEAFLOOR, A CASE STUDY FROM THE SOUTHERN BALTIC

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Measuring the seabed with bathymetric LiDAR is among the most difficult tasks to perform with airborne surveys. Despite this, Airborne LiDAR Bathymetry datasets are currently increasingly widespread due to the greater availability of technology and open access to measurements from different sources. Sustainable management of shallow coastal zones requires accurate exploration, monitoring, and protection, as well as planning and construction of coastal protection structures. Therefore, repeated assessment and monitoring of such zones are absolutely necessary for the abovementioned purpose.

This study provides a comprehensive method for automatic exploration and mapping of bedforms and anthropogenic structures based on DEM from topo-bathymetric LiDAR, Riegl VQ-1560i-DW. This bathymetric scanner can register accurate point clouds with a penetration range of up to 0.7 Secchi depth, allowing reaching the range from 0 to -8.5 m in this case study. Data processing included object-based image analysis with a Random Forest classifier and 21 predictor variables. They allowed distinguishing nine classes of bedforms and three classes of coastal protection structures. The developed method was applied to six research polygons and an approximately 50 km nearshore zone of the Baltic, reaching more than 90% overall accuracy.

Because of sea-level rise, the management of such zones needs a quick and adequate method for mapping and monitoring shallow areas for their proper assessment and rapid response. The simple approach presented in this study is straightforward, clear to test and implement so that it can be easily utilized in other Airborne LiDAR Bathymetry datasets, including potential change detection analysis for consecutive datasets from different timesteps.

SPATIO-TEMPORAL MAPPING AND MONITORING OF A SUB-ARCTIC INLET

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It is only once a system's baseline has been well characterized that variations outside of the normal range can be identified. However, with current climatic trends, we are running out of time to establish natural baselines against which to measure ecosystem shifts. As a result of strong seasonal variations, cold-ocean systems may be particularly sensitive to climatic variability, unfortunately, this also leads to most of our observations being strongly biased towards warmer months of the year. This lack of seasonal representation may be particularly true of habitat mapping studies, as considering how much of our ocean remains to be mapped, it is rare that we have the opportunity to revisit the same location over time. This means, that most habitat maps represent a snapshot in time, from which potential spatio-temporal variation is missing. In 2020, benthic video imagery was seasonally acquired in the Holyrood Inlet of Conception Bay, NL, Canada, and combined with previously acquired multibeam and backscatter maps. We constructed full-coverage maps representing the spatio-temporal change in megabenthic invertebrate species assemblages across seasons, and to better understand the dynamics occurring in response to the spring phytoplankton bloom, a camera was deployed on a cabled seafloor observatory to acquire high resolution time-lapse imagery. As should probably have been expected, significant differences in species assemblages across seasons were recorded. Specifically, in response to the spring phytoplankton bloom which started in mid-March, organism densities quadrupled, mainly driven by the appearance of the sessile sea cucumber *Psolus c.f. phantapus*. This spatio-temporal benthic dataset from a sub-Arctic environment highlights the need for habitat mapping to start considering temporal variations in order to ensure robust datasets for monitoring and early detection of future perturbations.

INTEGRATION OF MULTI-BEAM AND UAV DATA TO MONITOR MORPHOLOGICAL CHANGES IN TIDAL SALT MARSHES OF THE VENICE LAGOON

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Salt marshes are important habitats for ecosystem services, they serve as one of the most powerful carbon sinks and act as natural defense against extreme storm conditions and sea level rise. They are seriously threatened by accelerating sea-level rise and sediment deprivation, which result in a consequent reduction of their extension. Accurate information on morpho-dynamics and spatial distribution is crucial for the management and protection of salt marshes. However, reconstructing the topography of salt marshes with classic methodologies is challenging because their accessibility is limited by the poor compaction of the muddy soil and by the presence of a dense vegetation. We present a new approach that permits the mapping of salt marshes through the integration of unmanned aerial vehicle (UAV) acquired aerial images and multi-beam echosounder data. The study was conducted from 2020 to 2021 in a section of the San Felice Channel, in the northern Venice Lagoon basin. The topography of the emerged part of the studied area was reconstructed using Structure-from-Motion (SfM) techniques applied to aerial imagery. We obtained a precise and accurate three-dimensional Digital Elevation Model of dry areas and shallow water, which was then integrated with bathymetric data of the submerged part of the study area. The two terrain models were interpolated to create a comprehensive morphological map of the San Felice salt marsh and tidal channel for two consecutive years. The results suggest that the method is a promising tool to map salt marshes extensively. Moreover, analysis of the changes of the morphological maps shows erosion along the shoreline of the salt marsh and accretion in the adjacent tidal channel of San Felice. This study provides a cost-effective and sustainable way of monitoring of estuarine areas to implement environmental management plans.

MAPPING LOCAL AND SPECIES CONTRIBUTIONS TO BETA DIVERSITY IN THE PORCUPINE BANK CANYON

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Submarine Canyons have been identified as important conduits of organic matter from the shelf to the deep sea as well as hotspots of biodiversity. The Porcupine Bank Canyon (PBC) incises the Irish continental margin and harbours diverse cold-water coral (CWC) ecosystems ranging from 600-1000 m water depth. However what drives biodiversity and how does it relate to the complex geomorphologies of the upper PBC?

This study investigates the relationship between geomorphology, habitat and biodiversity using high-resolution multibeam echosounder data at 25m resolution and its bathymetry derivatives as well as biological data from an extensive ecological survey conducted using ROV video dives in 2017. The variance of a dissimilarity matrix of 29 sites with 56 ± 2 quadrats each was decomposed to map local contributions to beta diversity in the upper PBC and determine species contributions to total variance.

Results indicate evenly spread contributions to beta diversity along the ledge of the canyon. Two sites further removed from the canyon ledge are depauperate leading to significant deviations from the prevalent species community patterns — one on the flat shelf adjacent to the canyon flank and one near the thalweg of the southern branch. The CWC Desmophyllum pertusum (aka. Lophelia pertusa) has the highest species contribution to beta diversity, underscoring its sensitivity to local environmental gradients and potential role as an ecosystem engineer. The findings suggest that mixing and increased food supply at the canyon ledge and steep flanks may provide improved conditions for diverse species assemblages and coral mound development.

SEAFLOOR LANDFORMS OF THE CENTRAL PART OF HAAKON MOSBY MUD VOLCANO (BARENTS SEA) RECONSTRUCT THROUGH ROV VIDEO PHOTOGRAMMETRY

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Submarine mud volcanoes are seafloor landforms formed by upward migration of subsurface gas together with fluids and sediments by buoyancy and gravitational forces. Haakon Mosby mud volcano is a 1 km wide active mud volcano located at 1256 m depth in the Barents Sea (72°N, 14°44E). It is characterized by strong thermal and geochemical gradients from its center to the margins resulting in a zonation of chemosynthetic habitats.

Two zones of the active central part of the volcano were explored using Ægir6000, a work-class ROV (Remotely Operated Vehicle) equipped with three HD video cameras that filmed the ocean floor at different angles. The ROV, moving at a constant speed of 1 knot, followed predefined routes to guarantee optimal lateral overlap between adjacent transects. From the videos of the nadiral camera, a photogram every two seconds was automatically extracted. Then, the images were processed in Agisoft Metashape® following a well-established photogrammetry workflow. As final outputs, we obtained 3D mesh, orthomosaics and DTMs at ultra-high-resolution (mm) allowing us to obtain detailed morphometric maps.

These data made it possible to reconstruct accurate georeferenced 3D models that represent one of the most exciting submarine landforms with a resolution never achieved before at this site. These models can help clarify the ongoing processes in this area and their evolution over time. This work was supported by the Research Council of Norway, for AKMA - Advancing Knowledge on Methane in the Arctic, project number 287869.

CREATING A MAPPING TOOL TO ESTABLISH BEST PRACTICES FOR SALT MARSH RECONSTRUCTION IN THE VENETIAN LAGOON

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Salt marshes are crucial ecosystems at the boundary between land and sea that provide a number of ecosystem services such as reducing tides and storm impacts on coasts, filtering excess nutrients and pollutants from the water, and providing nursery areas for fish and birds. Moreover, they can serve as an important organic carbon sink due to their ability to sequester atmospheric CO_2. Over the last century, the Venetian lagoon has experienced extensive salt marsh loss and continuous degradation, induced by a consistent and ongoing net loss of sediments from the lagoon and exacerbated by natural and anthropogenic processes including sea level rise (SLR) and waves generated by wind and boat traffic. In response to these issues, numerous interventions concerning lagoon morphology have been proposed and implemented over the years, with the aim of protecting the existing habitat as well as creating new salt marshes and mudflats. In the current setting of the Venetian lagoon, the salt marsh reconstruction is based on the reuse of dredged material coming from the maintenance of the shipping channels and previously was carried out using materials imported to the lagoon from a variety of sources. This poses a first challenge linked to the heterogeneity of the materials dredged from different parts of the lagoon as well as imported sands together with the lack of traceability. On top of that, the survival of an artificial salt marsh is crucially dependent on the complex interplay between geomechanical, hydraulic and biotic processes, and highly variable outcomes for reconstructed salt marshes. Some of these have rapidly eroded and are now mostly submerged or did not develop proper halophytic vegetation.

In this context, we initiated an extensive mapping exercise to integrate in a single GIS environment the large amount of information collected from different sources (e.g. collection of past reconstruction works from "Magistrato alle Acque di Venezia" and "Provveditorato Interregionale per le Opere Pubbliche per il Veneto, Trentino Alto Adige e Friuli Venezia Giulia", presently ongoing and planned reconstructions from the latest "Piano Morfologico e ambientale della Laguna di Venezia" from "Ministero della Transizione Ecologica", manually integrated from the design cartography, sediments characteristics at specific locations from "Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto" ("ARPAV"), morphological and ecological conditions of specific salt marshes from "Provveditorato Interregionale OO.PP." and internally conducted surveys, etc…). In addition, we have begun periodic monitoring, mostly by drone inspections, on specific reconstructed salt marshes, in order to evaluate the morphological conditions (e.g. submerged and above-water parts, vegetated area, presence of morphological features, etc…) as well as the successional development of the different vegetation communities.

This GIS-based approach to organizing information is improving our understanding of the factors and design procedures which determine the success or failure (both in terms of resilience and ecological functionality) of a salt marsh reconstruction, and has proved an essential component for the parallel activity of reviewing available design documents and operational plans of some recently completed salt marshes. Finally, the acquired knowledge is already being used in the design of a series of interventions on two pilot sites, with the aim of promoting the development of ecologically functioning marshes and, more generally, promoting a "natural-capital" based

approach to the development of Venice, as an alternative to continuing decline of the stability of the lagoon system.

AN ACCURATE METHOD FOR HIGH-RESOLUTION AND CONTINUOUS MAPPING OF LOOSE SEDIMENTS IN THE CONTINENTAL SHELF: TWO CASE STUDIES IN THE MEDITERRANEAN SEA, BAGNOLI-COROGLIO AREA (GULF OF NAPLES, ITALY) AND LAMPEDUSA ISLAND (SICILY CHANNEL, ITALY)

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The modeling approach presented in this research can be seen as an accurate method for high-resolution and continuous mapping of loose sediments in the continental shelf, which can be used in several applications. Seafloor topography and grain size distribution are pivotal features in marine and coastal environments, able to influence benthic community structure and ecological processes at many spatial scales. Accordingly, there is a strong interest in multiple research disciplines to obtain seafloor geological and/or habitat maps.

For this purpose, we calibrated a linear regression model relating grain size distribution values, extracted from samples collected in a 16 km^2 area near Bagnoli–Coroglio (southern Italy), against backscatter and depth-derived covariates. The linear model achieved excellent goodness-of-fit and predictive accuracy, yielding detailed, spatially explicit predictions of grain size. Additionally, the same model was also projected onto a test area of 18 km^2, i.e., Lampedusa Island, although here no ground-truth samples were available, except for a few remotely operated vehicle images, along with a former map of the seafloor features based on a mixed expert-based and unsupervised approach. The results from the Bagnoli–Coroglio area showed excellent accuracy and negligible areas of extrapolation, while the map for Lampedusa was largely in concordance with expert-based previous seafloor mapping. The method relies on free software and can be validated and/or recalibrated using 1.3 ground-truth samples per km^2 of survey area.

Regardless of some limitations (i.e., inability to predict rocky outcrops and/or seagrass meadows), our modeling approach proved to be a flexible tool whose main advantage is the rendering of a continuous map for sediment size, in lieu of categorical mapping approaches which usually report sharp boundaries or rely on a few sediment classes. These features can be pivotal in ecological, geological and management applications in marine coastal ecosystems.

BENTHIC HABITAT MAPPING USING MULTIBEAM ACOUSTICS AND GROUND-TRUTHING TECHNIQUES IN THE TIDAL CHANNELS OF THE NORTHERN VENICE LAGOON

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The Venice Lagoon is a complex, heterogeneous and highly dynamic system, subject to anthropogenic and natural pressures that deeply affect the functioning of this ecosystem. Thanks to the development of acoustic technologies, it is possible to obtain maps with a high resolution that describe the characteristics of the seabed.

With this aim, a high resolution Multibeam Echosounder (MBES) bathymetry and backscatter survey was carried out in 2021 within the project Research Programme Venezia 2021. Ground-truthing samples were collected in 24 sampling sites to characterize the seafloor and validate the maps produced with the MBES acoustic data. Ground-truthing included the collection of sediment samples for particle size analysis and video footage of the seabed to describe the biological component.

The backscatter data was analysed using the unsupervised Jenks classification. We created a map of the habitats integrating morphological, granulometric and biological data in a GIS environment. The results obtained in this study were compared to those collected in 2015 as part of the National Flagship Project RITMARE. Through the comparison of the repeated morpho-bathymetric surveys over time we highlighted the changes of the seafloor geomorphology, sediment, and habitat distribution. We observed different type of habitats and the presence of areas characterized by erosive processes and others in which deposition occurred. These effects led to changes in the benthic communities and in the type of sediment.

The combination of the MBES surveys, the ground truth data and the GIS methodology, permitted to construct high-resolution maps of the seafloor and proved to be effective implement for monitoring an extremely dynamic area. A consistent, repeatable, logical site-specific workflow was designed, whose main assumptions could be applied to other seabed mapping case studies. This work can contribute not only to broaden the knowledge of transitional environments, but also to their monitor and protection.

CARBONATE REEFS AT MESOPHOTIC DEPTHS: OFFSHORE SOUTH-EAST MALTA

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The mesophotic zone is a world between worlds - between the well-lit and clear shallow seas, and the cold, dark and deepest depths of the ocean. In the Mediterranean Sea the mesophotic region (between 40 and 130 metres water depth) offshore south East Malta is not well documented. Recent surveys have identified hundreds of small structures, which have been visually verified as carbonate edifices by an ROV, in two distinct water depth ranges. The first group depth range is about 40 to 80 metres below present sea level, and the second group at 80 to 120 metres depth.

The sea level in the Mediterranean has fluctuated over the last glacial period by over 120 metres. It is therefore conjectured that the shallower group mounds may have originated as euphotic reef formed on a terrace which has subsequently been drowned. The various standstills of post-glacial transgression may account for some of the abrasion seen on some mounds. However, the deeper group of mounds do not correspond so well with the glacial cycle and are suggested that groundwater and hydrocarbon discharge (such as methane) account for the diverse colonisation of these mounds.

The mounds are generally rock outcrops and not boulders, but covered with abundant organisms of Cnidaria (e.g. Antipathella subpinnata, Antipathes dichotoma) Echinodermata and Porifera, giving refuge and feeding grounds for both pelagic and benthic organisms, some being classed “Near Threatened” on the IUCN Red list. Unfortunately, the environment is being impacted by anthropological activities, in particular, trawling. The backscatter mosaics show a network of trawling marks, criss-crossing the area in-between and through these mounds. The areas surrounding the mounds are generally lightly rippled flat sediment.

Protection from trawling is proposed for these areas. This would require legislative action to be taken, to declare the seafloor offshore South East Malta as a Marine Special Area of Conservation, in the same way that other reef and biogenic buildup areas offshore Malta are detailed (ERA, 2021).

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EXPLORING NATURAL HARD-SUBSTRATE HABITAT IN BELGIAN WATERS: CASE STUDY ON A RECENTLY DISCOVERED HOTSPOT

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The ecological relevance of marine subtidal natural hard-substrate habitats is a globally undisputed fact. In predominantly sedimentary seafloors, such as for the Greater North Sea, their ecological relevance substantially increases given the paucity of foundation species. The southern North Sea is a marine region with relatively scarce amounts of hard-substrate seafloors (e.g., gravel beds). Strong tidal currents, frequently inclement hydrometeorological conditions, and considerable water depths for e.g., diving, challenges the implementation of surveys with high spatial and taxonomic resolution, hindering our understanding of the characteristics and functions of this type of habitat in the North Sea. The goal of this study was to extend the knowledge on a recently discovered natural hard-substrate habitat (i.e., rocks, stones, and associated biota) beneath the busiest shipping lane of the world, in the offshore Belgian part of the North Sea; a maritime region wherein the historical and modern turmoil of mankind has brought this fragile habitat to a considerably degraded state, mainly due to intensive bottom disturbing commercial fishing practices. Different data types were investigated to obtain comprehensive information on the environmental and anthropogenic driving factors of the discovered and mapped habitat. A combination of acoustic, videographic and sediment sample data was used to obtain quantitative information on biologically colonised hard substrate distribution patterns (i.e., benthic habitat mapping), on the number and sizes of stones, and on the bio-geo relationships explaining the occurrence of epilithic and long-lived sessile organisms. Modelled hydrodynamic variables helped to elucidate small scale distribution patterns of the identified taxa. Moreover, regional, and local patterns of commercial fishing activity further explained the resilience of the identified taxa, suggesting that the shipping lane acts as a prevention against bottom disturbing fishing activities. The operationally viable procedural workflows and information presented in this study, may assist in the formulation of management policies and practices to safeguard these reefs in Belgian waters and elsewhere in the southern North Sea.

A NEW BENTHIC HABITAT MAP OF THE CAMPANIA REGION (ITALY) MERGING DATASETS WITH DIFFERENT SOURCE, SPATIAL RESOLUTION AND TIME-PERIOD

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This work presents an updated benthic habitat map of the Campanian seabed (southern Italy), focusing on seagrass and coralligenous beds. This map has been outlined in the framework of the FEAMP ISSPA (Innovation, development and sustainability in the fishery and aquaculture sector for the Campania Region) Project, financed by the Campania Region under the European Fund for Fisheries and Aquaculture (EMFF). The project aims at identifying the most suitable areas for aquaculture farms, taking into account the protection of vulnerable marine ecosystems. These areas will be identified through a multicriteria analysis in GIS environment taking into account a suite of different spatial information (from chemical and physical variables of the area to human uses). In this perspective, an updated benthic habitat map is essential to support spatial prioritization.

The analyzed datasets were heterogeneous in terms of acquisition methods, sources, scales and time-periods. We collected all spatial information about benthic habitats and species occurrences from scientific papers and reports; we recovered geophysical raw data collected in the Campania Region from previous projects (e.g. CARG project) and reprocessed them with new technologies. After a gap analysis, we acquired and interpreted new geophysical data where seafloor acoustic reflectivity data were fragmented or absent.

From the evaluation and integration of this information, we manually interpreted the data and produced three maps for the seafloor: Geomorphology, Substrate, and Biology. The final benthic habitat map has been generated from the combination of these three factors. Despite challenging, this effort represents an excellent opportunity to capitalize on already existing information, collecting new data only in presence of critical gaps. In the era of MSP and MSFD, this effort should be exported across Italian regions to allow a sustainable use of marine resources.

SEAFLOOR MAPPING IN A HYPERTIDAL SETTING: MINAS BASIN, NOVA SCOTIA, CANADA

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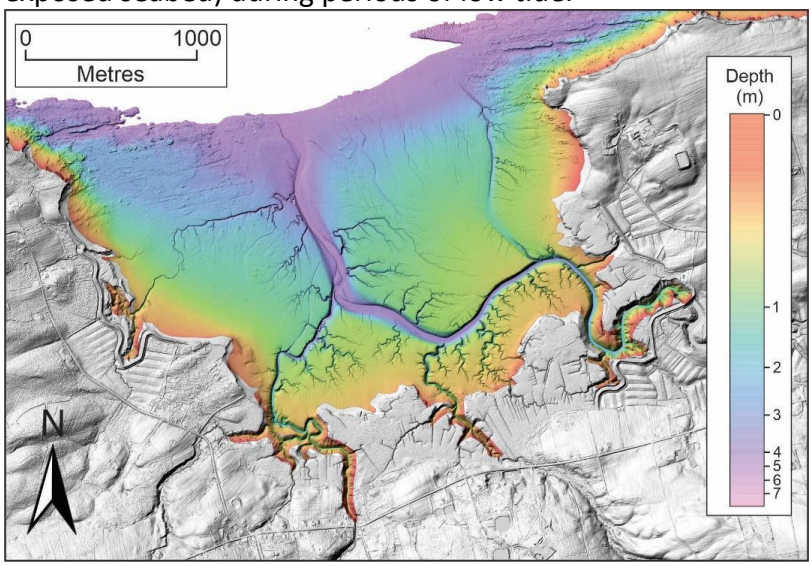
The Bay of Fundy is a large embayment located on the east coast of Canada between the provinces of Nova Scotia and New Brunswick. At the northeastern end of the Bay of Fundy lies the hypertidal Minas Basin that exhibits the highest recorded tides in the world of 17 m. As a result of the hypertidal nature of the Fundy–Minas system, strong currents are generated, reaching a maximum speed of approximately 5 m/s in Minas Channel at the entrance to Minas Basin. Over the past century, investigations in this region has been episodic, with peak activity associated with proposals for large infrastructure construction (barriers and turbines) associated with tidal power development by harnessing the currents. Concern that physical, chemical and ecological changes are taking place in the unique coastal environment Fundy–Minas system has lately generated renewed research.

Much of the Minas Basin is less than 20 m deep and its waters are turbid. The extreme tidal range exposes a large area of intertidal mudflats and salt marshes around the periphery of the basin. The mudflats and marshes host high densities of invertebrates and are a food source for large populations of migrating shorebirds. This intertidal zone presents a particular surveying challenge to the collection of water depth data. Historically, intertidal zones were not surveyed due to the danger involved in operating surface vessels in coastal areas that dry between tides. To obtain bathymetric data for this study, the intertidal portion of Minas Basin was mapped during periods of low tide using aircraft-mounted LiDAR (see image below). The mapping revealed the complex topography of the mudflats and the dynamics of sand bedforms in energetic settings.

The nature of the seabed and the subsurface of the Minas Basin is poorly understood; the only known geophysical profiles date to the mid-1960s. The ultimate objective of the research program is to map the entire seabed of Minas Basin using multibeam sonar either from a surface vessel or from an autonomous underwater vehicle. However, in this hypertidal setting, any vessel/AUV mapping campaign requires an upper bathymetric limit to which to survey. Thus, the first step in reaching complete seabed coverage was to map to the lowest possible “depth” (i.e. exposed seabed) during periods of low tide.



PRELIMINARY RESULTS FROM NEW DATA ACQUISITION OFF THE INNER SHELF OF GULF OF GAETA, EASTERN TYRRHENIAN SEA, FOR THE GEOLOGICAL MAPPING OF SHEET N° 429 MONDRAGONE, 1:50.000 SCALE (CARG PROJECT)

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This work illustrates the preliminary results of the geophysical seafloor investigation conducted by the Institute of Marine Science of Napoli (CNR-ISMAR), for the geological and geothematic mapping of Mondragone area (sheet n. 429), at 1: 50,000 scale. The marine area included in the Mondragone geological sheet is located in the inner shelf of the Gulf of Gaeta, along the Volturno river coastal zone (Litorale Domitio), Eastern Tyrrhenian margin. This coastal area extends for ca. 50 km from the Garigliano Plain to the N to Monte di Procida to the S, and is characterized by a low-lying, relatively straight sandy coastline, mostly dominated by the fluvial dynamics of the Garigliano and Volturno rivers.

In May 2021, a geophysical survey, namely cruise Carg0521, was carried out by the CNR-ISMAR on board of the oceanographic vessel (O/V) "Lighea", of the Italian Institute for Environmental Protection and Research (ISPRA). During the survey a bathymetric dataset was collected using the Kongsberg 2040 multibeam in the Sinuessa sector, offshore Mt. Massico. The survey revealed an articulated seafloor morphology in a bathymetric range between the 10 to 20 m depth that substantially differs from the flat surrounding area. Moreover, a reflectivity dataset acquisition is currently underway by means of a Sidescan system Klein 2000. The survey will cover the entire marine area included in the sheet n. 429, from the coastline down to a maximum depth of ca. 30 m.

After the processing of the geophysical data acquired so far, a seafloor grab sampling survey, namely cruise Carg0222, was planned, again on board of the O/V “Lighea”. The sampling plan, included transects perpendicular to the coast, and a number of diffuse sampling points placed on the basis of the acoustic facies recognized both multibeam backscatter and sidescan sonar acoustic mosaic. A total of 44 grab samples were collected, 30 of which in the Sinuessa sector, characterized by a high morphological and acoustic variability. The results of this study include high-resolution images of the bathymetric and sidescan sonar data acquired in 2021, along with interpretation of sediments and rocks at the seafloor, and recognition of coralligenous assemblages acquired in 2022.

ACKNOWLEDGEMENTS

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HIGH-RESOLUTION MAPPING OF THE SEAFLOOR OFFSHORE MARZAMEMI VILLAGE (SOUTHEASTERN SICILY, IONIAN SEA): EXTENT AND DISTRIBUTION OF CORALLIGENOUS REEFS

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Coralligenous (C) habitat consists of calcareous formations of biogenic origin characteristic of subtidal systems in the Mediterranean Sea. It develops only specific environmental conditions, and its growth is controlled by the delicate balance between bioconstruction and bioerosion processes. C outcrops typify specific areas of the Mediterranean continental shelves. Offshore Marzamemi village (southeastern Sicily, Ionian Sea) peculiar columnar-shaped C outcrops were documented in 2001. Nevertheless, an in depth study of their extension and distribution in the area is still missing. Indeed, this is one of the main goals of the project CRESCIBLUREEF - Grown in the blue: new technologies for knowledge and conservation of Mediterranean reefs .

A new 17 km^2 high-resolution morpho-bathymetric map was produced using a R2-Sonic2022 MBES system, ground-truthed by ROV surveys. The combination of bathymetric and backscattering data, together with the ROV videos, allowed us to identify five main habitats. From a geomorphological point of view, it was possible to divide the area into four main marine terraces. These terraced landforms are probably the result of eustatic sea-level variations coupled with tectonic processes. Of relevant importance is the correlation between C reefs distribution with this geomorphological layout. Indeed, C build-ups result to be more widely spread over the shallowest and deeper terraces at selected depth ranges, from 36 to 42 m and from 82 to 102 m of water depth, respectively.

This study represents a starting point for the understanding of such a complex habitat, which is among the most important in the Mediterranean Sea and under protection by several legal instruments. Further investigations are needed to better understand the C settling in respect to this inherited continental shelf landscape. This is valid under both the biological and geomorhological point of view, as C habitat is a hotspot of biodiversity, and the outcrops affect present-day continental shelf landforms and landscapes.

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Session 3 – Submerged landscapes and cultural heritage

UNDERWATER CULTURAL HERITAGE HIGH-RESOLUTION MAPPING: CASE STUDY FROM THE VENICE LAGOON

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Underwater Cultural Heritage (UCH) sites are common resources having scientific, historical, ecological, educational, and recreational values. However, our knowledge of UCH is still very limited. Moreover, these resources are fragile and non-renewable. Being submerged or buried under the sea-floor, UCH sites are generally hard to identify and study, and difficult to preserve. Once found, then, the UCH sites are rarely accessible to the public. Global sea level rise, consequences of climate change and ecosystem degradation due to human activities are threatening the future conservation of UCH sites. At the same time the general lack of funding devoted to UCH protection and preservation imply that in the long term these resources could be destroyed. Coastal, transitional and lagoon environments, in particular, offer a variety of submerged cultural archaeological sites, given that humankind has populated these areas for millennia for their high productivity. However, very shallow water, heavy silt suspension and very low visibility often limit the access to these important archaeological resources. At the same time, these environmental conditions allowed so far the preservation of the sites. In this contribution, we show how high resolution multibeam echosounder and sub-bottom profiler together with selective video inspections, not only allow for paleoenvironmental reconstruction, but it also can provide new evidence of the presence of archaeological structures both over and within the seafloor. We focussed on a case study in the Lagoon of Venice (Italy) that, together with the historical city of Venice, is a UNESCO World Cultural and Natural Heritage. In the Venice Lagoon, UCH research done so far often lacks high-resolution mapping and positioning. The new data collected supports a new interpretation and quantitative description of the mapped structures shedding new light on the significance of the Roman occupation of the Venice Lagoon. In the attempt to preserve this precious underwater cultural heritage, we presented a reconstructive hypothesis and a 3D digitization of the mapped structures that are currently endangered by erosion and subsidence processes. This work represents a starting point for a renovated effort of discovering, documenting, and preserving the highly valuable UCH in the Venice Lagoon.

ANCIENT LAND-SEA CONNECTIONS IN MPONDOLAND, ON THE SOUTH AFRICAN WILD COAST

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The South African continental shelf and adjacent coastal plain comprise the submerged and emergent portions of a continuous landscape that has waxed and waned over millennia in sync with changing sea levels and global climates. For 90% of the evolutionary history of the genus Homo, climates have been cooler and sea levels significantly lower than today. These exposed landscapes have provided plant and animal resources key to early hunter-gatherer survival. The Mpondoland Paleoclimate, Paleoenviroment, Paleoecology, and Paleoanthropology (P5) Project is an international and multidisciplinary collaboration of scientists that have worked in Mpondoland for over a decade. P5 research leverages the region's exceptionally narrow continental shelf—maximally 9 km wide—that constrained the outward movement of coastlines during prior glacial periods ensuring that records of coastal foraging are preserved in sites along the modern coastline. Our archaeological excavations along Mpondoland's coastline have revealed evidence for human occupation spanning the last 300,000 years in a persistent coastal context, and in this project we link human use of ancient coasts with hydroacoustic data, as well as correlation to coastal geological deposits to reconstruct scenarios for coasts on the submerged landscape. At Waterfall Bluff, P5 has recently documented the first directly dated evidence for coastal foraging during the Last Glacial Maximum anywhere in Africa. Mpondoland's rare archaeological records, therefore, provide important and unique records about how hunter-gatherers adapted to coastlines during and across glacial-interglacial phases. We are addressing research questions about how early humans used Mpondoland's coastal landscapes by reconstructing specific ancient coastlines and obtaining paleoenvironmental data linked to coastline-environment interactions, and have developed a strong focus on education and outreach with the local community. Here, we aim to provide an overview of the project and present results of relevance to Submerged landscapes and cultural heritage.

UNDERWATER ARCHAEOLOGICAL STRUCTURES AS BIODIVERSITY HOTSPOTS: CASE STUDY FROM THE TIDAL CHANNELS OF THE NORTHERN VENICE LAGOON, ITALY

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Transitional environments are characterized by a high rate of particulate matter supply from rivers and sediment resuspension directly affecting the transparency of the water. Hydrodynamics modulates the particulate matter distribution among the different zones of the lagoon. The Lagoon of Venice is the largest lagoon in the Mediterranean. It is connected to the adjacent Adriatic Sea throughout three inlets, where water exchanges take place twice a day and is classified as a restricted lagoon. The tidal regime is classified as microtidal with extensive nanotidal, and it is the most marked in the Mediterranean. There are several anthropogenic pressures on this lagoon. The presence of the historical city of Venice and the inhabited islands in the lagoon contribute to the organic supply to be added to one originated by agriculture and urbanization of the hinterland. Moreover, the presence of a large port and industrial area increases the human impact on the environment. Waves produced by boats act on the erosion of saltmarshes and sediment resuspension further affects transparency. All these elements cause a high turbidity and consequently a great difficulty in the visual inspections of the deeper channels requiring the use of adequate techniques for the investigation of benthic communities. For these reasons, a high resolution multibeam echosounder survey was conducted and an extensive ground truthing was carried out through underwater imagery in the cannels of the Northern Venice Lagoon. Starting from high resolution bathymetry and backscatter maps, we focused on the search of hard substrata and fouling communities. These communities are very different from those characterizing sedimentary environments. The hard substrates in the Venice Lagoon are mainly of anthropogenic origin. In this study we investigated several possible archaeological sites that could represent hard substrate suitable for fouling community. These structures have been investigated to define their actual presence and position and the state (emerged or buried), to verify if the necessary requisites existed for the establishment of a hard substrata community.

During this survey, two points of particular interest emerged, as biodiversity hot spots. A protocol was developed to analyze the fouling community and define the coverage through image analysis technique.

Session 4 – The Anthropocene and the effect of human footprint on marine habitats

KEYNOTE

MAPPING THE GLOBAL SEAFLOOR DETECTING HUMAN IMPACTS ON IT

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During the Anthropocene, humans are increasingly impacting all environments causing changes in composition and distribution of sediment, structure and functioning of ecosystems, morphology of the seafloor and even 3D geometric evolution of coastal lithosomes. Tidal environments are no exception as in the case of the iconic Venice lagoon, the largest lagoon in the Mediterranean and one of the UNESCO World Cultural and Natural Heritage sites. With a total surface of 550 km2 a N-S shore-parallel extent of about 50 km, the lagoon is connected to the Adriatic Sea through three inlets with a maximum depth of about 13 m and flushed by a semi-diurnal tide with a typical excursion of 60 cm, reaching 1 m during spring tide. In managing and planning future uses of the area, decision makers have so far regarded the lagoon as a purely physical system, neglecting the complexity of the lagoon ecosystem, the relevance of historical anthropogenic impacts and the future long-term scenarios of environmental and climate change. In other words, decisions are taken, typically, based on observations and projections that do not extend more than a few decades back in the past and into the future, respectively. This presentation aims at broadening our view of the lagoon by addressing: 1. The long-term co-evolution of natural processes and human interventions in shaping the lagoon; 2. The need to consider all varieties of impacts of human activities, and behaviours, including those on the hidden seafloor of the lagoon; 3. The factors leading to high water events in this low-tide environment and the generation of storm surges in climate change scenarios, based on the experience of two prolonged high waters during November 1966 and November 2019.

1 - Long term evolution. The morphology and extent of the Venice Lagoon have been significantly modified by humans since remote times: i) the islands within the northern Lagoon have been inhabited since Roman times up to the Medieval Age; ii) the city of Venice became one of the largest cities in Europe with a population of over 100,000 inhabitants by the end of the 13th century; and iii) today the area hosts more than 25 million visitors yearly. Human activities progressively modified the environment through: the diversion of its major tributaries outside the lagoon to prevent sedimentation in marginal areas and progressive infill of the lagoon (from the 15th to the 17th century); the construction of rigid defences to protect the barrier islands from storm waves (1740–1782); the construction of successive sets of jetties at the inlets (1808– 1927), halting their ability to shift laterally; the land reclamation for urban and industrial development (1927–1960); the digging of the straight “Canale dei Petroli” between the central inlet and Marghera refinery area to allow big oil tankers in the Lagoon in the late ‘60s; subsidence induced by ground water and natural gas extraction (about 10 cm from 1930 to 1970); the stabilization or the construction of artificial salt marshes (since the 1990s); and the construction of mobile barriers (MOSE) at the three inlets against flooding. Comparison modern and historical maps, including historical bathymetric maps of the inlets of the Venice lagoon, shows how profound changes reflect the persistent efforts to preserve navigable ways through the inlet preventing silting since AD 1300, causing increased

erosion end export of sediment from the lagoon. The construction of Canale dei Petroli not only does not favour energy dissipation, because of its straight course, but is also transited by large vessels at speeds above 8 knots leading to the resuspension of increasing volumes of sediment that are progressively transported outside the lagoon in this ebb-dominated system (Sarretta et al., 2010). In response to this process all inlets present anthropogenic ebb-tidal delta reaching several meters in thickness in less than a century.

2 – A view from the hidden seafloor. The impact of humans is also visible on the seafloor of the lagoon through high-resolution swath bathymetry and acoustic back scatter data which help detecting (Madricardo et al., 2019): the presence of litter, the formation of scours induced by propeller wash from motorboats, elongated scours induced by the acceleration of tidal currents around human constructions, typically concrete structures or poles (bricole), and keel scars from boats that adventure in the shallows and get stuck there. A particular area of energetic interaction between tidal dynamics and man-made structures are the engineered inlets of the lagoon, with deep areas of seafloor scouring around the base of recently constructed dams protecting the inlets from waves. Such scours are destinated to undermine the structures in very short times (Toso et al., 2019; Fogarin et al., 2019, Janowski et al., 2020).

3 – Humans and the dynamic of “high waters” and flooding. “High water” in Venice develops seasonally, reflecting a mixture of astronomical tides and meteorological (storm surges) forcing, as well as predisposing factors like eustatic rise and natural subsidence (4 cm in 100 years) enhanced by human uses including pumping of freshwater from beneath the lagoon (10 cm between 1950 and 1070). Over time, sea level rise combined with soil subsidence has lowered the level of Venetian pedestrian sidewalks such that, at present, their lowest parts are only 70 cm above mean sea level. With the spring tide excursion at 1 m, any small perturbation of this delicate situation means that water invades Venice’s narrow streets (calli). In November 1966, the storm that flooded the historical centre of Florence, hit also Venice and generated the highest high water ever recorded there (194 cm above mean sea level). The flooding resulted from several meteo-oceanographic processes including astronomic tides, seiche and storm surge. In this specific occasion, sheer luck was the fact that the astronomical and meteorologic components peaked out of phase and helped avoid an even much worse disaster in Venice. Although meteorological forcing is only one of the components that affect water levels in the lagoon, 70% of high-water events occur in autumn when eastward-moving low-pressure systems pass over the northern Adriatic Sea. Pressure eventually increases from west to east, with associated occurrence of southeasterlies (Sirocco winds). The inverted barometer effect (i.e., low atmospheric pressure favours local sea level increase) and the long-fetch Sirocco that piles up water mass in the northern Adriatic raise water levels. These low-pressure systems are frequently generated by baroclinic instability in the Western Mediterranean, especially in autumn when the season’s first northerly cold storms propagate over the still-warm Mediterranean seawater. Sometimes, depending on the track of the low-pressure center, northeasterlies (Bora winds) can blow over the Venice lagoon and the very northern Adriatic, causing a local, but intense, piling up of waters toward the southern sector of the lagoon, a configuration that is dangerous for the city of Chioggia.

In summary, centuries of increasing human impacts, intensified after World War II, led to the deepening of the lagoon and an increased export of sediment across the inlets while anthropogenic subsidence has exacerbated the impact of eustatic rise and, ultimately, the magnitude high-water events. The structures to protect the lagoon from the high water are now constructed in the anthropically modified inlets with external barriers sitting on the anthropogenic ebb deltas and appear already undermined by the action of wave and tidal currents at their base. Events of high

water are becoming more recurrent and more extreme, as in the case of November 2019, almost equalling the event of November 1966 but with a more prolonged impact extending over a week. Events like that will puzzle decision makers in the next several decades: keep the MOSE barriers active continuously for several days to protect the town from flooding or let the tide flush the lagoon taking into the open sea the polluted waters from industry and increasing touristic population?

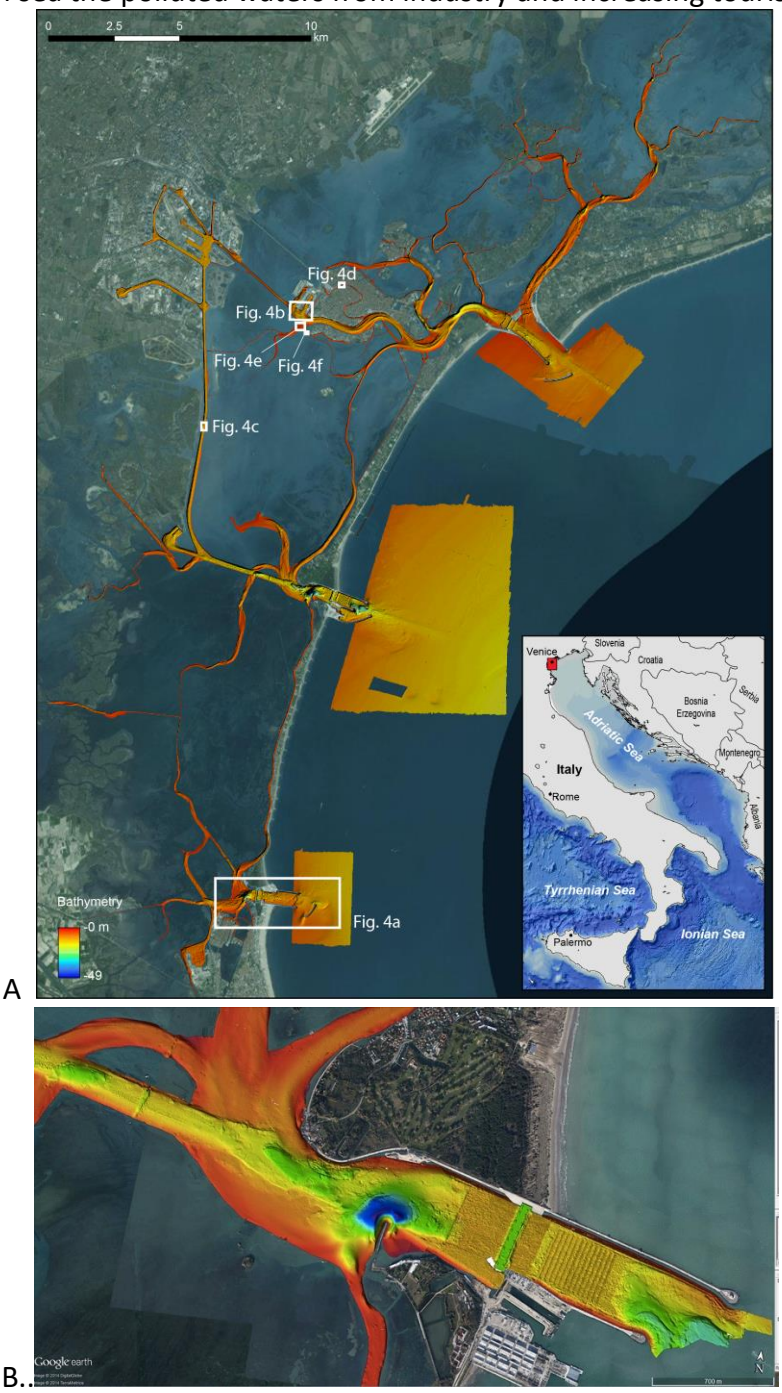

Fig. 1 (from Madricardo et al., 2019). A) Location of the Venice Lagoon on the northernmost tip of the shallow Adriatic Sea (above, inset). Extent of the lagoon (above) and of its tidal channels, representing 10% of its total surface. B) Detail of bathymetry of the Malamocco (central) inlet showing: in blue Buca delle Ceppe, a deep scour reaching almost 50 m water depth, excavated by tidal currents accelerating against a pier constructed in the late 1800; lodgment of MOSE barriers (green rectangle in the center of the inlet); bottom of rectilinear Canale dei Petroli (yellow to green color on the left) constructed downcutting natural, sinuous, channels (in orange).

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FATE OF PLASTIC POLLUTION IN BENTHIC MARINE ENVIRONMENTS – A MASS-BALANCE APPROACH

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Between 1950 and 2017, humans produced approximately 9.2 billion tonnes of plastic. Estimates indicate that somewhere between 75 and 199 million tonnes of plastic has entered the ocean. This includes lost fishing gear, plastic waste from shipping and other sources. Plastic can be found floating on the ocean surface, suspended in the water column and deposited in the sediments of coastal, shelf and deep sea benthic habitats (Harris, 2020; Harris et al., 2021). Locally, plastic particles are concentrated above levels that are safe for marine biota. But the overall picture we have of plastic sources and sinks is fuzzy at best and fundamental data, needed to build a mass balance model for ocean plastic pollution, are simply not available. Sampling of different environments has revealed extreme heterogeneity in the occurrence and concentration of plastic particles, governed by processes that are as yet unclear. For example, there is not a direct correlation between litter, mud deposition and bottom stress on the west European shelf (Fig. 1). This presentation provides a review of our current state of knowledge and highlights major data gaps for modelling and management of plastic pollution in relation to benthic habitats.

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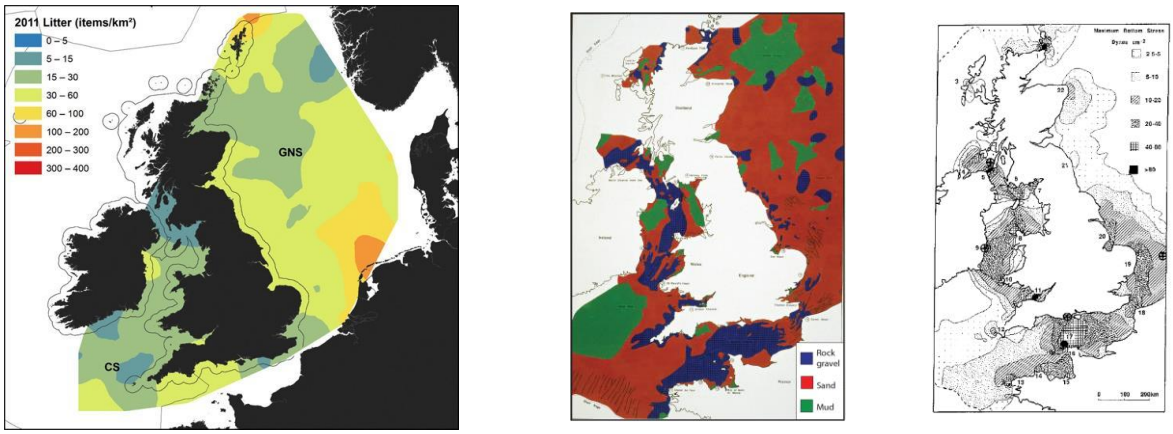

Figure 1. Maps of the west European shelf showing (A) distribution of liter (mainly plastic) in bottom sediments (after Maes et al., 2017); (B) distribution of bottom sediment types; and (C) tidally induced bed shear stress (after Harris et al., 1995).

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COASTAL ESTUARIES – BALTIC SEA HABITAT TYPES UNDER THREAT

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Coastal estuaries are important geologically and biologically diverse ecosystems that have significant ecological, social, cultural and economic value.

Estuaries comprise a large mosaic of habitats. The plant communities in estuaries are mainly formed by various types of emergent and submerged plants. The species composition varies depending on the biogeographical location of the estuary and the type of the bottom sediment. Vast estuaries are important habitats also for aquatic birds and shorebirds, as well as for birds of prey and passerines. Estuaries are also valuable spawning sites for fish.

Estuaries are important link between land and sea. They provide removal of e.g., nutrients and organic matter from of material fluxes from land to sea, i.e., “coastal filter”. They are naturally in a state of continuous transition. Transported sediments accumulate at the mouth of the river as the current slows, causing silting and moving the estuary towards the sea.

Coastal estuaries are stressed by increasingly intensive human activities. Human pressures include e.g., river water acidification and pollutants, dredging, port construction and damming of rivers. In the latest assessment of threatened habitat types in Finland, coastal estuaries were assessed as an Endangered (EN) habitat complex due to historical abiotic and biotic quality changes.

Anthropogenic radionuclides are one of those human pressures, which can be seen widely in the marine ecosystems. Fallout from the April 1986 Chernobyl nuclear power plant accident has rendered the Baltic Sea as the most polluted marine body in the world with respect to ^{137}Caesium (^{137}Cs). In the present study we determined (1) the levels of ^{137}Cs activity content in the bottom sediments of the Archipelago Sea and the Gulf of Bothnia, and (2) the spatial and vertical distribution of ^{137}Cs in the subsurface sediments.

Here we have investigated sediment cores from 104 sites around the Archipelago Sea and the Gulf of Bothnia, the northern Baltic Sea. Radioactivity from ^{137}Cs in sediments has generally declined due to the radioactive decay of ^{137}Cs over the last decades. However, ^{137}Cs contents in subsurface sediments remain at high levels compared to pre-Chernobyl levels. The highest ^{137}Cs activity contents in subsurface sediments occur especially in coastal estuaries. This is problematic because many of them are currently experiencing anthropogenic pressures.

Data on harmful substances in bottom sediments are useful for coastal management and marine spatial planning efforts while assessing risks associated with construction in coastal areas. Constructions like dredging in estuaries and other areas where sediments contain the high concentrations of radioactive or other harmful substances can cause re-mobilization and transport of these contaminants. Climate change is also likely to shift many of the parameters that affect sediment distribution and pollution in the coastal areas.

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MAPPING THE IMPACTS OF MULTIPLE STRESSORS ON THE DECLINES IN KELPS ALONG THE GREAT SOUTHERN REEF, AUSTRALIA

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Kelp forests throughout temperate regions of the world serve as foundation species that play a critical role in sustaining the health and function of marine ecosystems but are experiencing declines in abundance due to loss in resilience as the ocean climate changes. Along the southern coast of Australia, the Great Southern Reef (GSR), a temperate reef system extending over thousands of kilometres, is dominated by kelp forests that create habitat and support high biodiversity. In the eastern portion of the GSR, ocean warming is occurring at four times the global average and has already been linked to dramatic losses of kelp species and is contributing to the range expansion and population increases of two species of sea urchin. In this study, we use long-term (> 20 years) datasets on biological observations across the southeast section of the GSR (Victoria, Australia) to determine the impact of multiple stressors on two important kelps that serve as foundation species: *Phyllospora comosa* and *Ecklonia radiata.* Due to the known impacts of grazers on these kelp species, we first use the observation data of two species of urchins to develop spatio-temporal species distribution models of urchin abundances. We then combined the outputs of the urchin models with information on temperature, wave conditions, currents, and seafloor habitat to model the distribution of *P. comosa* and *E. radiata* through time to determine the impact of changing oceanographic conditions and biotic interactions on kelp forests. We found that both kelp species are decreasing in percent coverage over time and multiple environmental variables, including increasing temperatures, intensifying wave energy, changes in currents and recruitment patterns, and increases in urchin populations are all contributing to the declines of macroalgae. Additionally, future projections of temperature and wave energy show that these species will likely continue to decrease across 71% of Victoria. This information can help to better manage these important foundation species by providing maps of their current and past distributions, along with projections of climate change, to target different areas for urchin culling or macroalgae restoration to reduce future losses.

USING GEOGRAPHIC OBJECT-BASED IMAGE ANALYSIS AND SPECTRAL INDICES TO MAP CHANGES IN COASTAL HABITAT HEALTH FOLLOWING AN OIL SPILL IN MAURITIUS

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On July 25th of 2020, a bulk carrier known as the *MV Wakashio* crashed on the coral reefs of Mauritius, a small African island in the Indian Ocean. In the weeks following the crash, the ship began to break apart and leak engine fuel. The damaged ship spread an estimated 1,000 tons of oil along Mauritius's southeastern coast. The oil spill occurred in close proximity to critical ecosystems such as coral reefs, seagrasses, and mangroves. The direct impacts of the oil spill on these habitats have yet to be assessed, mainly due to the site's closure because of ongoing cleanups and legal investigations. However, satellite remote sensing is an invaluable monitoring tool that can provide insight into the spatial extent, distribution, and temporal changes of coastal habitats, whether occurring naturally or caused by an oil spill.

This study quantifies the changes in the health of the mangrove forests affected by this recent oil spill using PlanetScope imagery (3 m resolution). Two images were acquired for this analysis: a baseline image from March 2020, and a post-spill image from March 2021. Images from an ecologically similar but unaffected site were also used to isolate the effects of the oil spill through a space-for-time substitution analysis. All images were imported into the eCognition Developer 9 software to be segmented and classified through Geographic Object-Based Image Analysis (GEOBIA), with a focus on delineating mangrove habitats. A multiresolution segmentation was used, incorporating the visible light bands, near-infrared band, and several spectral indices known to have improved mangrove classification in other studies: Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Soil Adjusted Vegetation Index (SAVI), Enhanced Vegetation Index (EVI), and Green-Red Vegetation Index (GRVI). A nearest neighbor classifier was then run to classify mangrove objects within a coastal buffer. NDVI values within the mangrove objects were used as a proxy of mangrove habitat health: changes through time were analyzed for both sites.

The maps created using GEOBIA to classify mangrove forests resulted in classification accuracies of 85% and 80% for the affected and unaffected areas, respectively. Paired t-tests identified significant changes in the mangrove forests' NDVI values after the oil spill. There were significant declines in NDVI values for the mangroves within the affected area (mean decrease of 0.109) and within the unaffected site (mean decrease of 0.036). These two decreases were statistically significantly different, suggesting that the mangroves affected by the oil spill had a greater decline in health, likely due to the oil pollution held in the sediment and absorbed by the roots of the mangroves following the event.

The change maps created in this analysis highlight the areas that showed the most drastic decrease in mangrove habitat health, illuminating areas of concern. These maps will assist managers in targeting the mangroves that were more heavily affected by oil pollution for conservation or restoration. The generated workflow can also be used to further monitor the health of the mangroves in this area as they recover and will be adapted to quantify health changes in coral reef habitats in the affected area.

EVALUATING THE BENEFITS OF SIDE SCAN SONAR AS A DETECTION METHOD FOR ABANDONED, LOST, OR OTHERWISE DISCARDED FISHING GEAR

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Abandoned, lost, or otherwise discarded fishing gear (ALDFG) has surfaced as a significant conservation issue that continues to compromise the economic, social, and ecological aspects of the marine environment. To alleviate these concerns, methods of lost gear detection at the seabed can be applied to increase the precision of derelict gear retrieval and potentially improve the likelihood of success. Targeted in Canada's most productive American lobster (*Homarus americanus*) fishing area, a "hotspot" analysis was performed by mapping the density of reported lost gear, aggregated at a 3k x 3km grid resolution. This was used in combination with a suite of geospatial seabed environmental mapping data sets for the study area, including seafloor bathymetry, morphology and current speed and direction, to identify likely areas of ALDFG concentrations. The hotspot analysis was used to target the collection of 27 side scan sonar (SSS) transects in Lobster Fishing Area (LFA) 34 over a 12-day survey period in Clark's Harbour, Nova Scotia. Following a comprehensive review of the SSS data, 114 potential ALDFG contacts were visually identified. Subsequent retrieval missions were conducted by the fishing industry using grapples towed behind fishing vessels to remove the ghost gear. Effort was focused on target locations from the SSS survey data, as well as fisher's local knowledge of likely ALDFG locations not imaged by the SSS mapping. A total of 2111.47 kilograms of ALDFG were extracted from 15 retrieval missions, but only one SSS target resulted in retrieved lost gear. This finding indicates retrieval efforts without the use of SSS can yield a high rate of ALDFG removal success. While gear can be located using SSS, greater grappling precision and full coverage SSS surveys is recommended at smaller geographic scales, particularly in sensitive benthic areas where non-targeted grappling could cause impacts to the benthic ecosystem. Organizations should consider the cost of SSS surveys versus retrieval missions based on fisher's knowledge in future applications.

MAPPING THE ANTHROPOGENIC IMPACT ON SEAFLOOR IN THE TARANTO AREA (SOUTHERN ITALY)

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The environmental status of the Taranto coastal area (southern Italy) has been deeply investigated in the last decades as the area has been strongly influenced by anthropogenic activities since the second half of the 19th century. In this study, the direct and indirect impact of human actions on the seafloor of Mar Piccolo ("Little Sea") and "Mar Grande" ("Big Sea") basins as well as the evolution in aquaculture structures distribution are assessed by integrating different methodological approaches, including change detection techniques.

The analysis of the sea-bottom characterization is based on the interpretation of data from acoustic surveys (Multibeam echosounder and Side Scan Sonar) carried out in 2016-2017 as part of the multidisciplinary activities funded by the "*Special Commissioner for urgent measures of reclamation, environmental improvements and redevelopment of Taranto*". Furthermore, photointerpretation of aerial photos and orthophotos allowed us to analyse the distribution changes of mussel crops during the last two decades in the study area. Specific GIS tools supported the acoustic data analysis, interpretation, and mapping. The results of this study, shown as anthropogenic impact density maps obtained by the implementation of probability density functions, represent a useful tool for orienting coastal management actions and remediation activities. In addition, the study points out how acoustic surveys are an important instrument for supporting the geo-environmental characterization of coastal areas.

MAPPING OF SEAFLOOR MARINE MACROLITTER DISTRIBUTION IN THE VENICE COASTAL AREA

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Marine litter is a significant and growing pollutant in the oceans. In recent years, the number of studies and initiatives trying to assess and tackle the global threat of marine litter has grown exponentially. It is estimated that about 70% of marine debris sinks to the seabed with unknown consequences. For this reason, developing new techniques and protocols for mapping and monitoring the presence of marine litter on the seafloor is of fundamental importance. Within the EU co-founded H2020 Smart technology for Marine Litter SusTainable RemOval and Management (MAELSTROM) project, the presence of marine litter on the seafloor was investigated in two highly impacted sites in the Venice coastal area: a) an abandoned mussel farm at sea, b) a channel close to the historical city center in the Venice Lagoon. The marine litter was mapped and classified through high resolution multibeam echosounder mapping and videos. The marine litter items were visually identified both on the seafloor and the water column. Moreover, a dedicated workflow in ArcGIS was developed to extract the litter items starting from the high-resolution Digital Terrain Model (DTM) (5-10 cm horizontal resolution) extracted from the bathymetry data. At the same time, drop frames and pictures from the seafloor as ground truth were collected. Based on the obtained maps, we found in the mussel farm site at sea a high density of waste deriving from aquaculture activities both on the bottom and in the water column, such as ropes, buoys, nets and mooring blocks. In the lagoon site, instead, we found an accumulation of urban debris on the seafloor, such as tyres, piles, small sunken boats, crates, etc. The acquired data were used for the design of a specific Seabed Cleaning platform based on a cable robot technology aimed at removing the identified marine litter, which will be tested in the next months at both sites. The efficacy of the removal operations and their environmental impact on the benthic habitat communities will be also assessed through periodic monitoring campaigns over the next two years.

Session 5 – New approaches from coast to deep water habitat mapping

CLASSIFICATION OF ARCTIC SEAFLOOR BASED ON OBJECT-BASED IMAGE ANALYSIS (OBIA) TECHNIQUES

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Quantitative analysis of data acquired through seabed mapping techniques is crucial for describing the spatial patterns of submarine sedimentary environments, landforms and associated habitats. OBIA (Object-based Image Analysis) is currently one of the most widely used approaches used to classify seabed propertiesand objects on multi-source seabed images.

During an oceanographic expedition lead by CAGE (Centre of Excellence for Arctic Gas Hydrate, Environment and Climate) in 2020 (CAGE20_7) on the northwestern Svalbard continental margin, a small part of the Norskebanken seafloor, located in the proximity of active methane seeps at about 200 m of water depth, was explored using the Ægir6000, a work-class ROV (Remotely Operated Vehicle). The ROV collected HD videos with a downward-looking camera from which a orthomosaic and a DTM at ultra-high-resolution (mm) were obtained, applying photogrammetric techniques. These data allowed to give evidence of different geochemical and geomorphological attributes of the surveyed seafloor that make it peculiar from many perspectives. Firstly, it is characterized by the presence of methane seepage that produces clearly visible methane-derived authigenic carbonates (MDAC) and microbial mats. Secondly, glacial activity has generated typical submarine glacial landforms, such as ploughmarks, and a sedimentary environment typified by an abundance of pebbles. Finally, the area results populated by a rich assemblage of benthic organisms, with most living on the surface of the pebbles and the carbonate crusts variably dispersed on the seafloor.

Our work subsequently analyzed the 3D model in the geospatial processing software ArcMap to provide additional morphometric attributes, such as roughness, curvature and slope. Furthermore, an OBIA classification approach was performed using Trimble eCognition Developer 9.4, to outline the spatial pattern associated to submarine biogeochemical and physical processes taking place at the seafloor. eCogniton® allows indeed the users to automate the interpretation of geospatial data at different scales. A multiresolution segmentation algorithm, which minimizes the average heterogeneity of image objects for a given resolution, was applied to all the data at the same time (orthomosaic, roughness, curvature and slope). The image layer weights were set different for each morphometric attribute choosing the slope as the heaviest, followed by the roughness, while it was equal for curvature and orthomosaic. The optimal scale parameter found was 70 and for the homogeneity criteria, we established a shape and compactness value of 0.5 each. After the segmentation process, the classification algorithm was used to detect the samples belonging to each class by setting the brightness values, RGB standard deviation and RGB mean values of some distinctive image objects useful to establish the condition for each layer. OBIA classification on the orthomosaic has been successful in detecting the organisms (especially anemones and sponges), because of their marked difference in color compared to their surroundings. The ruleset established for the classification algorithm performed in our study consequently allowed us to classify and to label the three main substrate types that characterize the ROV surveyed seafloor (i.e.: high-density pebbles, low-density pebbles and fine sediment), as well as significant specimens of benthic fauna.

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3D PHOTOGRAMMETRIC CLASSIFICATION OF COLD-WATER CORAL REEFS WITH MACHINE LEARNING – PRELIMINARY RESULTS FROM PIDDINGTON MOUND, NE ATLANTIC

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Cold-water corals (CWC) such as *Lophelia pertusa* and *Madrepora oculata* develop three-dimensional complex frameworks that baffle sediment and generate coral mounds. Among benthic species, CWC's play a major role on the development of microhabitats that promote enhanced biodiversity. The use of Structure from Motion (SfM) photogrammetry combined with machine learning techniques has the potential to provide detailed descriptors of these environments.

This research combines photogrammetric techniques and machine learning methods to yield automatic high spatial resolution analyses of CWC reefs and seabed features. The aim is to develop a multiclass classification scheme using optimised algorithms by analysing the parameters for pre-processing, classification, and feature selection.

To this end, this study analyses a range of machine learning classification algorithms to understand the impact of feature and parameter selections on the classification accuracy. Four classes and four predictor variables were chosen to best represent benthic variability of the specific area and feature importance, respectively. Seven algorithms have been tested on the 3D point clouds generated from the photogrammetric reconstructions of the Northeastern segment of the Piddington Mound (Porcupine Seabight, NE Atlantic).

Preliminary results show that kernel-based methods such as Support Vector Machines (SVMs) yield an average F1 score of 65.6%, whilst ensemble classification algorithms such as Random Forests and Gradient Boosting Trees (GBT) provide an average F1 score of 82.9% and 83.6%, respectively. The results herein and the work in progress are expected to provide a baseline for novel machine learning workflows that can be tailored for 3D photogrammetry data of both marine and terrestrial environments.

DEEP LEARNING FOR SEAFLOOR SEDIMENT MAPPING: A PRELIMINARY INVESTIGATION USING U-NET

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Knowing the type and distribution of seafloor sediments is crucial for many purposes, including marine spatial planning and nature conservation. Seabed sediment maps are typically obtained by manually or automatically classifying data recorded by swath sonar systems such as multibeam echosounders (MBES), aided with ground-truth data.

While progress has been made to map the seafloor based on acoustic data in an automated way, such methods have not advanced enough to become operational for routine map production in geological surveys. Mapping seafloor sediments is therefore still a manual and partly subjective process, which may imply a lack of repeatability

In recent years, deep learning using convolutional neural networks (CNNs) has shown great promise for image classification applied in domains such as satellite or biomedical image analysis, and there is an increasing interest in the use of CNNs for seabed image classification.

In this work, we evaluate the performance of semantic segmentation using a U-Net CNN for the purpose of classifying seafloor acoustic images into sediment types.

Our study site is an area of 576 km2, located in the Søre Sunnmøre region, where seafloor sediments have been manually mapped by the Geological Survey of Norway (NGU). For our initial investigation, we simplified the NGU map into two classes – soft sediment and hard substrate – and trained multiple U-Net networks to predict the sediment classes using an MBES bathymetry grid and seabed backscatter image mosaic as source datasets. Our training reference was the expertly delineated sediment map, and the method thus seeks to mimic the human observer. Our initial analysis derived features directly from acoustic backscatter and bathymetry data but also derived slope and hillshade images from the bathymetry grid.

The MBES imagery was pre-processed and divided into patches of 256 m x 256 m (where 1 m = 1 image pixel). We evaluated models using a single input layer, e.g., backscatter mosaic, bathymetry grid, hillshade or slope respectively, and three models that used two input layers, hillshade & depth, hillshade & backscatter, slope & backscatter. Performance was evaluated using the Dice score (DS), a relative measure of overlap between the predicted and reference map.

Interestingly, results showed that for models using a single data source, the hillshade and slope models produced the highest performance with a DS of approximately 0.85, followed by the backscatter and depth models with a DS of 0.8. Models using dual data sources showed improved results for the backscatter/slope & depth model (DS = 0.9) while showing a lower DS (0.8) for the hillshade & depth model.

Our preliminary results demonstrate the potential of using a U-Net to classify seafloor sediments from MBES data, thus far using two sediment classes. Assuming here that the human observer has correctly annotated the seabed sediments, such an approach could help to automate seafloor mapping in future applications. Further work will provide an in-depth analysis on feature importance, further improve the models by using additional input layers, and use data where several relevant sediment classes are included.

FULLY CONVOLUTIONAL NEURAL NETWORKS APPLIED TO MARINE GEOMORPHOLOGY MAPPING ON THE IRISH CONTINENTAL SHELF DELIVER SATISFACTORY RESULTS FOR A MODEST EFFORT

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In this study we applied a Deep Learning seabed classification model to derive morphological classes over the entire Irish continental shelf using a high-resolution (25 m/pixel) MBES bathymetry dataset (INFOMAR: GSI/MI). Fully Convolutional Neural Networks (FCNNs) are an emerging set of algorithms within Deep Learning that produce pixel-wise classifications in order to create semantically segmented maps. While they have been extensively utilized on imagery for ecological mapping, their application on elevation data is still very limited, and to our knowledge no research has been previously published in the marine geomorphology realm.

We created a set of common derivatives from Benthic Terrain Modeller (BTM, version 3.0) toolbox that include: BPI2-10, BPI5-25, BPI25-250, VRM 3, eastness and northness (Gaussian filtered 5) and three types of hillshades. The class domain covers twelve semantically distinct surface textures and submarine bedforms present on the shelf, with our definitions aiming for simplicity, prevalence and distinctiveness. Fifty labelled samples for each class and derivatives were used to train several U-Nets with differing encoders: ResNet-50, VGG-13 and VGG-16.

Our results show an overall model recall of approximately 75%, with some classes reaching as high as 90%. For target classes exhibiting high recall, models also show high precision in predictions which confirms that the underlying class boundary has been learnt. However, objective scores only cover a small extent of the total area which can be misleading, and visual assessment is essential to understand if a model has performed correctly or not. From a geomorphologist's perspective, FCNNs can be successfully applied to a landscape for a rapid morphological exploration of the dataset. For example, prediction of semantically distinct classes as "duneforms" and "bedrock outcrop" can be very precise and reliable. Nonetheless, at present state FCNNs are not suitable for tasks that require more refined geomorphological classifications, as recognition of morphogenetic processes.

A Deep Learning Approach For Shallow Seafloor Mapping Using Drone-Based Imagery – Insights From ACTYS Project

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Shallow bathymetry data are fundamental input to numerous projects including coastal change monitoring, benthic habitat mapping and spatial planning of coastal infrastructure. However, traditional sonar-based surveying is not always an optimal solution due to natural and technical limitations related to the shallow coastal environment. Novel, proximal sensing technology offers unique possibilities for advancing current methods in shallow seafloor mapping.

ACTYS project leverages the capabilities of unmanned vehicles surveying and advanced image analysis algorithms, for detailed shallow bathymetry retrieval at centimeter scale. Thus, we focus on utilizing drone-based imagery along with complementary in-situ depth data collected with an unmanned surface vehicle (USV) from three study areas with varying seafloor types. The main objective of the project is the development of a sufficiently trained, deep convolutional network (cnn) for extracting bathymetry from a set of spectral and geometric input parameters. The training process is key for building a robust cnn model thus, we emphasize on the comparison of three different types of training data: a) 2D in-situ sonar measurements, b) dense point cloud patches from structure-from-motion (SfM) reconstruction using drone data, and c) 3D patches resulted from photogrammetric processing of underwater images. Following, these types of training sets are incorporated on a cnn that is designed as a stacked hourglass architecture with 6 hourglass modules, and intermediate supervision after each module. The explanatory variables include: i) reflectance of true color imagery bands along with their specific band ratios as well as ii) spatial metrics such as the pixel distances from the shoreline and from known depth points. Resulted bathymetry (both from SfM and cnn prediction) is validated with USV sonar measurements and shows very promising bathymetric accuracy; RMSE=0.5). The presented approach multiplies the strengths of geometric and spectral techniques in shallow seafloor mapping by incorporating them in a single deep learning workflow. This technique is expected to have an impact in detailed mapping of shallow seafloor features such as submerged archeological and geological structures.

ACTYS project (https://actys.ims.forth.gr/) has received funding from a FORTH-Synergy Grant.

ACOUSTIC FINGERPRINT OF THE BLACK CORAL ANTHIAPATELLA WOLLASTONI IN MULTIBEAM ECHO SOUNDER DATA

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Corals form complex 3D morphologies and hotspots of marine biodiversity. We targeted the Canary island Lanzarote with the goal to remotely sense the known black coral forests consisting of *Anthipatella Wollastoni* (Gray, 1857). We report NORBIT MBES chirp data to map the occurrence of the black coral in water depths between 40 and 100 meters. In principle, most corals can be detected in acoustic data collected by side scan sonars or multibeam echo sounders. However, the skeleton of *A. Wollastoni* is composed of protein and chitin, and thus difficult to detect in acoustic data when compared to corals with carbonate skeletons.

Indeed, the direct imaging of even dense corals fields in (multi-frequency) backscatter maps, bathymetric maps, downsampled water-column images or neighborhood analysis of point clouds was not successful. A promising approach feasibly in practical surveys was the use of multi-detections, allowing to detect several acoustic targets in one beam in real-time. Fields of black corals reported by divers and seen in underwater video are recognized in plots of multi-detections above the actual seafloor, and we report that the method can be used to predict potential sites of black coral occurrence offshore Lanzarote.

While promising, we discuss shortcomings of the method including the confusion of corals with multi-detects caused by the steep and rough morphology offshore Lanzarote. Expert knowledge on local habitats is required for data interpretation. We also report planned future work, including necessary studies on the sensitivity of the method to coral abundance and the application to other habitats.

IMPROVED BENTHIC GEOLOGIC MAPPING USING OBJECT-BASED AND MACHINE-LEARNING TECHNIQUES

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In the absence of any direct observations, benthic geomorphology serves as a direct indicator of benthic geologic processes. High-resolution acoustic mapping can reveal fine-scale geomorphological details, however quantitative, objective, and repeatable methods are essential to translate large amounts of acoustic data into usable information. We present a geologic mapping study on a large river in the northwestern USA that combines multibeam sonar data with photographic observations of the riverbed to produce high-resolution geologic maps illustrating fine-scale benthic geologic characteristics including sediment grain size, texture, and geomorphology. The multibeam sonar data set included a centimeter-scale bathymetry digital terrain model and a normalized acoustic backscatter mosaic for nearly 65 kilometers of the river. Within the coverage area of the multibeam data, approximately 700 underwater photographs were acquired. The bathymetry and backscatter were spectrally enhanced to highlight variations in riverbed geometry, roughness, and texture, and then digitally partitioned into homogenous segments using object-based image analysis (OBIA) techniques. OBIA techniques were also used to quantitatively analyze the underwater photographs and determine the sediment composition (mud, sand, gravel, cobble, boulder, bedrock) of the area shown in each photograph. A machine-learning algorithm was used to correlate acoustic signatures with sediment compositions and then extrapolate the resulting relationships to produce benthic geologic maps. The resulting maps depict the complete spatial distribution and abundance of sediment compositions for approximately 65 kilometers of the river with a spatial resolution of 1 meter. Accuracy assessments with independent testing data indicate an overall map accuracy of approximately 81%. To our knowledge, this the first study of its kind to map sediment composition over a relatively large, dynamic area with high degree of accuracy. The methods described here are immediately applicable to other studies for which detailed benthic geologic and/or habitat characterization is required.

SCALABLE BENTHIC CHARACTERIZATION USING MULTIPLE BOTTOM-FOLLOWING IMAGING DRIFTERS

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Collecting high-quality georeferenced optical imagery of the seafloor plays a key role in interpreting and ground-truthing broadscale remote sensing data. Traditional techniques to collect such imagery offer combinations of quality, coverage rate and cost that often lead to undersampling areas of interest. For example, traditional benthic imaging AUV or towed camera surveys typically consist of long transects, with minimal redeployments. Habitat observations along these transects are therefore spatially correlated and focus on single areas of the survey area, leading to undersampling of other areas. With initiatives like Seabed 2030, we are likely to acoustically map most of the world's seafloor in the coming years. However, our current approaches to optical imaging to characterize benthic cover will not scale to such extents.

We present an approach to collecting georeferenced seafloor imagery that has the potential to address large scale mapping challenges in a cost-effective manner. This approach hinges on using multiple small, simple bottom-following (i.e. constant altitude) imaging drifters on many short deployments. Their design restricts mission profiles to specifying a desired imaging altitude and bottom time, which significantly simplifies operations and training of operators. These drifters can be operated from smaller vessels or while multibeam mapping, which increases ship utilization. The relatively low platform cost allows for using several simultaneously which provides a degree of robustness to the loss of one or more of these assets. Future iterations of this approach will be deployable by uncrewed surface vessels, further reducing operating costs and enabling systematic visual sampling of large extents of seafloor.

These minimal platforms represent the observations-gathering component of an automated system running on the surface vessel. Starting with remote sensing data it adaptively selects target locations to deploy the imaging drifters. The observations from the drifters are fed into a predictive habitat model with uncertainty estimates that provide areas of high-value for further sampling. The drift of the platforms is also used by the system to estimate the local current field and improve the targeting ability of the following dives.

We present the components of this system and results from adaptive sampling deployments around a temperate rocky reef near Port Hacking, NSW, Australia.

FEATURE SPACE EXPLORATION FOR PLANNING INITIAL BENTHIC AUV SURVEYS

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Autonomous Underwater Vehicles (AUVs) are used to conduct benthic (seafloor) surveys, where the vehicle collects optical imagery of the seafloor. Due to the high attenuation of light in water, this optical imagery needs to be collected close to the seafloor, resulting in a small sensor footprint for the cameras. A typical AUV survey is able to collect full coverage imagery spanning a few tens of thousands of square meters. This is significantly less than the areas that need to be surveyed, which can be millions of square meters. Therefore, it is necessary for AUV paths to sample the survey areas sparsely, yet effectively. Broad-scale bathymetric data is readily available over large areas, and is often a useful prior of seafloor cover. As such, prior bathymetry can be used to guide AUV data collection. This research proposes methods for planning initial AUV surveys that efficiently explore a feature space representation of the bathymetry, in order to sample from a diverse set of bathymetric terrain. This will enable the AUV to visit areas that likely contain unique habitats and are representative of the entire survey site, which in turn facilitates the creation of accurate and comprehensive habitat maps. We propose several information gathering planners that utilise a feature space exploration reward, to plan freeform paths or to optimise the placement of a survey template. The suitability of these methods to plan AUV surveys is evaluated based on the coverage of the feature space and also the ability to visit all classes of benthic habitat on the initial dive. Informative planners based on Rapidly-expanding Random Trees (RRT) and Monte-Carlo Tree Search (MCTS) were found to be the most effective. These planners were used for AUV deployments in Tautra, Norway and Blanes, Spain, with these deployments highlighting the benefit of informative sampling for benthic AUV surveys. These planners are a valuable tool for AUV surveys, as they maximise the information collected on the initial dive, whilst making efficient use of the survey budget. They consistently deliver a comprehensive training set to learn a relationship between acoustic bathymetry and visually-derived seafloor classifications.

OPTIMIZING ENSEMBLE MODELS TO IDENTIFY SUITABLE HABITAT OF COLD-WATER CORAL SPECIES IN THE NORTHERN GULF OF MEXICO

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The northern Gulf of Mexico hosts several species of cold-water corals, but the broad-scale modeling of their suitable habitat has been hindered by the lack of available gulf-wide environmental data. However, in 2017, the United States Bureau of Ocean Energy Management released a 1.4-billion-pixel bathymetric dataset of the deep northern Gulf of Mexico, with a pixel size of about 12 m. The computational power required to analyze this dataset has limited the amount of analysis that has been done on it. In this study, we used HiPerGator, the University of Florida supercomputer, to optimize ensemble species distribution models of cold-water corals in the deep northern Gulf of Mexico.

In ArcGIS Pro, 18 terrain attributes (*e.g.*, slope, curvatures, measures of terrain complexity) were derived from the bathymetry, and a correlation analysis was performed to retain only uncorrelated variables. Coral occurrences were downloaded from the National Oceanic and Atmospheric Administration's Deep-Sea Coral Data Portal, and were filtered to conserve only the occurrences that were identified to the species level, had the highest available positional accuracy (*i.e.*, 20 m), and that overlapped the bathymetric data. All environmental variables were resampled to a 40 m spatial resolution to match the positional accuracy of the coral data, and all species-specific occurrences were randomized so that they were separated by at least 40 m to reduce the effect of sample bias. Environmental variables were then combined with species-specific occurrences in the SSDM (Stacked Species Distribution Modelling) package in R. First, an ensemble model was built for each species combining nine approaches: generalized linear model, general additive model, multivariate adaptive splines, generalized boosted regression model, classification tree analysis, random forest, maximum entropy, artificial neural network, and support vector machines. Models were produced using a k-fold approach (10 folds) and five cross-validation repetitions, and evaluated using the true-skill statistic. Results were then analyzed, and ensemble models were re-run using only the modeling approaches that met all of these thresholds: area under the curve, sensitivity, specificity, and the proportion of correct predictions ≥ 0.9; kappa coefficient over ≥ 0.8, and omission ≤ 0.1. Maps of probability uncertainties were also produced.

Robust models could only be produced for 13 species out of 18 available species. The two-step modeling process allowed improving all validation metrics: AUC [0.933-0.988], kappa [0.82-0.95], sensitivity [0.90-0.99], specificity [0.92-0.99], omission [0.01-0.10], and the proportion of correct predictions [0.89-0.95]. The most successful modeling approaches at making robust predictions were random forest (100% of ensemble models), support vector machine (85%), and multivariate adaptive splines (69%). No generalized boosted regression, maximum entropy, or artificial neural network models were retained. Bathymetry was the primary driver of species distribution for most species, except for *Callogorgia delta* (slope of slope) and *Desmophyllum pertusum* (terrain complexity). Only 22% of the study area was determined suitable for at least one species, mostly at the continental shelf edge and along the continental slope. Areas of high coral biodiversity (suitable for ≥ 4 species) covered only about 510 km^2 (less than 1% of the area).

With the deep Gulf of Mexico being developed for economic purposes, it is essential to identify areas with a high potential for biodiversity and endemism that can be set aside for conservation. This study produced robust models that can inform decision-making in such a context. Models would be improved with the availability of other environmental variables at a corresponding spatial resolution, and with more samples identified at the species level and with high positional accuracy. The tradeoffs between spatial resolution, taxonomic resolution, and sample size should be further evaluated.

COMPARING MANUAL AND AUTOMATED FEATURE ENGINEERING APPROACHES FOR MAPPING SEABED SEDIMENTS IN THE BAY OF FUNDY, CANADA

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Feature engineering of spatially continuous environmental data layers is a standard step in the benthic habitat and sediment mapping workflow. This includes the calculation of secondary data layers that describe the terrain or texture of the seabed, such as the slope, ruggedness, topographic position, and local variability. The particulars of feature engineering for different types of marine data such as bathymetry and backscatter surfaces has recently become a popular research topic, including the identification of relevant terrain attributes, approaches to textural characterization, variable selection methods, and multi-scale attribute calculation approaches. The proliferation of these techniques has produced useful advances for geospatial seabed characterization, yet has also made feature engineering possibly the most difficult step in the benthic habitat mapping workflow. A variety of different and sometimes contradictory methods and recommendations from the literature confound obvious and consistent solutions. The user must often either make arbitrary methodological decisions (e.g., the selection of particular features and calculation scales) or must test a variety of approaches to find the optimal solution. The former is likely to be sub-optimal, while the latter is often laborious and computationally expensive.

Recent developments in machine learning offer new potential solutions to feature engineering for benthic habitat mapping. Convolutional neural networks have emerged as the model of choice for many image recognition applications. One of the primary benefits afforded by such models is automatic and objective feature engineering, which may include qualities of multi-scale calculation and feature interaction. These approaches have been highly successfully in other domains. Marine geospatial datasets, such as bathymetry and backscatter surfaces, are often treated as raster images for the purposes of feature engineering and analysis, making such automated approaches relevant, yet there has been little uptake in this context to date. At present, we lack a thorough comparison of automated approaches with the current feature engineering paradigm.

Here, we evaluate and compare the utility of automated feature engineering via convolutional neural networks with current feature engineering approaches for benthic substrate mapping over a broad spatial extent (100s of km) in the Bay of Fundy, Canada. Autoencoders – a form of unsupervised neural network – are used to automatically generate a set of features from the input geospatial data layers (e.g., bathymetry, backscatter) at multiple spatial scales. For comparison, common terrain attributes derived from a bathymetric surface, and grey level co-occurrence matrices from a backscatter surface, are generated at multiple spatial scales using established methods. Both sets of features are tested as predictor variables for modelling distributions of substrate parameters including the mean grain size, sorting, and proportions of clay, silt, sand, and gravel from a multi-source compiled sediment sample dataset. Predictions of grain size parameters and substrate composition from the different feature sets are compared spatially and statistically to evaluate whether automated feature selection is an efficient and viable alternative to manual feature engineering for mapping seabed substrate properties.

ADVANCEMENT OF A TWO-PART SEABED GEOMORPHOLOGY MAPPING SCHEME FOR MULTIDISCIPLINARY APPLICATIONS: PART 2 - GEOMORPHOLOGY

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Seabed geomorphology exerts a first-order control on the distribution of marine ecosystems, and geomorphology and habitat maps provide foundational information for a broad range of marine applications. The 2019 GeoHab meeting in St Petersburg hosted a seafloor geomorphology mapping workshop where participants were familiarised with a range of mapping tools (Dove et al., 2020a). One of these schemes (a collaboration between Mareano-Infomar-Maremap-Geoscience Australia: MIM-GA) advocated for a standardised two-part classification of the seabed. Part 1 (Morphology: Dove et al., 2020b) standardises the terminology that is used to classify the surface form of the seabed (i.e. from bathymetry datasets) through the provision of an illustrated glossary of features that enhance the terms defined within the International Hydrographic Organization guide for undersea feature names. The second step in this approach (Part 2: Geomorphology) has since been drafted, and similarly utilises well established geomorphology classification schemes to assign a geomorphic origin to morphological features (Part 1: Morphology) on the basis of further seabed and subsurface data, and expert interpretation of formative processes. This second step provides key insights into the character and stability of seabed habitats and their distribution.

This talk will demonstrate the application of Part 1 and an early draft of aspects of Part 2 to better understand the genesis and stability of the Perth Canyon, Australia (Nanson et al, 2022). This example demonstrates the utility of this standardised terminology for providing seabed classification (Part 1 – Morphology), while also capturing the uncertainty associated with subsurface interpretations of seabed geomorphology (Part 2). The antiquity of the canyon and the relative stability of its steep walls that have been determined through the two-step mapping process provide important context for extrapolating aspects of detailed biologic surveys throughout the Perth Canyon Marine Park. Subsequent to the GeoHab meeting the community will be invited to provide feedback on the draft of Part 2 via a public document, to ensure that the approach is fit-for-purpose for providing foundational data for habitat mapping. A subsequent version of the scheme will reflect these inputs and form the basis of a workshop at the International Conference on Seafloor Landforms, Processes and Evolution (July 2022) where we have invited setting specialists (e.g. mass movement, coastal, fluvial geomorphologists) to provide final input to the scheme.

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THE BACKSCATTER IN FLUME PROJECT (BSIF): MEASUREMENTS OF SEDIMENT BACKSCATTER IN A FLUME – PRELIMINARY EXPERIMENT RESULTS AND PROSPECTIVE

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Single-beam and multibeam echosounders are abundantly used for marine research applications. They transmit acoustic signals at different frequencies and record the amplitudes of the echoes produced by the seafloor sediments or suspended particles in the water column, helping scientists to characterize the nature of these targets. Unfortunately, the lack of reference calibrated data acquired under well-controlled conditions severely hampers the interpretation of data acquired at sea. To overcome this, a comprehensive project is planned to record calibrated measurements of reference sediment targets in an artificial channel (the Delta Flume). This contribution presents the results of a preliminary study aimed at validating the feasibility of such an experiment. A series of acoustic measurements were made in the Delta Flume with single- and multibeam systems (Kongsberg Maritime Simrad EK80 and EM2040c, Aquatec AQUAscat 1000) to evaluate the echo intensities coming from the flume floor or produced by fine-sand plumes. A priority was to assess whether the echoes from the flume side walls would significantly interfere with the measurements of the actual targets. The overall quality of the results fully demonstrates the relevance of in-flume measurements and provides a solid basis for developing a large-scale project including multifrequency measurements on a variety of sedimentary floors and plumes. The purpose is to complete the in-flume measurements by an application of their results to a series of actual case studies in various domains that are of direct interest to the GeoHab community.

Fig. 1. Delta Flume overview and equipment plan. 1. Overview of the flume (Google Earth 8/2019; a. Construction hall; b. 51°59.038'N, 4°22.943'E; c. BSiF test compartment; d. Wave generator. 2. Compartment wall in the Delta Flume with a water level of 9 m.

Fig. 2. Backscatter in flume (BSiF) concept.

FROM INTERPOLATED SURFACES TO 3D POINT CLOUD ANALYTICS FOR BETTER HABITAT MAPPING

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Multibeam echosounder systems (MBES) are designed to measure seafloor depth. However, the output bathymetry of such systems is very much dependent on the bottom detection algorithm that may occasionally fail due to various acoustic scattering in the ocean. Among settings known to cause spurious echoes are fish, gas seepage, or obstacles on the seabed like ship wrecks. Submerged aquatic vegetation (SAV) which occurs globally in the photic shallow coastal zones also cause significant scattering and thus modulate MBES measurements. In turn, such irregularities may be highly valuable from an environmental perspective.

We focus here on *Zostera marina* seagrass habitats that we intensely studied in regard to their opto-acoustic detectability using airplanes and ships during the EU project ECOMAP in the Baltic Sea. To acoustically detect them we developed a new point cloud processing and analyses method based on bathymetric soundings and not working on an interpolated raster digital elevation model. We acquired MBES data with a NORBIT system running around 400 kHz in 1–8 m water depth supported through RTK and Applanix Wavemaster. The survey area was known to be populated with seagrass and the bathymetric soundings were highly modulated. The depth values reliably coincide with the canopy height of *Zostera marina*. Instead of classifying the data with a digital terrain model and the given derivatives, we implemented methods to extract predictive features from the native but cleaned point cloud of the MBES soundings in a similar way to terrestrial LiDAR data analysis. We calculated the eigenvalues to derive nine characteristic features, which include linearity, planarity, and sphericity. The features were calculated for each sounding within a cylindrical neighbourhood of 0.5 m radius and holding an average of 88 neighbouring soundings during our survey. A data workflow was constructed to derive canopy height as well as seafloor depth and we applied a random forest machine learning supervised classification to distinguish between the two cases of “seafloor” and “vegetation”, resulting in high prediction accuracy.

This study outlines for the first time that dedicated MBES point cloud derivatives can be very valuable to design hitherto not considered predictive features — an approach that could substantially improve bathymetric measurements and habitat mapping.

CLASSIFYING SURFICIAL SEDIMENT USING A GLIDER-MOUNTED SINGLE-BEAM SONAR

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Slocum gliders are used globally to profile icebergs and oceanographic parameters (e.g., temperature, salinity, dissolved oxygen, and chlorophyll), track whales, and classify seafloor sediments. On the Scotian Shelf in the western North Atlantic, these gliders are commonly used for tracking North Atlantic Right whales. Typically, gliders are deployed several times a year with missions lasting several weeks to over a month. Some of the gliders are equipped with a single-beam echo sounder which provides profiles of backscatter amplitude used to search for zooplankton presence in the water column. However, the returns from the seafloor are largely unused and could provide information on seafloor hardness.

In this study, single-beam seafloor backscatter returns from a Slocum glider mission deployed on the Scotian Shelf in 2014 were examined to determine whether seafloor hardness can be extracted from the single-beam backscatter returns. Multidimensional scaling and density-based clustering were used to segment and then classify bottom types. The segmented seafloor types were compared to results from a sediment distribution model using a Random Forest algorithm to predict sediment classes (based on percent grainsize).

Sediment distribution maps are an important element of habitat mapping. The substrate of an environment can impact how and where habitats establish, and if they are endangered, recover. This case study shows that relative seafloor hardness can be extrapolated from backscatter returns obtained using a single-beam profiling sonar. These results can be used to fill gaps in sediment distribution maps as well as increase the accuracy of sediment distribution models, which is important for predicting and mapping habitats as well as mitigating negative effects on benthic populations.

A LAYBACK MODEL FOR GEOREFERENCING UNDERWATER IMAGERY FROM A TOWED CAMERA SYSTEM

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While Multi-Beam Echo Sounder (MBES) data can provide a magnificent understanding of the seafloor, e.g., in terms of seabed geomorphology and substrate characteristics, it is only by combining MBES data with underwater direct observations that scientists can directly relate seabed features to habitat types, species diversity, and their distribution. Because this link is spatially-based, the georeferencing accuracy of the ground truth data is of paramount importance.

, This is addressed by adopting accurate underwater positioning systems (e.g.: ultra-short baseline, USBL), but sometimes this is not applicable due to time, economic and operational constraints. In addition, the problem is greater as the depth increases.

We set up this imagery georeferencing problem as a multivariate regression and tackled it using Deep Neural Networks. The model consists of two parts, the first part estimates the planar distance of a towed camera from the vessel location. The second part calculates the camera position based on the vessel position, its direction, and the estimated distance.

The model uses vessel and camera Inertial Measurement Unit (IMU) data as predictor variables, and it predicts the vessel-camera planar distance (response variable). To train the model we used navigation data from a survey where USBL positioning had been used with the same towed-camera system.

Before training the model an extensive data cleaning and pre-processing operation is conducted, including filtering unwanted conditions and performing conversion of the dx, dy offset from the USBL data, into a 'distance value'. Upon training, the model can estimate the vessel-camera distance which is then used in a distance-bearing vincent formula to derive the final, corrected camera position.

The adjusted camera position is made available over the network allowing to 'plug in' the estimated values into other software e.g.: It can be consumed during the acquisition of Multi-Beam echosounder (MBES) data for real-time visualization of the towed camera position during a survey. In addition to increased navigation safety, the image quality is also improved as this setup facilitates a more smart navigation of the camera over the seafloor, for example, by enabling it to maintain a constant altitude.

DEMONSTRATING THE UTILITY OF THE MULTISCALE DTM PACKAGE FOR SEAFLOOR HABITAT MAPPING

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Terrain attributes describe seafloor morphology and can be directly calculated from bathymetry. These measures fall into five distinct categories: slope, orientation, curvature, rugosity, and relative position. Bathymetry and these derived terrain attributes are often the only continuous high-resolution data available for describing seafloor environments. As such, they are commonly used as surrogates in statistical models to predict habitat or species distributions and for describing seafloor geomorphology. One of the current key research topics in benthic habitat mapping is the multiscale calculation of terrain attributes to better capture geomorphic patterns at different spatial scales. However, the lack of computationally efficient, user-friendly, and open-source multiscale analysis tools has hindered the widespread adoption of these methods by the seabed mapping community. Here, we present a new R package called MultiscaleDTM (https://github.com/ailich/MultiscaleDTM), which facilitates the calculation of all five classes of terrain attributes using established methods (e.g., focal and polynomial calculations) from regularly gridded bathymetry (or elevation) data at multiple spatial scales. When choosing which algorithms to implement, we relied on suggested best practices from the habitat mapping literature – particularly in relation to measures of curvature which are seldom clearly defined, and rugosity measures which are often confounded with slope. In addition to existing terrain attributes, we also propose and implement a new rugosity measure that is statistically decoupled from slope and demonstrate that it performs better than existing measures via simulations. Moreover, the software also includes a 3D visualization tool to aid in the understanding of the meaning of various terrain attributes (https://ailich.shinyapps.io/Terrain_Attributes_Explorer_App/).

The utility of this software package for benthic habitat mapping is demonstrated with a case study. From an existing bathymetry surface, we demonstrate how the package can be used to derive measures of each of the five classes of terrain attributes at several different spatial scales of analysis. We then show how providing these capabilities in R streamlines integration with application-specific geospatial statistical analyses by leveraging connection with existing tools within R to perform an unsupervised classification. The unsupervised classification was conducted via principal components analysis of the resultant terrain attributes followed by k-means clustering to produce a map of distinct acoustic clusters. In practice, this map could be interpreted using ground-truthing or could be used to inform sampling design. Although a simple unsupervised example is shown here for demonstration purposes, the resultant terrain attributes could also be used in more sophisticated analyses available in R such as supervised classification via machine learning or object-based image analysis.

LESSONS LEARNED FROM AN EVER-EXPANDING BIOTOPE MAP

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Habitat mapping is central to Norway's multidisciplinary offshore seabed mapping programme, MAREANO (www.mareano.no), with maps of biotope distribution being one of the core deliveries. Since it began in 2005, the MAREANO programme has mapped more than 200 000 km^2, largely in previously undocumented areas where we have no prior knowledge of the biotopes present. Biotopes are classified from an ever-growing volume of video observations and are based on species composition and associated environmental attributes. Various multivariate analysis methods have been used over the years for the classification, several of which the dataset has now outgrown as we approach six thousand (200 m) video samples. Following this classification step, a model is built that generates full coverage maps showing the predicted spatial distribution of biotopes.

Biotope classification and modelling has, until now, been conducted sequentially by MAREANO sub-area in order to deliver timely management-relevant results. This approach is useful locally but has limitations when we wish to gain an overview of the spatial distribution of biotopes across the entire mapping area, which now spans several biogeographic regions. Following a dedicated effort to pool information from all video data to date we have now been able to analyse data across all areas simultaneously. We have provisionally classified data from the period 2006-2019 into 43 biotopes using TWINSPAN in R. We present preliminary classification results and show how they have been used to generate full coverage biotope maps by combining them with predictor variables and Random Forest modelling. We highlight strengths and weaknesses in the classification and modelling results, as well as examining various methods for evaluating model performance both on a spatial and non-spatial basis.

These preliminary results have already served as a provisional delivery for the development of management plans. We note several avenues for further development, spanning classification, modelling, and predictor variables and hope to address these as the classification and modelling continues. We also discuss the potential for further development of the final map product and associated information (e.g. map uncertainty) to suit user needs, as well as the potential for alignment with the Nature in Norway classification and descriptive system. Finally, we reflect on the many lessons learned in the process of making and updating biotope maps as MAREANO data coverage has increased over time.

THE EFFECT OF SPATIAL AUTOCORRELATION IN MACHINE LEARNING-BASED MODELING OF DEEP-SEA POLYMETALLIC NODULES SPATIAL DISTRIBUTION

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Deep-sea polymetallic nodule fields are of particular interest due to the increasing global demand of metals for green and decarbonized technologies, such as electric cars and wind turbines (e.g. Ni, Co, Cu). Mn-nodules significantly contribute to deep-sea ecology as they provide hard substrate that supports a higher abundances and biodiversity of deep-sea benthic fauna.

High-resolution mapping of the deep-sea is typically done by autonomous underwater vehicles that collect a vast amount of hydroacoustic and optic data of the seafloor. The spatial analysis of such data has been advanced by recent developments in machine learning and automated image analysis, allowing for a quantitative predictive seabed mapping. Despite these improvements, the spatial autocorrelation of the polymetallic nodule distribution and its influence on the predictive modeling have not been extensively studied.

This study presents data from a polymetallic field in a geomorphologically complex part of the Peru Basin. The spatial autocorrelation analysis provided valuable information regarding the patchy distribution of nodules, enlightening the importance of a correct variable selection before applying machine learning for spatial modeling. A Quantile Regression Forests (QRF) model was developed using three cross-validation techniques namely random-, spatial-, and feature space cluster-blocking. The results show that the commonly used random-cross validation underestimates the true prediction error but spatial- and feature space cluster-blocking do validate the prediction performance better.

The QRF model prediction itself shows high accuracy in predicting the nodule abundance in morphologically similar areas but als shows an increased uncertainty in areas with new feature space conditions even at local geographical scales. Therefore, we used the recently proposed “Area of Applicability” model-based method to map those geographical areas where feature space extrapolation occurs, causing predictions to be less reliable. In those areas, further sampling would be required.

THE POTENTIAL OF ARTIFICIAL INTELLIGENCE IN PHASE-MEASURING BATHYMETRIC SONAR DATA PROCESSING

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Compared with multibeam echo sounders (MBES), phase-measuring bathymetric systems (PMBS) generate considerably higher volumes of wide-swath bathymetric data. In a typical operation, PMBS may generate thousands of data points per ping across the swath. Such large volumes of data have historically led to more involved data processing steps associated with PMBS than are necessary with MBES. A typical data processing chain for PMBS data involves the sequential application of a number of user-configured discrete filters to reduce these data volumes by filtering out outliers. As the application of those filters is user-dependent, it may have an impact in the reproducibility, consistency and accuracy of the results.

The first part of this presentation outlines the application of unsupervised Artificial Intelligence (AI) techniques to the issue of filtering PMBS data in real survey conditions. Results of unsupervised AI applied to real PMBS datasets are showcased with comparisons obtained from experienced data processors using traditional processing methods. Further evaluations are presented to highlight the impact in data quality and in real-time performance, leading to the conclusion that unsupervised AI bathymetric data filtering can provide hands-free, expert-equivalent outlier identification in real-time, which relegates human intervention to the final quality control of the processed data.

The second part is a discussion about the potential areas that artificial intelligence techniques can be applied within other real-time PMBS data products. This includes application to the decimation of PMBS bathymetry and backscatter data. Further, artificial intelligence also has the potential to automatically segment the seafloor into different acoustics classes, which can yield, through ground truthing, to reliable sediment classification.

The final part of this presentation aims to provoke thoughts and ideas, and it encourages audience-driven discussion for identifying further user-focused challenges which could be improved utilizing an Artificial Intelligence approach.

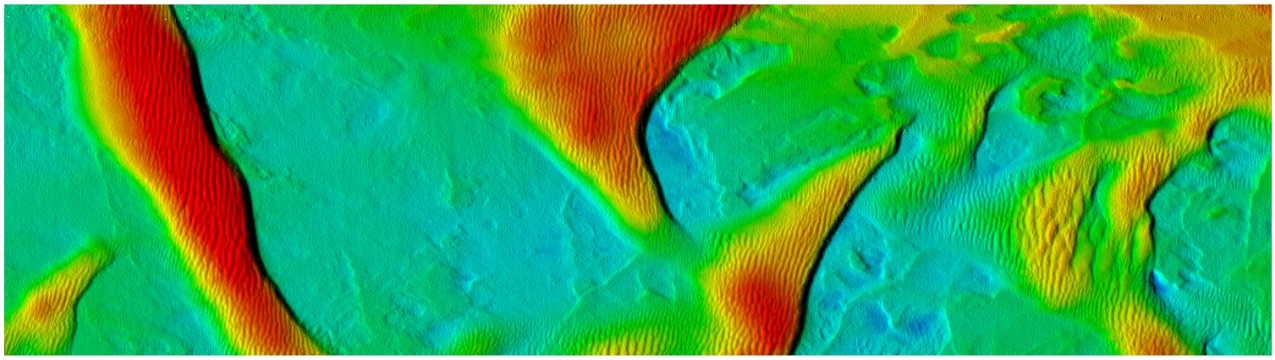

Figure 1. Unmanned PMBS bathymetric data processing using unsupervised AI. Lowestoft, United Kindgom.

KEYNOTE

THE NIPPON FOUNDATION / GEBCO SEABED 2030 PROJECT – DELIVERING THE DEFINITIVE GLOBAL MAP OF THE OCEAN FLOOR

J. McMichel-Phillips

Seabed 2030 is a collaborative project between the Nippon Foundation of Japan and the General Bathymetric Chart of the Oceans (GEBCO) that aims to bring together all available bathymetric data to produce the definitive global map of the ocean floor by 2030, and make it freely available to all.

Former UNESCO-IOC Vice Chair Steve Hall serves as Seabed 2030 Head of Partnerships and will introduce the program, explain why bathymetry matters to human society, our achievements to date and how we can use the community's resources, technologies and innovatory skills to fill the gaps in datasets by the end of the UN Ocean Decade – everyone can make a difference.

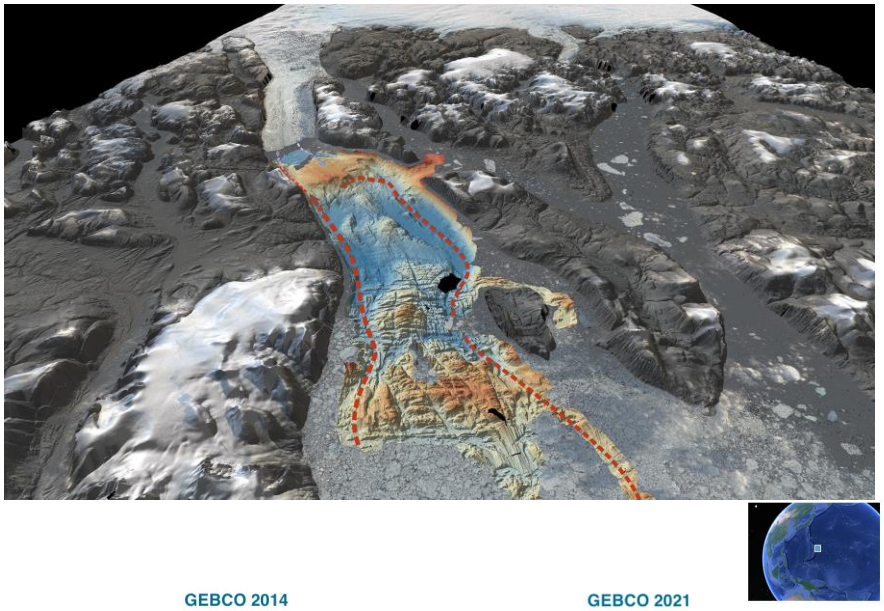

Fig. 1. Bathymetry off Ryder Glacier, Greenland 2019 (with thanks to Martin Jakobsson, Stockholm University)

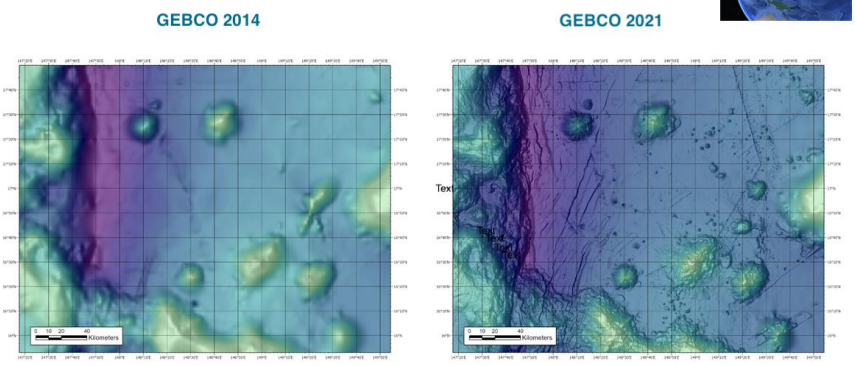

Fig 2. Example of GEBCO resolution 30 arc second 2014 vs 15 arc second 2021

Find out more about Seabed 2030 at https://seabed2030.org
Contact Steve Hall at partnerships@seabed2030.org

USING SATELLITE-DERIVED BATHYMETRY DATA FROM 4S PROJECT TO MONITOR SHALLOW WATER AREAS – THE CASE OF BUGIO (PORTUGAL)

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K. Hartmann[2], K. Knauer[2]

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Nearshore, shallow water seafloors are usually subject to day by day regular changes, but also highly dynamic. Under high wave conditions during a major storm, these regions can experiment significant morphological changes in hours or days. Most Hydrographic Offices are concerned with such areas as they directly affect most harbors and navigation channels. However, monitoring the changes on such places is always a difficult and cost demanding task when using regular bathymetric survey methods.

To overcome these difficulties one identified solution is the use of satellite imagery and satellite derived bathymetry. The EU-funded project 4S (Satellite Seafloor Survey Suite) intends to develop a cloud-based software and use satellite data to provide the users with hydrographic data allowing them to map and monitor seafloor habitats, morphology and depth. The Portuguese Hydrographic Institute is part of the 4S consortium headed by EOMAP, and is working on a study case near Lisbon, more specifically, the Golada do Bugio sandbank, just near the main entrance corridor for Lisbon harbor.

Bugio sandbank is part of the Tagus estuary ebb delta, a transition zone between river and sea, with complex morphodynamics. The Hydrographic Institute regularly monitors the evolution of this area and expects to use 4S data to aid this task. Furthermore, these data can also provide valuable information to understand the morpho-sedimentary dynamics of the Tagus estuary ebb delta and adjacent south littoral that shows an erosive trend since the mid-twentieth century.

By using data from the 4S project, we will evaluate changes through time, analyzing bathymetric information from different dates, considering different situations. The bathymetric models obtained from 4S data will be validated with hydrographic surveys data. Consequently, we expect to recognize the value of the 4S data and the usefulness of this methodology.

COLLECTING HABITAT DATA DOESN'T HAVE TO IMPACT THE HABITAT – USING USVS TO COLLECT OCEAN DATA IN A CARBON NEUTRAL & ENVIRONMENTALLY SAFE MANNER

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A research or survey vessel has been the way to collect marine habitat data. These vessels typically use from 50 litres/hour during survey to 230 litres/hour in transit. The vessels can also be very noisy, impacting the local sea life and run the risk of collision with marine mammals.

At XOCEAN we have developed Uncrewed Surface Vessel (USV) technology with the prime aim of collecting ocean data in a sustainable manner. The USV uses a tiny amount of fuel (1/1000th of a traditional vessel) and can remain at sea for up to three weeks. The USV is normally travelling at approximately 3 knots survey speed so has minimal impact on its surroundings. It is also acoustically very quiet. To further de-risk the use of new technology and to utilise new methods of working, XOCEAN collect the ocean data as a service and have collected over 35,000 hours of ocean data for renewable energy companies, government agencies, academia and other survey companies.

The USV is capable of full "over-the-horizon" operations, and we will present the technology that makes this achievable, the sensors that we typically deploy and case studies from fisheries stock assessment to full marine geophysical surveys to show the quality and accuracy of the ocean data collected.

USING UNCALIBRATED REFLECTIVITY BACKSCATTER FROM THE BATHYMETRIC DATA STREAM OF A PHASE-MEASURING SIDESCAN SONAR: OBJECT DETECTION AND BOTTOM CLASSIFICATION

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Seafloor characterization and object detection in shallow water coastal environments is becoming increasingly important in the understanding and management of critical coastal shallow water habitats. Toward that end, detection, characterization, and localization (DCL) techniques are being developed around the use of the EdgeTech 6205 Phase-Measuring Sidescan Sonar (PMSS). This instrument offers the ability to simultaneously collect dual-frequency (550 kHz, 1600 kHz) co-located sidescan imagery, swath bathymetry and uncalibrated reflectivity (amplitude) backscatter (550 kHz). To date, little to no work using the latter data set from phase-measuring systems has been in the peer-reviewed literature.

This talk will highlight preliminary and ongoing analyses from a project funded by the United States Department of Defense that aims to detect, locate, and differentiate between unexploded ordnance (UXO) and various objects on the seafloor using a PMSS in very shallow waters <5m. Specifically, the results discussed here will focus on quantifying the efficacy of using reflectivity backscatter from the phased bathymetric data stream to conduct DCL on inert UXO and 'clutter', e.g., lobster pots, boat propellers, car tires and other items typically found on the seafloor. Parameters such as object orientation, distance from nadir, survey vessel heading and speed, as well as grain size and composition and bottom type are also incorporated into the statistical analysis. Results from object DCL through the use of multinomial logistic regression will be presented. These statistical methods allow for the weighting of the sounding attributes to be dynamically modeled to represent the best fit combination to differentiate between objects on the seafloor and variations in bottom types. Datasets and results from sand, cobble, and mud bottoms will be shown.

Phase-measuring sidescan sonars can be powerful tools when the datasets they collect, such as reflectivity backscatter, are used in conjunction with other data streams from the sonar. If users can integrate and synthesize all the available data streams new methods of seafloor characterization and object detection may be possible.

ISKAFFE: A TOOL FOR BACKSCATTER DATA QUALITY CONTROL

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The quality of multibeam sonar backscatter data is important for accurate and reliable habitat mapping. However, it is often less than ideal. Common issues include signal drops, gaps in coverage, untimely changes in settings, poorly compensated beam patterns or transmit sectors, etc. Moreover, these issues can vary greatly in how obvious, widespread, important, and correctable they are. Unfortunately, there is currently no standard for backscatter data accuracy (by contrast with bathymetry data) and there are no means by which to evaluate backscatter data quality. This issue is particularly important when multiple parties are involved in data acquisition and processing, where backscatter data quality may be linked to contractual obligations. The concern is widespread in the geological and biological habitat mapping community, as outlined in the "Guidelines and Recommendations" 2015 report of the Backscatter Working Group (BSWG).

At the Geological Survey of Norway (NGU) we have begun development of a free and open-source software to tackle this problem. Tentatively named *Iskaffe*, the software is intended to take raw multibeam sonar data files as input, detect and report backscatter data issues, and output quantitative information about the overall quality of the dataset. When used during a survey, the software will alert surveyors when problematic data have been recorded and should aid their decision on whether and how to remedy issues. When used post-survey, it will help evaluate whether the dataset meets quality targets. The software is intended to be a lightweight tool with limited functionalities, so that it is easy to learn, use and adopt.

Iskaffe is coded in MATLAB using the multibeam sonar data processing toolbox *Coffee*, but will be useable as a stand-alone executable. Here, we present the current prototype of the software, outlining its algorithms and functionalities. We discuss our plans for its development and usage in the context of the Norwegian offshore seabed mapping programme MAREANO. The software is currently under internal development by NGU, but we welcome collaboration with the GeoHab community. This may include field or post-survey beta testing and/or co-development of the software tool itself so that it eventually supports additional data formats, detects and assesses additional issues, or includes additional functionalities of interest to the community.

AI MEETS SEABED: MAKING THE BENTHIC ANALYSIS OF VIDEO RECORDS, AIRBORNE AND SATELLITE DATA MORE EFFECTIVE

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Artificial Intelligence (AI) methods have found increasing use in our daily lives. Still today underwater videos, and the global 'big data' of aerial imagery and satellite data lack a systematic and automatic analysis to identify benthic communities and habitats. AI methods have the potential to increase the efficiency of those analyses and make them more objective, compared to manual interpretation.

We present the prototype and concept of Benthic-Online. Benthic-Online is a cloud-based AI workflow which can be accessed via a web application (browser-based user interface). It has the capabilities to analyze user's underwater videos or aerial image records but also satellite imagery from commercial satellite data. The concept of the analytical workflows follows the same concept for all inputs: The uploaded video or satellite data, which intersect the study sites, are subdivided into tiles, these are single frames for the underwater videos and image subsets for the aerial and satellite imagery. This typically results in several thousands of subsets. These are categorized into n clusters of significant differences in shape, color and texture using an unsupervised image classification. This approach includes two steps: first, a self-supervised task from representation learning to obtain semantically meaningful features and second, the information of the first step is used as a prior in a learnable clustering approach. Each of those clusters are then automatically linked to a thematic class, i.e. 'dense seagrass meadow' and the user can modify those thematic classes as well as increase or decrease the number of classes. As a result, Benthic-Online provides a georeferenced outcome of the benthic thematic classes for video transects (i.e. a classified point shapefile), and a thematic benthic classification map of the shallow water zone for the satellite data and aerial imagery. Especially for the classification of aerial and satellite data we include the information on bathymetry. Bathymetry itself is derived from another cloud-based workflow, SDB-online. Both of which are installed in a cloud environment and enables the upscaling and rapid analysis of the inputs.

The proposed AI-based prototype will be demonstrated in the German Baltic Sea and Caribbean Sea and we will showcase the performance and also thematic classification accuracy of this concept.

This project has received funding from the European Union's Horizon 2020 research and innovation programme H2020-SPACE-2020 under grant agreement No 101004221

CHARACTERIZATION OF BENTHIC HABITATS USING ACOUSTICALLY CALIBRATED MBES AND ANGLE VARYING GAIN CORRECTION OF BACKSCATTER– AS A PART OF ECOMAP PROJECT

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To date, the most commonly recorded data using MBES have been bathymetry and the relative intensity of the backscattered acoustic signal called "backscatter". Although this information has been successfully used in oceanographic research, backscatter does not provide clear information about the acoustical characteristics of the habitats present on the bottom because it depends on many variables. It depends on echosounder-related parameters, such as signal frequency, directional characteristics of the transducer; factors related to the environment, such as temperature and salinity; factors related to geophysical features of the seabed. Real values of the bottom backscattering strength (BBS) presented as a incidence angle function are an important physical feature of benthic habitats and are helpful in their differentiation.

An acoustically calibrated NORBIT's multibeam echosounder iWBMSh (model STX) was used in the study. The research provided real bottom backscattering strength values as a function of incidence angle, for a frequency of 150 kHz for the seabed types found in the Baltic Sea study area. Recording of real BBS will enable creation of a catalog of benthic habitats and their physical characteristics to improve their automatic classification. Acoustically calibrated MBES, for example from NORBIT, are already available on the commercial market and real BBS should be recorded wherever possible.

The backscatter parameter is often used for automatic or semi-automatic classification of benthic habitats. However, a major complication is the strong angular dependence of the relative acoustic signal intensity values recorded by MBES. Until now, the most common solution to this problem has been algorithm of Geocoder - angle varying gain correction implemented in commercial FMGT software. We propose an alternative solution - the BBS-Coder program, which implements angle varying gain correction using empirical data. The program will be made available on the website of the ECOMAP project, one of the goals of which was to develop methods for seabed research using acoustic techniques.

NOVEL APPLICATION OF EUNIS-BASED MAPPING PRODUCTS TO DEMONSTRATE THE POTENTIAL FOR MARINE SPATIAL PLANNING PROCESS USING A NATURAL CAPITAL-BASED APPROACH IN THE UK

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Interest in the application of natural capital approaches to marine ecosystem management has fueled exploration of novel mapping techniques in the UK. Pilot studies are underway in the Marine Natural Capital and Ecosystem Assessment Programme (mNCEA) that demonstrate how pre-existing spatial mapping and assessment products for the UK Marine Strategy and OSPAR, may be used to produce biological asset and risk registers in English marine plan areas. Use of these registers when considered alongside the impacts to ecosystem service provision from the assets, is fundamental to understanding the wider consequences of anthropogenic activities in marine areas.

Initial reviews showed the European Nature Information System (EUNIS) benthic habitat classification provides appropriate common units to represent benthic habitat assets (Natural Capital Committee, 2019 and Mulholland et al., 2021). EUNIS-based combined maps are ideal for representing the benthic habitat assets as they collate the best available information on the distribution of seabed habitat assets at any location in UK waters, covering both subtidal and intertidal areas. These products combine modelled data from EMODnet Seabed Habitats (EUSeaMap), with hundreds of survey maps that provide the best level of detail possible, to produce combined maps with no gaps. EUNIS-based combined maps are also incorporated into OSPAR biodiversity condition assessments, such as the indicator for the Extent of Physical Damage to Predominant and Special Habitats (OSPAR, 2017), further adding to their potential use when developing asset and risk registers for marine plan areas.

Here we present early findings from the first year of the four-year mNCEA Programme, focusing on a demonstration of how existing spatial mapping and assessment products could be used towards an ecosystem service-based approach to marine management (van Rein et al., In Prep). We highlight the gains and limitations of these early studies while sign-posting future efforts to integrate assets, ecosystem services and beneficiary data across environmental and socio-economic datasets.

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THE NEANIAS CLOUD-BASED UNDERWATER SERVICES

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Within the EC H2020 NEANIAS project three cloud-based underwater services are offered, emphasising the importance of seafloor, habitat, and underwater cultural heritage mapping. While targeting various end-users, from interested laymen to dedicated students, scientists or ambitious engineers, the services provide user-friendly solutions addressing bathymetric post-processing, seafloor mosaicking and classification.

The Bathymetry mapping (UW-BAT) service provides a cloud-based edition of the well-known MB-System open-source software package within a JupyterLab environment. The service generates bathymetric grids and maps throughout a flexible and expedient workflow, by implementing sound speed corrections, applying tides and filters, and selecting the required spatial resolution. An implemented VNC desktop allows the use of X11-based graphical user interfaces for manual editing.

The Seafloor Mosaicking from Optical Data (UW-MOS) service provides a solution for representing

a large area of the seafloor, in the order of tens of thousands of images, and tackling visibility limitations from the water column. The service performs several steps like camera calibration, image undistortion, enhancement, and quality control. The final product could be a 2D image Mosaic or a 3D model.

The Seabed Classification from Multispectral, Multibeam Data (UW-MM) service focuses on seabed

classification by implementing cutting-edge machine learning techniques and at the same time providing a user-friendly framework. The service unfolds within four steps: uploading the data, selecting the desired seabed classes, producing the classification map, and downloading the results.

Therefore, NEANIAS Underwater services exploit cutting-edge technologies providing highly accurate results, regardless of the level of expertise of the end-user, and reducing the time and cost of the processing. Moreover, the accessibility to sophisticated services can simplify and promote the correlation of interdisciplinary data towards the comprehension of the oceans, and the contribution of these innovative services is expected to be of high value to the marine community.

IMPROVING SEAFLOOR AND MARINE HABITAT MAPPING IN DATA POOR REGIONS USING ICESAT-2 SATELLITE-BASED LIDAR AND VERY-HIGH RESOLUTION IMAGERY FUSION

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From the study of coastal hazards to the modeling of ocean currents and the mapping of marine habitats, bathymetric data are essential to the understanding and management of coastal environments. However, most of our oceans remain mapped at very coarse spatial resolutions (i.e., ~450m). While high resolution seafloor mapping technologies exist (e.g., airborne bathymetric LiDAR or ship-based multibeam echosounders), they remain expensive and time-consuming to deploy, leaving large parts of the world's coastal areas poorly known.

We report on key outcomes of the PhotonExplorer project that explored how data from the recent ICESat-2 ATLAS satellite sensor can help access bathymetric information in shallow areas useful for marine habitat mapping. Launched in 2018, ICESat-2 ATLAS carries a green LiDAR system from which photons are able to penetrate water down to around 40m depth in optimal conditions. First, we present how ICESat-2 data was used as a substitute to in-situ bathymetry control points in a bathymetric inversion method applied on Pléiades-1 very-high resolution imagery, helping generate a 0.5m resolution bathymetric grid with a vertical accuracy of 0.89m. These data were used to generate a benthic habitat map of a tropical reef ecosystem with an overall accuracy of 96.62%. Second, we present exploratory work allowing to compute multi-scale rugosity measurements along ICESat-2 transects that could potentially be used as a surrogate for variable biodiversity in poorly known coastal waters. Finally, we compared ICESat-2 data to existing airborne LiDAR data to help quantify vertical and horizontal precisions compared to the International Hydrographic Organisation Special Publication 44 hydrographic standards.

Together, the study confirms the high potential of ICESat-2 observations for generating diverse data products for remote and poorly known coastal waters without the need for in-situ data.

SHALLOW WATER MAPPING AND MONITORING IN THE BROWSER – SDB-ONLINE

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3. Instituto Hidrografico Portugal, PT
4. Fugro Germany Marine GmbH, DE
5. Smith Warner International Limited, JM
6. Quality Positioning Services; NL
7. National Research Council, The Institute of Marine Sciences (CNR-ISMAR); IT
8. Hellenic Centre for Marine Research (HCMR), GR

The analysis and interpretation of multispectral satellite or airborne imagery have been established as a tool to map and quantify shallow water bathymetry, seabed habitats and seafloor characterization. However, the applied methods and workflows vary from highly analytical to image interpretation approaches, which are typically a very labor-intensive activity, heavily relying on the experience of the analyst. Thus, it is no surprise that quality of the remote sensing derived information varies across teams, providers and researchers. The current Horizon2020 innovation project 4S works to overcome this dependency. The 4S team – an international team of CNR ISMAR (IT), FUGRO Germany (DE), Hellenic Centre for Marine Research (GR), Instituto Hidrografico (PT), Länsstyrelsen Västerbotten (SE), Quality Positioning Services QPS (NL), Smith Warner Int (JM) and led by EOMAP (DE) - works to develop, test and establish solid satellite-derived workflows embedded in the cloud and accessible through an online webapp – SDB-Online. The user is able to access SDB-Online (www.sdbonline.eomap.com) via the browser and generate the shallow water information anytime and anywhere. The game changing innovation of this solution is that the analytical workflows in the backend follow proven scientific methods and are based on the inversion of the radiative transfer equation, often referred to as 'physics-based' analytics. This concept allows to derive information even in the absence of any local survey or on-site data. In our presentation, we will demonstrate the new tools for sites in (a) Portugal, where it is applied to map and monitor river mouth morphology, (b) the German Baltic, where we demonstrate the performance to map benthic habitats and bathymetry and (c) in southern Italy, where we demonstrate the capability of precisely measuring water depth and the extent of the seagrass Posidonia Oceanica.

This project has received funding from the European Union's Horizon 2020 research and innovation programme H2020-SPACE-2020 under grant agreement No 101004221

A GEOMORPHOLOGICAL OBJECT-BASED IMAGE ANALYSIS APPROACH TO INVESTIGATE THE HYDRODYNAMICS SURROUNDING COLD-WATER CORAL MOUNDS

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Cold-water corals are habitat engineering organisms whose growth and proliferation are profoundly influenced by the hydrodynamics of the environment in which they live. Seabed sediment bedforms provide an excellent picture of the mean current velocity and direction surrounding these habitats and are readily captured by multibeam echosounders. Many approaches have been designed to automate the classification of such bedforms imaged in multibeam echosounder data. However, these classification systems only apply a geomorphological contextualisation to the data without making direct assertions on the velocities of benthic currents that form these bedforms. Here, we apply an Object Based Image Analysis workflow to derive a geomorphological classification of seabed sediment bedforms through k-means clustering to the Moira Mounds region of the Belgica Mound Province, NE Atlantic. This classification was used as the basis for a current velocity estimation that was powered by a Fast Fourier Transform in combination with a bedform velocity matrix. Results showed a bimodal distribution of mean current speed congruent with previous research in the area. A reduction of current speed with increasing proximity to the mounds was observed within this region and this is postulated to occur due to the obstruction associated with coral mounds. This study is proof of concept of a tool for assessment of vulnerable marine ecosystems for Marine Protected Areas and can inform management and monitoring practice across a variety of spatial and temporal scales.

LONG-TERM AUTONOMOUS ROBOTIC SOLUTIONS FOR COASTAL TO DEEP SEAFLOOR ENVIRONMENT MAPPING AND MONITORING

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To preserve biodiversity and seafloor integrity of coastal to the deep-sea environments, it is more and more needed to carry out extensive survey programs, that may be expensive and require long ship times. To overcome these issues, the mapping and monitoring coastal and deep seafloor environment require new adaptable and scalable solutions that are able to operate for long term missions in a semi-autonomous mode. With this aim, the ENDURUNS consortium is currently developing an Automated Unmanned Vehicle (AUV) with gliding capability powered using hydrogen fuel cells. The use of hydrogen fuel cells offers the ENDURUNS AUV substantially longer autonomy than the commercially available AUVs powered with conventional Li-ion batteries. The AUV can be easily scaled up further enhancing its autonomy as well as increasing its payload capacity. The extended autonomy of the ENDURUNS AUV platform lends itself for long-term marine coastal observations coupled with mobility capability. In this way, semi-permanent observations and monitoring can be realised at low cost, whilst providing valuable input to the existing network of fixed observatories. The AUV is supported by an Unmanned Surface Vehicle (USV), which has the role of the mothership. The USV can recover and deploy the AUV, provide accurate positioning input and, when necessary, act as a relay, transmitting data to the Remote Control Centre of Operations.

HYDROGRAPHIC AUTOMATIC TOOL FOR SEDIMENT ANALYSIS AND THEMATIC MAP: CASE HISTORY OF GARDA LAKE

S. Bigelli, V. Ferrero, M. Marro, R. Nardini, M. Demarte, R. Ivaldi

Italian Hydrographic Institute, Italy

A semi-automatic tool, based on the acoustic backscatter, integrated with video-camera data and ground-truth was used to characterize and classify sediments and to realize a bottom mapping including information for the safety of navigation in compliance with the International Hydrographic Organization (IHO) standards, hydrodynamics studies, and habitat mapping.

As part of the survey activity, conducted at Garda lake, an integrated mapping was carried out with the aim of characterizing the south-eastern area of the lake, between Sirmione and Lazise.

In particular, following the survey carried out with a survey boat MBF 1213 equipped with the high-resolution EM2040C Dual-Head multibeam, the bathymorphological surface and the related backscatter mosaic were generated. Furthermore, the entire sub-area was characterized by temperature profiles. From the integrated analysis of products, using a semi-automatic classification procedure, 40 sites of interest were identified on which to carry out ground-truth sampling devoted to classifying, implementing, and validating a rapid environmental assessment.

The samples were analysed in the sedimentological laboratory obtaining particle size data and biological information characterizing the lake system of the investigated area. This information was put into a system to create a thematic map identifying local habitats.

INTEGRATING THE EUROPEAN OPEN SCIENCE CLOUD (EOSC) INFRASTRUCTURE TO PURSUE THE OPEN SCIENCE PRINCIPLES: THE RELIANCE SERVICES PORTFOLIO AND THE USE CASE SCENARIOS OF THE SEA MONITORING COMMUNITY

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Facilitating wider access and reuse of research data in environmental sciences has rapidly gained traction because of the need for research integrity, reproducibility, and accountability as well as new opportunities for large-scale data analysis and reanalysis. In November 2018, the European Commission launched the European Open Science Cloud (EOSC) infrastructure to push European research towards a culture of Open Science where research data are findable, accessible, interoperable, and reusable (FAIR).

In this context, the H2020 project RELIANCE aims at providing Earth Scientists and Copernicus user communities with innovative and interoperable services for an open-by-default, efficient, and cross-disciplinary research management environment supporting FAIR data and Open Science principles. The service portfolio covers the entire research lifecycle management, from data discovery and access to processing, sharing, collaboration, results validation and reuse, metadata enrichment for search and recommendation, versioning, and evolution management. At the core of this offering are Research Objects, the placeholders of scientific methods, materials, and breakthroughs as well as intermediate results produced on a day-to-day basis, rich with descriptive metadata.

Three Virtual Research Communities (VRC) are involved in demonstrating the RELIANCE services value through a set of multidisciplinary and interdisciplinary case studies involving the Earth Science domain. Among these, the Sea Monitoring VRC involves marine scientists studying the influence of climate change and anthropic activities on marine habitats, oceanic circulation, seawater chemistry, biogeochemical cycles, and their economic and social impacts on coastal systems from prehistoric to industrial times.

Our contribution shows how the RELIANCE services integrate with those already available in EOSC to foster the FAIR data and Open Science principles through a showcase of the Sea Monitoring Community multidisciplinary scenarios including mapping of seascape and habitats in the Mediterranean sea.

THE AMARE PLUS GEOPORTAL, A TOOL FOR IMPLEMENTING NETWORKS OF MARINE PROTECTED AREAS IN THE MEDITERRANEAN SEA

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The Interreg MED AMAre PLUS Project aims at connecting Marine Protected Areas (MPA) in the Mediterranean Sea. It developed methodologies, recommendations, and tools dealing with multiple stressors assessment, coordinated environmental monitoring, multi-criteria analyses, and stakeholders' engagement, to be adopted at transnational level.

The AMAre PLUS Geoportal represents a critical tool to improve knowledge within and among MPAs. This user-friendly web application is a common space accessible by different stakeholders and providing GIS tools for MPA managers and decision makers. It is implemented on a common infrastructure homogenizing all the information collected, following MPA manager's opinion and international standards. The geoportal is part of a spatial data infrastructure for managing multidisciplinary spatial data including i) a relational spatial database following the data specifications proposed by the INSPIRE Directive, ii) a metadata catalogue describing all the resources accessible through the geoportal and the project data policy, and iii) OCG web services witch guarantee the interoperability with other infrastructures.

Today, fine scale spatial data are accessible through the AMAre PLUS Geoportal for 18 MPAs within the Mediterranean sea. This tool lays the foundations for developing a common knowledge across the Mediterranean Sea; it represents a starting point for developing shared strategies for monitoring vulnerable habitats, environmental status, essential ocean variables, human activities inside and around the protected sites, for the assessment of the protection, and for a constructive comparison between MPAs.

PROGRESSION OF A TWO-PART SEABED GEOMORPHOLOGY CLASSIFICATION SCHEME WORKSHOP: PART 2 (GEOMORPHOLOGY)

R. Nanson, R. Arosio, D. Dove

When: Wednesday 6th July 2022 (3 hours)
Where: Valetta, Malta (as part of the International Conference on Seafloor Landforms, Processes and Evolution)
Facilitators: Rachel Nanson, Riccardo Arosio, Dayton Dove
Agenda (draft):

(1) Genesis of the two-part mapping scheme (15 minutes)
(2) Part 1: Morphology overview (15 minutes)
(3) Part 2: Geomorphology draft scheme introduction (15 minutes)
(4) Breakout sessions: (15 minutes for each setting X 3)
Participants break into sub-environment systems (and move between 3 specialty settings of their choice: Glacial, Fluid flow, Bedrock volcanic/continental-scale, Marine, Coastal, Fluvial, Biogenic, Mass Movement) to discuss a draft geomorphic framework for each system
a. Environment 1 (e.g. Glacial: 15 minutes)
b. Environment 2 (e.g. Fluid flow: 15 minutes)
c. Environment 3 (e.g. Coastal: 15 minutes)
(5) High level summary from setting facilitators (X 8) (60 minutes)
(6) Workshop summary discussion points and reflections from attendees (30 minutes)

Detail: The 2019 GeoHab meeting hosted a well-attended seafloor geomorphology mapping workshop, where speakers presented a range of seafloor morphology mapping tools and schemes (report here). One of these schemes (subsequently published) was "A two-part seabed geomorphology classification scheme, Part 1: Morphology Feature Glossary", which is designed to support a consistent and standardised approach to classifying the seafloor morphology (i.e. from bathymetry datasets). The list of terms and definitions for the scheme were modified primarily from the International Hydrographic Organization guide for undersea feature names.

We now invite interested geomorphologists to help guide the final stages in the development Part 2: Geomorphology, to build on the geomorphic settings outlined in Dove et al (2016) initial report. Interpretations of seafloor geomorphology necessarily draw on subsurface data and context to interpret formative processes. There are a wealth of existing geomorphology classification schemes that represent the suite of systems that are either preserved or actively developing on the seafloor. We will present a draft framework for these systems, and invite participants to provide their input and feedback.

Workshop product: TBC Workshop report and / or a special issue (Marine Geology?) on the application of this approach to examples of all geomorphic settings.
To register for the workshop please email Rachel.nanson@ga.gov.au

UNDERWATER PHOTOGRAMMETRY: FULL MOTION VIDEO AND INTEGRATION OF MACHINE LEARNING ALGORITHMS – A CASE STUDY APPLIED TO MSFD SEABED HABITAT MONITORING

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The Marine Strategy Framework Directive (MSFD) aims to effectively protect the marine environment across European Seas, adopting measures based on ecological indicators, methodological standards, and monitoring programs.

A specific monitoring program for the following benthic habitats: i) Habitat 1120 - Seagrass (*Posidonia oceanica*); ii) Habitat 1170 – Reefs (Coralligenous and Cold-water corals, CWCs); and iii) Habitat 1110 – Sandbanks (Rhodoliths beds), aiming to characterize their environmental status is carried out by Italy within Descriptor 1 - Biodiversity (D1).

This study presents the application of a multi-resolution and multi-scale approach for the MSFD monitoring program. A method based on machine learning algorithms is tested to improve and speed up the mapping and monitoring procedures. To this effect, the Full Motion Video (FMV) technique by underwater photogrammetry, DEM (Digital Elevation Model), backscatter, and bathymetry from high-resolution Multibeam (MBES) and ROV-imaging are integrated.

This methodological approach was tested using data collected in 2020-2021 in three Italian sites: Cirella Island to characterize the Posidonia oceanica meadows and northern Elba Island continental shelf to map Rhodolith beds in the Tyrrhenian Sea and around Linosa Island to study the distribution of CWCs in the Ionian Sea. The bathymetric surveys were carried out by means EM 2040 MBES (high-resolution bathymetry and backscatter data) while high-resolution videos and photos were collected by using a towed vehicle equipped with cameras, and a Remotely Operated Vehicle (ROV Perseo). Acquired data were georeferenced using NATO's Stanag 4609 protocol, which describes an exchange format for moving images. FMV videos were converted in Trasport Stream (.TS) file format, allowing the synchronization of the video frames with navigation data. Finally, the entire dataset was analyzed using ArcGIS Full Motion Video In particular, the latter can overlay high-resolution backscatter and bathymetry multibeam data with the image data by matching a representative delimiting footprint size by the FMV frame acquired by the video camera, allowing a rapid location XY and habitat characterization. In particular, the latter can overlay high-resolution backscatter and bathymetry multibeam data with the image data by matching a representative delimiting footprint size by the FMV frame acquired by the video camera, allowing a rapid location XY and habitat characterization.

All the frames were processed using the Structure from Motion (SfM) algorithm to generate very high-resolution 3D and orthomosaics models. The latter were used for microscale analysis and validation data (Ground-Truth) to classify bathymetry and backscatter. Bathymetry, backscatter, and satellite images (for shallow water) were classified by means eCognition software, according to the Object Image Analysis (OBIA) approach. Multi-data integration procedure (FMV, SfM, and OBIA) significantly improves quality and strongly reduces the time-consuming of the seafloor and habitat mapping.

This approach can be adopted within the MSFD providing advantages in data processing and improving the quality of data analysis and interpretation.

Machine Learning application in the ecological study of marine habitat can play an important role in improving the knowledge on species and habitat distribution and condition and, therefore, it represents a key element for the conservation of the marine environment.

OFFSHORE BEDROCK MAPPING: APPLICATIONS FOR REGIONAL OUTCROP AND POTENTIAL REEF HABITAT MAPPING ON THE IRISH CONTINENTAL MARGIN

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The Irish continental margin (ICM) hosts many complex sedimentary basins, and diverse geomorphological domains displaying bedrock outcrops that can host a large variety of habitats from shallow to cryptic. Recent benthic video surveying in the ICM has indicated extensive areas of bedrock exposure. However, the accessibility and identification of outcrop remains difficult due to the difficulty of sampling rock at significant water depths and by limited geological knowledge of sedimentary basins offshore Ireland .

With the use of Sea Rover video transects covering all the ICM, INFOMAR multibeam echosounder dataset, and a developed novel Bedrock Suitability Index, this study aims to improve the appraisal of the regional geology and bedrock mapping of the Irish margin in order to determine potential reef habitat areas. Key terrain variables, diagnostic of bedrock outcrop all along the ICM, have been derived from bathymetry. By identifying the suitable ranges for outcrop occurrence in the variables, the most suitable class for reclassification of each terrain variable was created close to the recorded median. Further suitable bedrock location in non-surveyed areas have been calculated using these variables with map algebra.

This work has improved the Bedrock Suitability Index (BSI) previously developed for the Porcupine Bank Canyon by fine tuning the variables to the wider margin. The improved BSI model has been constructed across the ICM producing a high resolution (25m^2) model of predictive bedrock outcrop locations. Validation by video observations and correlations of predicted bedrock exposures has established an appropriate level of confidence with BSI accuracy.

Session 6 – Habitat mapping and climate change

CLIMATE CHANGE AND AN URBAN SEA – IMPACT OF THE EVENTS OF 2021 ON THE SALISH SEA

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2. Moss Landing Marine Labs/Tombolo Mapping Lab, USA

In 2021, weather disasters plagued the Pacific Northwest of North America that have significant consequences to terrestrial and marine habitats. These have been termed "natural disasters" yet there is little 'natural' about these catastrophic events as they were driven by climate change and increased human activity in the global environment. The events started with a "Heat Dome" (atmospheric trap of hot ocean air like a lid or cap) in June, quickly followed by unprecedented high temperatures and winds producing wildfires, accompanied with a significant drought. The drought conditions ended in September with two "Weather Bombs" (rapidly developing severe storms) and in November a larger disaster, a massive flood brought on by an 'Atmospheric River" (a super-saturated band of warm air moving over the Pacific Ocean). The unprecedented loss of forest to fire and drought left the mountainous coastal region of the Salish Sea with unstable soils that when exposed to the Atmospheric River were washed away in massive volumes through slides and flooding rivers to the coastal lowlands and into the Salish Sea. The Weather Bombs resulted in significant storm waves and high winds that contributed to a container ship loosing 109 containers along the Vancouver Island coast, containing toxic chemicals and all kinds of household goods. Added to this were the chemicals, debris and drowned livestock, all heading for the Salish Sea during the flood. The turbidity generated by these events in the southern Salish Sea, including the islands and channels of the US/Canada archipelago, was visible from space (Fig. 1).

So what do all these weather events have to do with marine habitat? First, the culmination of these so-called natural disasters happened during the spawning season of Pacific salmon, which require gravel substrate habitats in the streams and rivers. The dramatic changes in the salmon watersheds brought on by siltation or total erosion of spawning beds was almost instantaneous. It may be a considerable time before the impact of this is known. Offshore the Salish Sea, an inland Urban Sea, has a broad range of estuarine and marine habitats, many that are unique, ranging from sponge reefs to forage fish sub-tidal habitats of dynamic bedforms. The impact to these habitats due to the contamination from containers breaking up along the coast, contaminants reaching the Sea from the devastating floods, and in particular, the massive turbid discharge and sedimentation that resulted from these events, has yet to be realised. Salmon, for which the Salish Sea is noted, are most susceptible to warming water temperatures, availability of forage fish, and healthy spawning habitats, all of which have been severely impacted from human activity and climate change.

Figure 1: Flooding and subsequent marine turbidity as from NASA satellite image – November 2021.

BENTHIC ECOSYSTEM MAPPING FOR SUSTAINABLE OCEAN STEWARDSHIP IN A SHIFTING OCEAN CLIMATE

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In the Northwest Atlantic (NWA), marine ecosystems have been identified as particularly vulnerable to pressure from rapid changes in ocean parameters driven by climate shifts due to the region's important effect on the Atlantic Meridional Overturning Circulation (AMOC) and to its significant role in ocean uptake of anthropogenic CO_2. Climate-induced change on the range and distribution patterns of benthic fauna are expected, but precise prediction on how these changes will occur, or the underlying abiotic and biotic drivers of change, are mostly unknown. When faced with warming temperatures, studies have shown that many species are likely to exhibit poleward range shifts. However, the role that availability of suitable benthic habitat plays in this process is largely unknown due to a scarcity of available seafloor mapping data. This is a critical gap in almost every study to date examining climate impacts on benthic faunal distributions.

To address this knowledge gap, a major, multi-year research program commenced in 2020, funded through the Ocean Frontier Institute (OFI): *The BEcoME project – Benthic Ecosystem Mapping and Engagement* (www.ofibecome.org). Through a series of inter-connected, cross-disciplinary work-packages (Figure 1), the BEcoME project is addressing what role benthic habitat plays in controlling shifting patterns in species and biodiversity caused by a changing ocean climate. This overarching question is being examined across spatial scales, from: 1) broad-scale geomorphology mapping over the entire NWA, to; 2) fine-scale surficial geology and benthic habitat mapping using innovative technologies over local case study areas. This presentation will provide an overview of the project, with a focus on preliminary results from two of the project work packages (WPs): 1) WP4.3 Seafloor characterization using multispectral multibeam sonar; 2) WP5 Deep learning for seafloor imagery processing.

MARGINAL SEAS TASK GROUP OF THE DEEP-TIME DIGITAL EARTH (DDE), IUGS BIG SCIENCE PROGRAM

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2. Institute of Coastal Systems – Analysis and Modeling, Helmholtz-Zentrum Hereon, Germany
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4. Guangzhou Marine Geological Survey, China Geological Survey, China

The DDE Marginal Seas Task Group has been established in 2021 in order to contribute to the quantitative study of the interface between continents and oceans. This interface – the marginal seas and their coastal zones - play a crucial role providing people with habitat, food, trade ways, and facilitated socio-economic networking. Because the marginal seas are increasingly threatened by rising sea-level, floods, storms, tsunamis, coastal erosion and environmental hazards effective strategies for sustainable development are becoming a cross-bordering task for the international scientific community. A road to master this challenge is paved by the **mission** of the DDE Marginal Seas Task Group which is focused on the development of a master strategy for describing the processes in marginal seas holistically as an interaction between geo-, eco-, climate-, and socio-economic systems during the late Pleistocene, Holocene and Anthropocene. This strategy includes big data analyses, functional numerical models and AI approaches and will allow to answer three fundamental questions:

- How did marginal seas of different climatic zones and tectonic settings change their paleo-geography, -oceanography, and -environment during the natural climate and environmental variation of the Last Glacial Cycle?
- What are the future expectations for the development of marginal seas and their coastal zones facing the challenge of climate change and increasing human impact on the environment for this century?
- What strategies for sustainable development of the marine and coastal realm can help to mitigate the major threats to marginal seas driven by rising sea-level, floods, storms, (meteo)tsunamis, coastal erosion, silting and environmental hazards.

Our **vision** is to contribute to keep balance between the protection of the natural environment of marginal seas and the economic use of their resources based on new data and new model driven cognition methods.

The main action of the Task Group in 2021 was the initiation of a DDE research project “Morphological Evolution of Coastal Seas – Past and Future” together with international partners targeting interdisciplinary data describing structure and evolution of three exemplary Eurasian marginal seas (North Sea, Baltic Sea and South China Sea). Measurable outputs will be reports and maps of paleogeographic and future shelf seas scenarios. Results are shown by maps and videos. Our time scale will cover the last 130 kyr for paleo-scenarios and the time until 2100 AD for future scenarios (the time span of future climate modeling). Computerized sea floor and coastal mapping will play an important role and forms the interface with the GeoHab community.

FROM INCISED VALLEYS TO SUBMERGED REEFS: THE QUATERNARY LEGACY IN HABITAT DISTRIBUTION

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Drowned landscapes, including paleoshorelines, and "give up" submerged reefs are formed during the deglaciation, being highly influenced by the changes in rates of sea-level rise. Thus, modern shelf seascape is, in many cases, a legacy of eustatic fluctuations (glacial and interglacial) during the Quaternary. Although the influence of submarine geomorphology in habitat distribution is widely disseminated in the scientific community, here we investigated distinct drowned landscapes and reefs in order to understand the habitat evolution. The occurrence of distinct types of drowned coastal morphologies and submerged reefs have been mapped in the eastern Brazilian shelf using high-resolution multibeam data, regional bathymetric maps and underwater images. The submarine features mapped are shelf-incised valleys, paleocoastlines, paleolagoon and drowned reefs (Fig. 1).

The geomorphological analysis indicated that paleoshorelines, incised valleys and outer shelf reefs were established during the Younger Dryas slowstand and drowned during meltwater pulse 1B. These features, usually occur from 65 to 55m deep and, in this case study, are related to mesophotic rhodolith bank habitat and/or crustose coralline algae reefs. Shallow drowned reefs (12-30m deep) can be related to a stillstand prior to MWP-1C or the 8,2k event. These shallow habitats encompass drowned reefs associated with adjacent submerged channels, forming an inner-mid shelf complex habitat. Relict shelf geomorphology combined with Holocene carbonate sedimentation and low sediment input imprint a complex shelf geodiversity spatial pattern, defining the seascape and driving physical/benthic habitat distribution. Critical mesophotic habitats, that are part of modern seascape, represent drowned paleoenvironments.

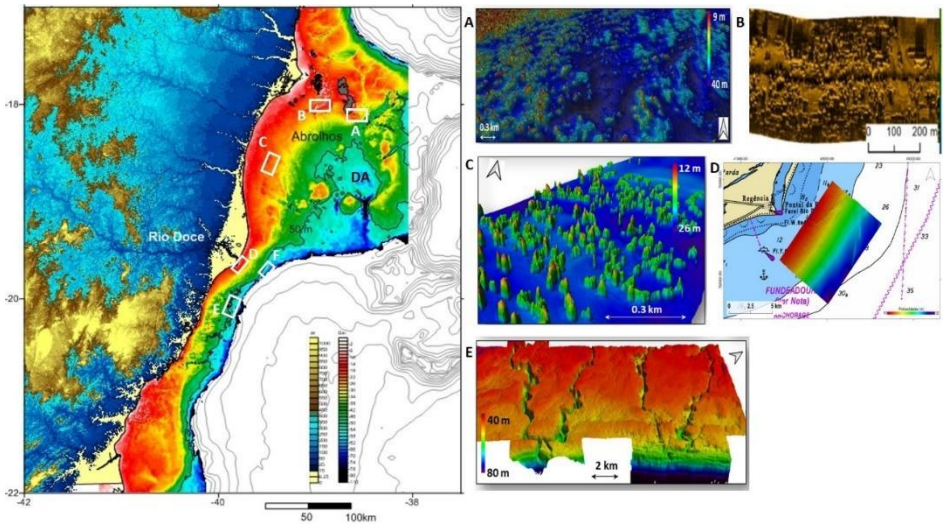

Figure 1: Regional bathymetric map with high resolution maps of drowned landscape and reefs

Session 7 – Habitat mapping for maritime spatial planning (MSP) within an ecosystem based approach

INVESTIGATION OF NATURA 2000 MARINE BENTHIC HABITATS IN THE LATVIAN EEZ: IDENTIFICATION, CHALLENGES AND DESIGNATION OF NEW MPAS

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Latvian coast of the Baltic Sea belongs to the most exposed shores of the Baltic Sea, hosting two habitats protected by Habitat Directive (Annex 1, Council Directive 92/43/EEC) - stony reefs (1170) and sandbanks (1110).

Stony reefs are one of the most prominent, ecologically significant habitat types in the Eastern part of the Baltic Sea, and considered as a biodiversity hotspot for attracting invertebrates, fish, birds and plants. They are an area of hard substrate (rocks, boulders and pebbles) surrounded by patches of sand. On the Latvian coast, reefs present almost a two-dimensional hard bottom substrate for the benthic communities on otherwise very exposed, straight coastline. The three-dimensional structure can only be found on several tens of cm height range, representing the size of the largest boulders. It can be summed up that stony reefs in the south-eastern Baltic exist on the verge of environmental limits, making them even more vulnerable to environmental disturbance, but their existence still more precious for the ecosystem functioning. Reefs have evident ecological zonation defined by depth and associated with vegetation and benthic animals. However, no territory is assigned special protection status for sandbanks because of the lack of clear definition that would describe the real conditions in Latvian coastal waters. Sandbanks are defined as topographic features that are slightly covered with water not deeper than 20m and usually associated with macrovegetation. Nevertheless, we have identified such structures from the shoreline to deeper offshore zones with no vegetation that only partly meet the regular definition. Sandbanks can be often found in association with reefs and often in Latvian coasts biotopes are patchy; reefs are mixing with soft bottom substrates.

Latvian coastal protected areas suffer from increasing eutrophication and onset of invasive fish species, plundering the coastal habitats. This alone accentuates the necessity of investigations into the areas outside of the current marine protected areas (MPAs). Currently 3 areas (approx. 4000 km²) in the exclusive economic zone (EEZ) are targeted for research. These are elevated areas at 28-50m depth, which were thought to be of mixed substrate as indicated by existing sediment maps, however pilot studies have revealed the presence of reefs. The aim of the project is to assess the extent and ecological state of offshore reef habitats in the Latvian EEZ. The habitats will be evaluated against the criteria for designation of new MPAs and once identified, their connectivity to coastal MPAs will be assessed, to possibly provide the genetic material for restoration of coastal habitats. The offshore MPA assessment will enable conservation of areas of particular importance for biodiversity and ecosystem services provision through a well-connected system of effectively managed, and ecologically representative protected areas.

We performed seabed mapping using ROV underwater camera 500x500m in research area. Seabed composition, features and living organisms were registered by an expert. Biological samples were collected by qualified scientific divers and identified in laboratory to highest possible taxonomic level. We suppose that due to long term anthropogenic influence on benthic biotopes, they frequently do not meet good environmental status and are degraded, furthermore loss of some typical species could occur. Expanded definition of reefs and sandbanks adapted to the situation of

Latvian coastal and offshore waters has been developed and bottom communities were described in depth range 5-35m. Funded by LIFE project "LIFEREEF No. LIFE19 NAT/LV/000973".

USING PATCH CHARACTERISTICS OF BENTHIC COMMUNITIES DERIVED FROM HABITAT SUITABILITY MODELLING TO INFORM SPATIAL MANAGEMENT OF THE MARINE ENVIRONMENT

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Habitat suitability modelling (HSM), also known as 'environmental niche modelling' or 'species distribution modelling', includes a suite of methods to predict the spatial distributions of species, assemblages, or communities using habitat data. Standard outputs of HSM include: 1) correlations between habitat variables and species' distributions; 2) estimates of predictive uncertainty; and 3) predicted distribution maps of the modelled taxa. Together, these outputs can be used to investigate relationships between marine benthic habitat parameters (e.g., depth, substrate, seafloor topography) and species and community occurrences. Outputs of HSM can be used to inform the development and/or evaluation of spatial management of the marine environment. Here, we demonstrate the potential utility of HSM outputs for spatial management using a patch dynamics approach. Predicted spatial distribution maps of benthic communities resulting from several HSM analyses were used to describe their patch characteristics based on five patch metrics: number of patches; patch area; minimum distance between patches; contiguity; and patch density. Community patch characteristics were then used to develop spatial management recommendations in the New Zealand region. Results of this study will be presented and methods to apply similar approaches at various spatial scales will be discussed. This study is an extension of the results presented at GeoHab 2021 in the presentation "Using substrate and seafloor terrain variables to predict benthic community distributions on two New Zealand seamounts".

MONITORING SEDIMENT TRANSPORT AND GRAIN SIZE DYNAMICS ALONG THE ISRAELI CONTINENTAL SHELF USING MULTIBEAM BATHYMETRY AND BACKSCATTER DATA

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The main source of sediments along the Israeli continental shelf is the Nile Delta, which undergoes erosion since 1960 when the Aswan dam was constructed. Along the Israeli inner-shelf, these sediments are transported northward and westward by wind-derived currents and storms. In the frame of the National Monitoring program of the Israeli EEZ, the Israel Oceanographic and Limnological Research (IOLR) started in 2017 an annual seafloor and sub-bottom mapping to monitor the morphological and sedimentological changes and to quantify the influence of man-made infrastructures on the seabed along the Israeli continental shelf. The survey program onboard R/V Bat-Galim along 13 transects across the shelf, from WD 10-100 m includes the Kongsberg EM2040 multibeam, Knudsen 3260 Chirp sub-bottom profiler and sediment sampling with box-core. The multibeam is operated at 400-kHz yielding horizontal resolution of 0.25-1.0 m (depending on water depth), and vertical uncertainty of several centimeters. Using the QPS FMGT software, both angular response curves (ARA) and 0.5 m horizontal resolution of Backscatter data (BS) were derived. The multibeam acoustic return intensities (BS) were locally calibrated at selected reference areas using *in-situ* sediment sampling.

The analysis of the bathymetric surfaces from the consecutive years 2017-2021 shows that the shelf is stable in terms of sediment processes except along the marine infrastructures and natural seafloor features (e.g. rocky bottom outcrops) where patterns of sediment accumulation and erosion are observed. The variability along the marine infrastructures is mostly seen in the shallow water (less than 30 m) where yearly changes of up to +/-0.4 m of sediment accumulation/erosion in the vertical axis were measured. The locally calibrated multibeam BS enabled grain size mode evaluation ranging from very fine gravel (-1 phi) to clay (9 phi). Additional *in-situ* sampling validated the reliability of the grain size classification method for the Israeli, continental shelf. Accordingly, we show that the Israeli continental shelf south of Haifa Bay is characterized by a sandy seafloor strip at WD 0-35 m and a muddy strip that extends west up to WD 100 m (in agreement with previous studies). Gravelly areas are identified at the coast-parallel Kurkar outcrops (Calcareous sandstone rocky ridges or rock patches) in water depths of 10-15m and 35-40m and in some places even at WD of 90 m. This demonstrates that grain size classification by locally calibrated multibeam BS is likely to be a very useful and cost effective method for monitoring changes in seafloor characteristics over large areas over time.

A STEP TOWARDS EFFECTIVE ECOSYSTEM-BASED MANAGEMENT IN MALAYSIA MARINE PARKS: STANDARDISED BENTHIC CLASSES USING MARINE LANDSCAPE APPROACH

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Marine Parks Malaysia has long used the Coral Video Transect (CVT) technique to assess the coral health within the marine parks area. It has been used as the primary data collection method to enhance coral reef management within marine parks. This method, however, does not provide a wide array of benthic habitat characterisation and its spatial extent. The lack of spatial representation of coral reefs and their habitat characterisation within the marine parks hinders the implementation of effective ecosystem-based management.

Ecosystem-based management requires the identification of biological and ecologically important areas. The following can be achieved by identifying the natural variability present in environmental parameters and can be translated into ecologically relevant natural zones. This is the marine landscape approach concept and can be adopted into the ocean zoning plan via Marine Spatial Planning (MSP) for strategic marine ecosystem management in Malaysia.

Here, multibeam bathymetry and backscatter data will be used to identify the relevant natural zones. First, we will produce the marine landscape map using an objective automated technique. Next, using the fine-scale information from existing CVT data, species indicator analysis will be performed to evaluate the ecological relevance of the zones in the marine landscape map. Potentially, should the marine landscape be ecologically relevant, indicator species will be identified, whereas if no indicator species can be identified, the cluster lacks ecological significance. Finally, we will evaluate the ability to integrate fine-scale input from the CVT to the broad-scale marine landscape map produced through this study.

Two marine parks were chosen based on the data availability and motivation from a joint effort between UMT, UTM, DOF & NHC. The marine parks are Labuan Marine Park and Tioman Marine Park. Through these study areas, we will propose a framework to be adopted by the Government of Malaysia, its national agencies and departments that have responsibilities relating to ocean health and marine resource utilisation. The framework will address i) the type of data that agencies can contribute as baseline data ii) classification using marine landscape approach to integrate existing data and future survey planning iii) marine landscape as the first level structural variation for the standardised benthic classes. The framework is meant to be incorporated at the implementation and operational level within the marine parks management.

SYNTHESIS AND DEVELOPMENT OF 'SENSITIVE ECOSYSTEM ASSESSMENT AND ROV EXPLORATION OF REEF' (SEAROVER) SURVEY OUTPUTS FOR RESEARCH AND POLICY SUPPORT

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An ongoing requirement exists to quantify the abundance and distribution of offshore biogenic and geogenic reef habitats in Irish waters to fulfil Ireland's legal mandate and to generate baseline data from which appropriate monitoring systems can be established. To address this, an extensive offshore reef survey of Ireland's continental slope was commissioned by the Marine Institute in partnership with the National Parks and Wildlife Service (NPWS), funded by the European Maritime and Fisheries Fund (EMFF), and coordinated and led by INFOMAR (Integrated Mapping for the Sustainable Development of Ireland's Marine Resources).

The Sensitive Ecosystem Assessment and ROV Exploration of Reef (SeaRover) project facilitated data acquisition during 3 separate survey legs. These took place between 2017 to 2019 onboard the ILV Granuaile (2017, 2018) and the Marine Institute's RV Celtic Explorer (2019). The Marine Institute's remotely operated vehicle (ROV) Holland I was used for each of these cruises. The Holland I was equipped with a high-definition (HD) camera, various composite video feeds and a robotic arm for sample collection. In total 154 separate locations were surveyed by ROV over 63 days at sea which covered 3500 km2 of seabed at depths between 150 m and 3000 m. This included 27 sites within Irelands six offshore SACs and the collection of 336 hours of HD footage of the seabed, 122 sediment samples and 211 biological samples that will enable future studies into the ecological diversity of the north Atlantic.

A follow on EMFF funded project was commissioned to deliver a synthesis of SeaRover findings, and subsequent preparation of advisory services. The EMFF Funded 'Synthesis and Development of Advisory Products: SeaRover' project will synthesize the output of the SeaRover acquisition phases and, in consultation with the most important end-users, map out how the data should be disseminated, analysed and developed into products and tools used for policy support. This will facilitate contribution to the provision of conservation objectives for the offshore Special Areas of Conservation (SAC) work, and will help fulfil national obligations to map vulnerable fisheries resources. These projects align with sub-article 6.2 of the Habitats Directive (EC 92/43/EEC) which requires member states to take measures to avoid deterioration of protected habitats.

The synthesis and development of SeaRover data will ensure the availability of comprehensive biological baseline datasets which will be critical to the formulation of future policy on the management, monitoring and conservation of Ireland's deepwater ecosystems. This paper will look at SeaRover synthesis outputs to date, and the proposed pathway for delivery of these data to researchers and the development of products to inform policy in this area.

WHY DOES BENTHIC HABITAT MAPPING MATTER FOR BRAZILIAN SCIENCE AND MANAGERS? A MULTI-SCALE APPROACH IN THE SOUTHEAST BRAZILIAN SHELF

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Seabed habitat mapping is a baseline information for ocean management and indispensable for marine spatial planning. Here, we use a case study and published data to discuss the concepts and ideas of seabed habitat mapping and the importance of a multi-scale approach. The basic case study is the iron ore tailing dam failure that occurred along southeast Brazil, releasing around 40 million m3 of tailings. Part of the tailing slurry reached the river mouth and was dispersed along the coast and inner shelf by the riverine plume and prevailing shelf sedimentary processes. A combined regional seabed data analysis and ecosystem vulnerability assessment, including habitat and natural/anthropogenic threats, was applied to define high-priority areas to carry out a higher resolution seabed habitat mapping.

Three high-priority areas were defined and assessed in terms of their ecosystem vulnerability to the tailing impact, conservation status, degree of exposure to the disaster and ecosystem services that were potentially disrupted due to the disaster: i) a marine protected area (MPA-Costa das Algas) with an extensive rhodolith bed with rare interaction with the tailings plume; ii) a mud depocenter at the river mouth that encompasses an important fishing ground severely impacted by tailings deposition; and iii) a coral reef area, never mapped before and with a potential medium to long-term interaction with the tailings. The high-resolution habitat maps were produced using multibeam data, backscatter + morphometric classification (RSOBIA) and underwater footages. The habitat classification was essential for the first ecosystem vulnerability analysis, corroborating the importance and applicability of regional habitat mapping as baseline information and in contributing to impact monitoring projects.

The higher resolution obtained in the habitat mapping study provided a significant improvement on the level of habitat heterogeneity and extension, proving to be a crucial information for a reliable decision-making process, but also for setting a monitoring program design. Although Brazil lacks a national habitat map for the entire continental margin, local or regional academic efforts are now producing habitat maps that can be used as a basic tool for spatial planning. This scenario is about to change as Brazil committed to the Sustainable Development Goals (SDG) of the United Nations, including the establishment of a Marine Spatial Planning by 2030. Thus, it is urgent to plan and implement a national database capable of supporting a habitat classification effort on a broader national scale, bearing in mind that spatial planning should consider a multi-scale approach.

BENTHIC HABITAT MAPPING UNDER MULTILEVEL APPROACH IN THE ARCHIPELAGO OF SAN ANDRÉS, PROVIDENCIA AND SANTA CATALINA, COLOMBIAN CARIBBEAN

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The Colombian Archipelago of San Andrés, Providencia and Santa Catalina located in the southwest Caribbean, is composed of ten reef complexes and was declared as the Seaflower Biosphere Reserve (Seaflower BR) in 2000 by the UNESCO. The Direction of Coastal Marine Affairs and Aquatic Resources (DAMCRA) of the Colombian Ministry of Environment and Sustainable Development (MINAMBIENTE), entrusted the INVEMAR to update the maps of ecosystems at a 1:50.000 scale of the seabed between 0 and 30 m deep in five reef complexes (Serrana, Roncador, Quitasueño, Providencia and Santa Catalina, and San Andrés). The coral area covers 54,6% of the Seaflower BR corresponding to 46,1% of the total extension in Colombia.

Among October and November 2021, two field trips were carried out to capture information on the benthic seascape over 590 stations using Rapid Ecological Assessments. The fieldwork included photographic records and coverage estimation percentages at a detailed level (coral species), at a semi-detailed level (biotic groups) and at a general level (biophysical coverage). The gathered information was analyzed with multivariate statistics to recognize spatial patterns of biotic groups and hard coral species assemblages. For the seabed delimitation and interpretation process, several images with spatial resolution of 10 m SENTINEL-2 sensor were obtained between December 2020 and December 2021. The images were processed to get bathymetric models with field data verification and were interpreted visually and through an algorithm in the Google Earth Engine (GEE) platform and field data verification.

An extension of 173.683 ha of underwater habitats were mapped by multilevel approach, adapting a 4 level ecological classification. At general level, 6 types of coverage were identify. At detailed level, 19 habitats or ecological units were identified and delimited including associations of scleractinian coral species. The general level allowed monitoring based on remote sensing techniques and low demand of field information, while the detailed level allowed monitoring the ecological identity, but requires extensive field information. These maps are a very useful tool for the country and due to their multilevel approach, they can be adapted to different needs and scales, such as the identification of sites with conservation and restoration potential and the management of natural resources.

COMBINING SATELLITE IMAGERY AND ACOUSTIC DATA TO SUPPORT HABITAT CHARACTERIZATION OF THE BRAS D'OR LAKE ESTUARY TO SUPPORT STEWARDSHIP OF CULTURALLY, ECOLOGICALLY, AND COMMERCIALLY IMPORTANT SPECIES

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Recent proposed amendments to the Fisheries act have stated that traditional knowledge must inform fish habitat decisions and that these decisions must consider the adverse effects on the rights of Indigenous peoples. However, to date, management which is driven by western science, has not been effective in communicating information to Indigenous communities or integrating knowledge shared by these communities into their assessments and management plans. Apoqnamatulti'k is a three-year collaborative study that focused on three culturally, ecologically, and commercially important species: American Lobster and American eel in the Bras d'Or Lake and Atlantic Tom cod and American eel in the Bay of Fundy, Nova Scotia, Canada. Apoqnamatulti'k was built using a Two-eyed seeing framework and a mutual goal to share what we learn together with communities and decision makers to contribute knowledge to help inform management and stewardship of study species in a way that values different ways of knowing. The American eel is a long-lived (> 25 years), single breeding, endangered species. American eels are primarily benthic and spend 74% of its life burrowed beneath the substrate. Although considered a habitat generalist, the winter dormancy of eel in estuaries has suggested a preference for soft-bottom habitats in shallow depths (< 30 m). The Mi'kmaq of Eskasoni First Nation, Cape Breton, Nova Scotia is seeking new baseline ecological knowledge on the spatial and temporal movements and associated habitat of valued species.

In this study we paired acoustic telemetry and shared knowledge to track the movements of American eel and American Lobster in the Bras d'Or Lake with habitat mapping using multibeam backscatter and bathymetry data and Sentinel-2 satellite imagery to capture habitat use of these species in this region. Bathymetry and backscatter data provided by the Candain Hydrographic service and processed by the Canadian Geological Survey of Canada was used to generate a Benthoscape of the Bras d'Or Lake estuary. Ground truthing data was compiled from two previously collected datasets consisting of grab samples and seabed photos, along with newly collected seafloor data at selected ground truth locations. An object-based image analysis and IsoCluster analysis using ArcGIS Pro 2.8 was performed on MBES data to classify habitat in deeper regions of the Lake. The same classification method was used on Sentinnel-2A satellite imagery to classify nearshore habitats with attached vegetation as these habitats are critical for food and refuge for American eel throughout their life history. The MBES and Satellite data sets were then merged to create a seamless Benthoscape map of the Lake and nearshore areas in the East Bay region of the

Lake. This map was then used to quantify the types of available habitat that may be used by acoustically tagged study species and in what seasons. Detections of eels were used to determine habitat suitability indices and average habitat use. American eels were found on shallow silt mud (< 50 m) in all four seasons and demonstrated a use of vegetated habitats in summer, fall, and winter.

Information on spatial and temporal distribution of eel and their habitat use has direct application to the identification and protection of important habitat and can also help fill knowledge gaps required to improve management plans and aid in designing effective monitoring programs, for threatened and at-risk species.

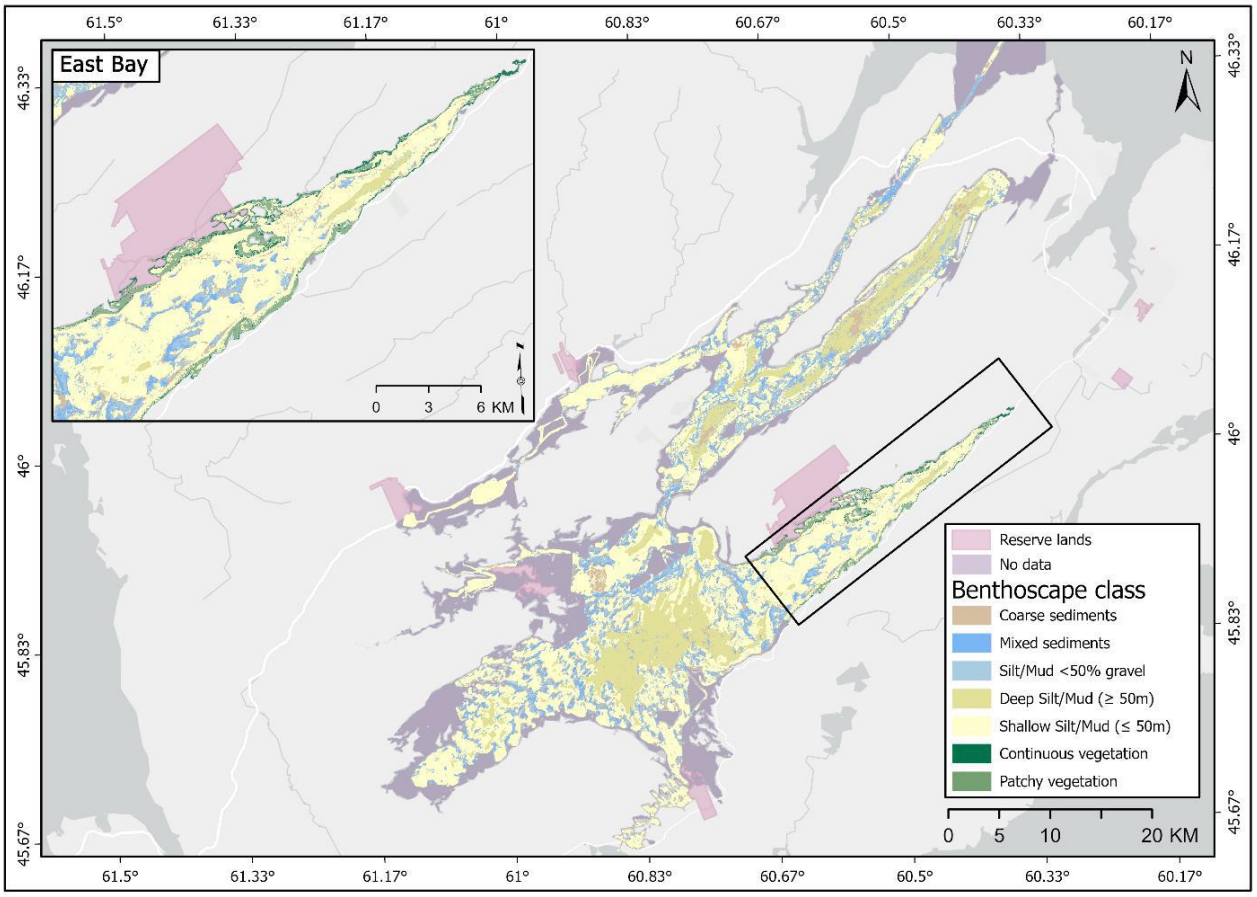

Figure 1. The classified and combined Benthoscape map comprised of the shallow sublittoral region (satellite imagery) and the sublittoral region (MBES data) of the Bras d'Or Lake, Nova Scotia. The Benthoscape was produced using an object-based image analysis segmentation and an unsupervised Iso Cluster analysis.

TOWARDS THE BEST MAPPED COASTAL ZONE IN THE WORLD? THE NORWEGIAN MARINE BASEMAPS INITIATIVE

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The Norwegian Marine Basemaps initiative has one overarching goal – to provide the best mapped coastal zone in the world – in order to provide knowledge for socio-economic development, energy and food production, healthy ecosystems, and to human survival overall. The Hydrographic Service (KV), the Geological Survey of Norway (NGU) and the Institute of Marine Research (IMR) are the main institutions behind the initiative.

A national, multi-institutional pilot project started in 2020, and ends in 2022. The primary goal has been to gain support for a full-scale national programme, by demonstrating the great value of detailed marine basemaps for value creation and coastal zone management. The most important output is a proposal to the government to start a full-scale programme from 2023, with a 467 million Euro budget (516 million US dollar), over a twenty-year period.

The pilot project has focused on three geographic areas, with area selection heavily influenced by the interest from local and regional authorities. An important part of strategy has been to cooperate on two levels – scientist to scientist/manager on the operational level, and between local&regional politicians and business developers/project managers in KV, IMR and NGU. Extensive user consulting, national and local reference groups, extensive communication including workshops, user stories published on web, news articles, newspaper chronicles and conference presentations have been key elements in the marketing strategy. A comprehensive socio-economic analysis performed by an independent consultancy company which focused on societal effects, priced consequences, and non-priced consequences concluded that the annual savings for the society equals the total budget – annually. This means that when the programme has finished mapping the coastal zone (area nearly 100 000 km^2), the annual saving will be in the order of 450 million Euro. The main part of this comes from various effects on the aquaculture industry.

There has been a strong focus on multidisciplinary cooperation and products, use of new and efficient technology, and short timeline from data acquisition to published products. Up till now, coastal mapping has been done using shipborne multibeam echosounders, towed video platforms or ROVs, and physical sampling from ships. This has left a “white ribbon” between land and the waters that can be surveyed by ships or boats. In the pilot project, we have tested airborne (unmanned aerial vehicles, planes) sensors in the shallow parts, together with unmanned surface vessels (USVs). The airborne sensors include bathymetric lidar, RGB photo and hyperspectral sensors (SWIR, NVIR). The USVs have been equipped with multibeam echosunders, and partly RGB cameras. We have also started to test two Kongsberg Maritime Munin+ AUVs, equipped with EM2040, HiSAS2040 (synthetic aperture sonar), Edgetech SBP and Cathx still cameras. If funded at the level we propose, the programme will collect huge amounts of data. We are therefore looking into using artificial intelligence (ML, DL) to speed up the interpretation. Similarly, data management and platforms for cross-institutional processing&interpretation are important aspects. And in the end of the value chain – having an end-user interface which serves the end-users in an adequate

manner is crucial. We are therefore spending substantial resources into making the data FAIR and developing user-friendly solutions.

MAPPING OF VULNERABLE MARINE ECOSYSTEM (VME) INDICATOR TAXA OFF CABO VERDE (EASTERN EQUATORIAL ATLANTIC OCEAN)

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Vulnerable Marine Ecosystems (VMEs) (FAO, 2009) form biodiversity hotspots in the deep sea and are highly vulnerable to physical impacts originated by extractive human activities. In order to implement effective deep-sea conservation and management plans, it is crucial to investigate VME occurrences and biogeography.

The Cabo Verde archipelago (off NW Africa, Eastern Equatorial Atlantic Ocean) is known to be an area with high marine biodiversity, where tropical and subtropical ocean fronts and currents meet. However, little is known about the distribution of the deep-sea communities in the region. During the iMirabilis2 expedition on board the Research Vessel Sarmiento de Gamboa (Orejas et al. 2022), the deep-sea megabenthic habitat on and around SW of the Cabo Verde islands was explored, for the first time, with the Remotely Operated Vehicle (ROV) Luso (EMEPC). The exploration revealed a seafloor geologically characterized by volcanic features with communities mainly dominated by cold-water octocorals and with areas presenting dense aggregations of scleractinians, sponges and echinoderms.

In this study, the spatial distribution of the most conspicuous VME indicator taxa is being investigated through species distribution models (SDMs) with the objective of understanding the environmental drivers affecting their spatial patterns and to predict species distributions in unexplored areas of Cabo Verde. We focus on four observed VME indicator taxa: the octocorals *Metallogorgia* spp., *Acanella arbuscula* and *Pleuxauridae* spp. and the scleractinian *Enallopsammia rostrata*.

Presence-absence data were retrieved from 46 hours of ROV video data from the iMirabilis2 expedition and terrain parameters derived from multibeam bathymetry were considered as environmental predictors. The statistical Generalized Additive Model (GAMs) and the machine learning Random Forest (RF) and Maximum Entropy (MaxEnt) algorithms are being employed. The output of these models will provide insights on the ecological conditions in which species occur in Cabo Verde and will contribute with fundamental information for policymakers in the light of marine spatial planning.

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MARINE HABITAT MAPPING TO SUPPORT THE USE OF CONSERVATION AND ANTI-TRAWL STRUCTURES IN KEP PROVINCE, CAMBODIA

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The marine habitats within the Kep Archipelago, Cambodia, support species of conservation importance and commercial value. Despite the area being designated a Marine Fisheries Management Area in April 2018, illegal trawling has continued, causing damage to the vulnerable habitats. To assist in the protection of these habitats, the non-governmental organisation Marine Conservation Cambodia, with consent from the Cambodian Ministry of Agriculture, Forestry and Fisheries and the Kep Municipality, has deployed Conservation and Anti Trawl Structures (CATS) around Koh Ach Seh island as a passive enforcement measure. These structures are constructed of cast concrete blocks, capable of snagging illegal trawling nets and providing a hard substratum for coral colonization.

Due to the challenging coastal environment and minimal available infrastructure, this study used small, rechargeable or low-power (12 V), low cost systems (combined cost of sidescan sonar and remotely operated vehicle <$15,000 USD) to acoustically map 15.5 km^2 of shallow (<5m) seabed surrounding Koh Ach Seh, Koh Angkrong and Koh Pou islands and ground-truth this area. From these data, habitat maps have been created to delineate the extent of the important benthic habitats and by precisely locating the existing CATS we have estimated the area protected by these structures. This information is hoped to help inform local management decisions, such as optimising the location of future CATS deployments. We critically assess our mapping approach and its suitability for other remote coastal regions and, with a view to future CATS deployments, evaluate the success of CATS in shallow regions under threat of trawling.

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TO WHAT EXTENT ARE MESOPHOTIC COMMUNITIES IN THE MEDITERRANEAN SEA PROTECTED BY THE CURRENT CONSERVATION NETWORK?

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Mesophotic ecosystems are benthic associations distributing from 30 m depth down to where the photosynthesis compensation point occurs. The taxonomic composition of mesophotic ecosystems varies with the geographical location, and at temperate latitudes like Mediterranean Sea gorgonians, antipatharians, and sponges predominate associated with bryozoans, mollusks, ascidians, and shade-adapted algae.

These ecosystems are threatened by a number of natural and anthropogenic stressors including seawater temperature increase, heat waves, bottom trawling, and abandoned fishing gears.

The establishment of effective governance to support the management and conservation of mesophotic natural resources is arguably amongst the best actions for the mitigation of the consequence of human activities on these precious ecosystems.

To date, a systematic, quantitative synthesis of the extent to which Mediterranean mesophotic taxa and habitats are included in conservation measures is lacking.

We reviewed the information on Mediterranean mesophotic ecosystems by considering studies from the early ‘00s to the present, to identify biases in terms of locations and taxonomic targets, and gaps in the current conservation network.

Quantifying the level of protection of Mediterranean mesophotic ecosystems is useful to assess the effort needed for effective conservation measures, and which integrative actions may be functional to their long-term survival

SENSING, INTEGRATION AND ANALYSIS OF DIGITAL INFORMATION IN THE MARINE GEOLOGICAL MAPPING – SEABEDMAP PROJECT. PHASE I

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The lack of scientific data on the Brazilian continental margin, especially on its equatorial margin is memorable. The scarcity of adequate ships and equipment are among the main problems; associated to the absence of standardization in data acquisition. In this sense, the main motivation for this research is aimed at minimizing this gap in the field of geological oceanography/marine geology, through the Geological Mapping of the Brazilian Equatorial Margin. That is, to seek to overcome one of the great challenges of marine geoscience: mapping the geological composition of the seabed through data acquisition, processing, analysis and dissemination, in order to put us in a better position to provide accurate maps and details of seabed sediments and substrate types.

The shelf adjacent to the State of Rio Grande do Norte (RN), the easternmost point of the Brazilian equatorial margin (Fig. 1), was selected as a pilot area due it undergoes strong pressure to economic development and use, for example: due to having the greatest offshore wind potential in Brazil, being the largest producer of sea salt and shrimp in the country, and under strong demand for coastal tourism, fishing, minerals and oil & gas exploitation, among others. In addition, it holds a little more data.

In order to be able to map extensive regions of the Brazilian seabed, in an economically viable way, the solution proposed in this research is the application of a set of specific remote sensing techniques ("Satellite Derivatives"), associated with in situ images and hydroacoustic measurements. On the other hand, the different types of sediments that make up the seabed also correspond to electromagnetic energy reflection bands, making it possible to determine the faciology of a region through the collection of bottom samples, for calibration of the algorithm used. Mathematical compensation of the electromagnetic energy loss through the water column permitted the observation of bottom features on areas previously considered optically deep (until around 70 m water depth). Using underwater leaving reflectance of the corrected image was possible to produce a lithofacial map of the entire shelf, in addition to an accurate mapping of important occurring bottom features (i.e. incised valleys, canyons, reefs, dune fields and sand bars).

The next phase involves the application in others areas and the integration of other multidisciplinary researchers to development of an intelligent system to support the classification and interpretation of large portions of the seabed, enabling the identification of areas whose natural characteristics may translate into more favorable technical, economic and socio-environmental conditions for the installation of offshore projects as well as greater probability of strategic mineral deposits.

Figure1. Location of the study area

Knowledge sharing and networking are essential to promote sound management and sustainable exploitation of mineral, biological and energy resources, by decreasing uncertain in decision making, proposing lower impact measures, and proper mitigation actions.

The project SeabedMap (MCTI / FINEP) is a joint effort between universities and research institutes (UFRN, Universidade Federal do Ceará - UFC, Instituto de Pesquisas da Amazonia - IEPA), the Geological Survey of Brazil (CPRM) and the Brazilian Navy.

MULTIBEAM BATHYMETRY AS THE BASELINE FOR MARINE RESEARCH: APPLICATION IN MARINE HABITAT MAPPING, SOUTH AFRICA

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Globally there is a shift to embrace "blue economies" that exploit marine services and resources for socioeconomic gain. In parallel with these developments, there is a strong focus on seabed mapping in support of marine spatial planning (MSP) and management of the marine space. MSP is evolving to include provision for ecological sensitivity and protection (i.e. marine protected areas - MPAs).

High resolution seafloor datasets are required to describe the seafloor geomorphology and habitat in the highest possible detail. This provides foundation for other research disciplines to build research question, for example monitoring of anthropogenic impacts on the marine environment and biodiversity. At any scale, integrated analysis of the seafloor habitats is anticipated to improve the understanding of ecosystem functioning from a multidisciplinary perspective and management of marine space.

South Africa is still somewhat behind globally in implementing large regional hydroacoustic surveys to cover the vast seafloor area of its exclusive economic zone (5 666km^2). This may possibly be due to the relative lacking of funds, poor communication and understanding regarding multibeam bathymetry but most likely a function of hydrographic surveyor remaining a scarce skill in the country. However, the government needs to drive systematic seabed mapping initiatives to establish multibeam bathymetry data and not rely on private customers or mining companies provided data.

Here we discuss 1) the value seabed mapping offers to habitats, marine research and MSP. 2) ACEP SMART Zones MPA project: a case study illuminating importance of more detailed multibeam bathymetry for habitat and biodiversity research, in South Africa.

EMODNET SEABED HABITATS: COLLECTING HABITAT MAPS ONCE, USING MANY TIMES

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EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu) hosts the largest European collection of habitat maps from individual surveys and survey-based sample points. There are nearly 1,000 habitat maps from surveys and nearly 500,000 sample points, freely available to view via the online interactive map or Web Map Service. Of these, around 900 habitat maps and 355,000 sample points are also freely available to download from the website or by Web Feature Service.

This compilation of polygons and points, with standardised attributes and metadata, presents a great opportunity to create new products which aim to answer specific questions, such as 'what is the current known extent of habitat X in region Y?'

For Europe, we have produced these so-called 'composite data products' for the Seagrass cover, Macroalgal canopy cover and Live hard coral cover Essential Ocean Variables (polygons and points) and for Biogenic substrate (polygons only).

The procedure is always similar: 1. Identify the most complete sources of spatial data on seabed habitat types in the target region. 2. For the target habitat(s), search the most commonly used classification systems for habitats/biotopes/biocoenoses that describe the target habitat(s). 3. Extract data from the sources identified in (1) and filter to select only the habitats/biotopes/biocoenoses identified in (2). 4. Apply some rules to remove overlapping information (if needed). 5. Compile all data into a single data product, making sure the provenance of every polygon and point is clear in the attribute table.

The end products are only as good as the data that feeds them and there are currently data gaps, but in producing these products we have demonstrated the added value of compiling and standardising seabed habitat maps and sample point data.

EMODnet is always searching for new habitat maps and sample points to standardise and publish for the benefit for all. We welcome contributions from anyone, anywhere.

ECOLOGICAL COASTAL UNITS – STANDARDIZED GLOBAL SHORELINE CHARACTERISTICS

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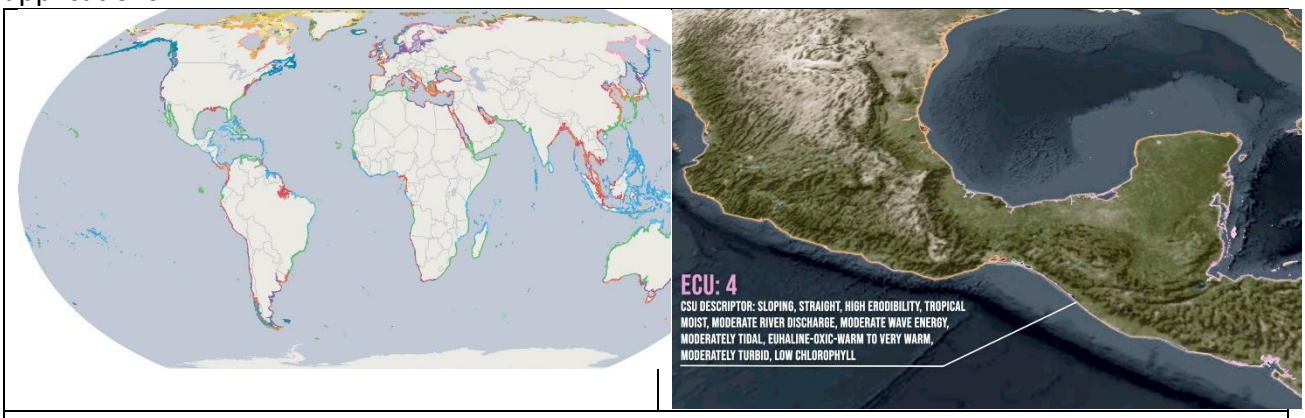
A new set of resources is now available that describe global shoreline characteristics. Ecological Coastal Units (ECUs) were developed by the U.S. Geological Survey (USGS) in partnership with Esri and the Marine Biodiversity Observation Network (MBON). The data were produced by extracting a 30 meter global shoreline vector from Landsat imagery, segmenting the vector into 4 million 1 km segments, and characterizing the land-side, water-side, and coastline-itself attributes for each segment. These data were developed as part of a Group on Earth Observations (GEO) initiative called GEO Ecosystems (GEO ECO) and is associated with a GEO ECO task to develop global coastal ecosystems data. The data are intended to support a variety of research and management applications at local to global scales. This presentation will review how the resource was developed and published, how it can be accessed, and how it may be used in a variety of coastal and marine applications.



The global distributions of the 16 ECUs.

The data allows for the visualization and query of any stretch of coastline on Earth, except for Antarctica. The underlying data are 4 million 1km or shorter coastal segments, each attributed with values from ten ecological settings variables representing the adjacent ocean, the adjacent land, and the coastline itself.

The 4 million coastal segments were classified into 81,000 coastal segment units (CSUs) using the Coastal and Marine Ecosystem Classification Standard (CMECS). Each distinct CSU is a segment with a unique combination of the classes of values of the ten ecological settings variables. The 4 million segments were also clustered into a set of 16 global groups of coastlines which are similar in the aggregate ecological setting described by the ten variables.

The set of 10 attributes describe the aggregated ecological setting in which the coastal segments occur. The values for these variables are drawn from a variety of data sources and attributed to the coastal segment midpoints.

10 YEARS OF EUSEAMAP: BENEFITS, LIMITATIONS AND PERSPECTIVES

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Within the framework of the Seabed Habitat lot of the EMODnet initiative, a consortium of specialists in benthic ecology, geology and seabed habitat mapping started in March 2009 the development of a prototype broad-scale seabed habitat map in four trial basins (Channel and Greater North Sea, Celtic Seas, Baltic, Western Mediterranean). This map was named EUSeaMap. Since then and through the various phases of EMODnet, EUSeaMap has been continuously improved. The spatial coverage was first extended to all European regions. It was then extended further North to include the Barents Sea and the spatial detail was substantially improved. At the end of the current EMODnet phase, in September 2023, it will also cover the Caspian Sea and parts of the Caribbean Sea.

Published in the standard European classifications EUNIS (version 2007 and the recent version 2019) and the so-called 'benthic broad habitat types' of the Marine Strategy Framework Directive (MSFD), EUSeaMap is today the only pan-European cartographic product that provides a standardised overview of the spatial distribution of seabed habitats across Europe. As such, EUSeaMap is of particular use in cross-border ecosystem-based management decision-making. For instance, some EU Member States used it as part of the MSFD assessments in 2012 and 2019, and are using it for the next assessment. Recently, the European Environment Agency used it for the assessment, at a Europe-wide level, of i) cumulative impacts of human pressures on marine ecosystems and ii) the European Marine Protected Area network.

EUSeaMap has demonstrated its value in a wide variety of applications. However, there are applications for which its use is limited (e.g. monitoring exercises, describing habitat extent variation in time).

The presentation will review the strengths and limitations of EUSeaMap and will identify potential development pathways. Drawing on over 10 years of application and user feedback, we will identify the applications for which EUSeaMap is fit-for-purpose, and those for which it is not. Lastly, the talk will discuss other types of products that could supplement EUSeaMap, particularly

in these applications for which it currently has limited use, and the conditions that should be met for these products to be implemented.

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