GEOHAB

Marine Geological and Biological Habitat Mapping

International Symposium 2023 May 8-12 th - Reunion Island

Book of abstracts

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WELCOME TO GEOHAB 2023

… and more significantly, welcome to the very first meeting of the GeoHab association in Africa! We are delighted to welcome you in the middle of the Indian ocean, to the French island of La Réunion, for this 22nd annual GeoHab symposium taking place from May 8 to May 12. We are excited to host 142 delegates including biologists, geologists, environmental scientists, spatial analysts, technologists, geophysicists and environmental advisors from all inhabited continents of the world. The table below provides a breakdown of participants per country:

Country	**Number of delegates**
La Réunion	*23*
United States	*15*
Canada	*14*
Norway	*12*
South Africa, France (outside La Réunion, incl. Mayotte and French Guyana)	*11 each*
Germany, Italy	*9 each*
Australia	*8*
Brazil, United Kingdom	*5 each*
South Korea	*4*
Belgium, Finland, Israel, Madagascar, Malaysia	*2 each*
Croatia, Denmark, Indonesia, Ireland, New Zealand, Portugal, Saudi Arabia, Sweden	*1 each*

We have a very full programme consisting of a workshop focused on 3D underwater mapping of habitats, over 100 oral and poster presentations, and quality time for networking. On Friday the 12th, the field trip will allow those who signed up to learn about the island's geology, bringing them to the bottom of the Piton de la Fournaise volcano. We are delighted to have brought 10 sponsored students to GeoHab 2023, funded by the Ron McDowell fund, and these students will showcase their ongoing work in an international setting. The students are travelling to La Réunion from Madagascar, South Africa, Australia, Italy, Germany, Canada and the United States of America.

We would like to express our gratitude to the sponsors of the conference. These sponsors are Kongsberg, Esri, R2Sonic (Gold level), Fugro (Bronze level), and the French National Research Institute for Sustainable Development IRD, the South African Council for Geoscience, the French government (DEAL/Préfecture de La Réunion and Région Réunion), UMR Espace-Dev, SEAS-OI and the Circum-Pacific Council (CPC) that has supported GeoHab for years. We greatly appreciate the assistance and expertise of the local organising committee and particularly Ms Véronique Rousseau-Mourier. We thank the international team that volunteered to organize the annual workshop: David Price, Loïc Van Audenhaege, Vincent Mahamadaly, Alexandre Sneessens, and Isabel Urbina-Barreto. Lastly, we thank the GeoHab 2023 scientific committee for their reviews of the many abstracts, the student sponsorship committee and the session chairs for agreeing to take that on during the event. We are very grateful to everyone that has made this conference possible.

This book of abstracts serves as the formal conference proceedings document and here you can read the scientific material that makes up GeoHab 2023. This compilation confirms the highly interdisciplinary nature of GeoHab, in both the broad range of environments and topics being studied, and the platform that GeoHab offers academics and ocean professionals to gather. We look forward to seeing you again next year in Arendal, Norway!

Sincerely,

Hayley Cawthra (Program chair) and Rodolphe Devillers (Co-Chair)

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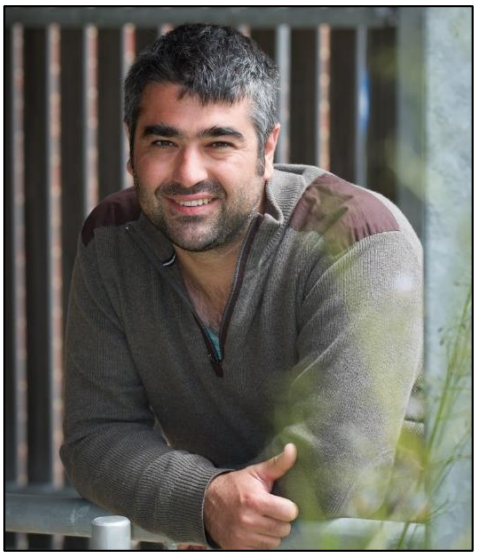
Dr Dan Ierodiaconou

Deakin University

Marine and Coastal monitoring and applications using citizen science



Daniel Ierodiaconou is an Associate Professor in Marine Science at Deakin University's Warrnambool campus in Australia. He employs multi-disciplinary approaches to improve our understanding of terrestrial and coastal processes, evaluation of marine reserves and marine ecosystem-based management. He is a principal scientist for the Victorian Coastal Monitoring Program. He leads the Deakin Marine Mapping Group and has developed new techniques to map our coasts and oceans, providing an accurate and comprehensive picture of coastal change and life and the diversity of marine environments. He is a marine scientist, strategic leader and board director with a passion for discovery and knowledge sharing supporting a harmony between people and place to ensure economic, environmental and social prosperity.

Dr Rochelle Wigley

School of Marine Science and Ocean Engineering- University of New Hampshire

An international capacity-development ocean mapping training program: successes and lessons learnt

Dr Rochelle Wigley has an M.S. in Igneous Geochemistry and a Ph.D. in Sedimentology from the University of Cape Town and a Graduate Certificate in Ocean Mapping from the University of New Hampshire. Dr. Wigley is currently Project Director for the Nippon Foundation / GEBCO Training Program at Center for Coastal and Ocean Mapping, University of New Hampshire. She oversees the management of the Training Program, mentors current students and is active in maintaining this international network of alumni. She was co-lead on the GEBCO-Nippon Foundation Alumni Team, grand prize winners of the Shell Ocean Discovery XPRIZE, and is a board member of Map the Gaps, where she facilitates alumni involvement in ocean mapping projects to ensure ongoing capacity development.

Dr Lucie Penin

University of Reunion Island

Using space when there is no time: What lava flows of variable ages tell us about the structure and dynamics of coral assemblages in eastern Réunion Island

I am an associate professor at University of Reunion Island. My research focuses on coral ecosystems, with a particular interest in the dynamics and maintenance of hard coral communities in the context of increasing disturbances. After almost a decade in the Pacific (French Polynesia, New Caledonia, Australia), I joined University of Reunion Island in 2011, to teach and pursue research on the ecology of coral reefs in the south-western Indian Ocean. I am particularly interested in demographic processes in hard corals of La Réunion, Rodrigues and Madagascar, especially through the supervision of theses. I work in collaboration with the Réserve Naturelle Marine de la Réunion as well, to evaluate the reserve effect on benthic communities. I have a particular interest in non-reef coral ecosystems, notably the lava flows of the Piton de La Fournaise volcano and the mesophotic coral ecosystems.

ABSTRACTS OF ORAL PRESENTATIONS

The NOMANS_TIF map: Ireland's first complete shallow seabed geomorphology map

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Since 1996, Ireland has undertaken one of the most ambitious seabed mapping programmes in the world. Thanks to the Irish National Seabed Survey (INSS 2003-2006) and INFOMAR programmes (2006-2026), to date about 780,000 km² (88%) of the seafloor within the Irish designated area has been surveyed in high resolution. While a great deal of work has been already achieved, the quality of the data and modern mapping techniques now offer a significant opportunity to develop a standard Irish mapping approach, and the most detailed and comprehensive geomorphological map of the Irish continental shelf.

In this study we introduce the NOMANS_TIF map, which represents the first high-resolution (up to 10 m/ pixel) seabed geomorphology map of the entire Irish continental shelf, up to a depth of 200 m below sea level (bsl). The map was produced using a protocol of modern machine-assisted mapping techniques to streamline and standardise the results. All previous mapping efforts and existing literature on the Irish shallow shelf geomorphology have also been collated and integrated in the map, re-delineating features using the standardised methodology and critically evaluating the previous interpretations. An internationally standardised terminology and classification scheme, in the form of the MIM-GA two-part scheme, have been adopted, aligning the NOMANS_TIF map to international geomorphological standards. The map includes both newly identified and re-assessed seabed morphological and geomorphological features (e.g. palaeochannels, drumlins, dunes etc.) and the different types of substrate (e.g. bedrock, unconsolidated or consolidated superficial deposits) that have been interpreted to represent the dominant composition within to the top 1-2 metres of the seafloor. This detailed geological digital map is intended firstly as a resource enabling to better inform multiple offshore activities and management of the marine environment on the Irish continental shelf. The information is of importance to a range of stakeholders connected to sea fisheries, aquaculture, renewable energy (wind, wave and tidal power), marine communications, dredging, and aggregate industry. Moreover, the map acts as a benchmark for future studies as it identifies gaps in the knowledge and highlights areas of contentious interpretation that require further work.

Amazon Reef Habitats: what do we already know?

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Although the presence of a reef system off the Amazon mouth is indirectly described in the literature since the 1970´s, only in 2016 that the occurrence of a complex mosaic of reef habitats was initially described along the Amazon shelf. Since then, a major discussion involving its extension and environmental significance took place. The backdrop for the discussion is a new frontier for oil and gas exploration in the South American Equatorial Margin. Here, the objective is to present an overview on the reef habitats along the Amazon Shelf and discuss the distinct reef types that have been mapped so far and the concept of a reef system.

The Amazon shelf sedimentation is mainly influenced by seasonal changes in the riverine plume and the prevailing westward-flowing North Brazilian Current. The riverine sediment discharge is deflected to the northwest, being responsible for the formation of muddy deposits along the northern South American coast and inner shelf (north-westward), extending for 1500 km. Seasonal plume dispersion and the North Brazilian current control modern sedimentation along the mid and outer shelf, leading to a northwest transition in sedimentary regimes, from a carbonate/mixed dominated mid/outer shelf to a plume/terrigenous dominated mid/outer-shelf. Shelf-break habitats are determined by antecedent geology (faults and outcrops providing rigid substrate), canyons heads and high rates of fine sedimentation (the edge of the Amazon Submarine Cone).

The combined influence of oceanographic and geological processes acting in different time and spatial scales has set the physical and biogeochemical conditions to the development and maintenance of the Amazon reef system. However, the Amazon Reef System is a complex mosaic of reef habitats characterized by: non-carbonate built reef structures occurring in depths ranging from 100 to 180 m, low-light conditions and under plume influence; rhodolith beds with giant sponges that prevail in a sector with a seasonal plume influence; and eastward, reef habitat is a tropical system with no plume influence and a carbonate dominated seabed (Rhodoliths and corals).

The Amazon reef system is not a tropical coral reef province, but a unique mesophotic ecosystem comprising distinct patches of hard-bottom habitats that prevails under the seasonal influence of a major river plume. The connectivity and extension of these hard-bottom habitats are still unknown and need to be addressed for a proper understanding of the ecosystem services provided by the reef system.

Seabed seeps: Oases in an (often) muddy world

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The MAREANO programme is a Norwegian multidisciplinary seabed mapping initiative that acquires a range of seabed data, including multibeam (bathymetry, backscatter and water column data), videos, sub-bottom profiles and samples. The data enable finding and characterizing geological features such as pockmarks and seep locations. For a decade, MAREANO has used MBES water column data to map gas seep locations, which have been compiled in a database and published on www.mareano.no. A number of the interpreted seeps have been investigated with towed video gear and signs of seepage activity have been identified (bubbles, bacterial mats, carbonate crusts or special communities).

Seeps occur in all kinds of sediments, as long as gas and/or fluids have enough space to migrate upwards. They can occur with or without visible seabed surface expression. Pockmarks, for example, are features commonly associated with cold seeps. These circular depressions often occur in soft sediments. They are formed by gas or fluids expulsions, often occurring hundreds or thousands of years ago. Pockmarks have been found worldwide, and MAREANO mapping has shown that millions of them occur in the Barents and Norwegian Seas. Some of them are still active.

Due to the chemistry linked to gas or fluid expulsion, seep areas often host specific habitats with a higher density and diversity of organisms than the surrounding areas. Seep-associated bacterial mats and chemosynthetic fauna are a primary source of food in areas where nutrition might be scarce (e.g. in deep environments). The bottom of active or recently active pockmarks is typically covered by gravel, shells and stones and/or locally by carbonate crusts which are a bi-product of seepage. These rare occurrences of hard substrates in a ‘soft muddy world’, provide oases for hard-bottom fauna.

Cold seeps emit greenhouse gases, but also give an important fundament for geological and biological diversities and may indicate subsurface geohazards. Here we will show examples of cold seeps in an Arctic environment and why it is important to study them in terms of management, geology, benthic habitats and climate.

Science communication in MAREANO – what are we doing to get our message across – and are we succeeding?

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MAREANO is Norway's national multi-disciplinary seabed mapping programme. MAREANO will increase our knowledge on the seabed and contribute to informed and sustainable ocean management and industry. The programme maps bathymetry, seabed geology, biological diversity, habitats and pollution in the seabed sediments.

Ever since the programme started in 2005, MAREANO has sought to deliver data, maps, and information to a broad spectrum of end-users. These range from scientific professionals within public management and academia, to NGOs, marine industries, and the general public. Over the years, the composition, and main interests of each of these groups have developed. At the same time technological advances have broadened the opportunities for science communication. MAREANO has sought to adapt its communication strategies accordingly. This means that some more traditional methods of science communication have largely given way to web-based solutions. However, with an ever-growing audience, who are becoming more and more accustomed to slick media delivery from news and other channels, we find that it is challenging to cater to all needs.

MAREANO has a dedicated communication group, and we use many tried-and-tested traditional methods to convey information from the programme. These include short news stories, longer feature articles, cruise blogs, and eye-catching pictures and videos. These are disseminated through websites and social media, and/or in local, national, and international media. Previously, we also produced brochures, and books. Each year MAREANO is presented in numerous meetings and conferences within Norway and internationally, and MAREANO results are documented in scientific publications. More recently we have also been making use of story maps, interactive websites and contributing to museum exhibitions, thereby reaching a larger, more general audience, which helps increase awareness of the programme and general ocean literacy.

Additionally, MAREANO uses more targeted knowledge dissemination to specific end-user groups, such as delivering inputs to the Norwegian ocean management forum, government white papers and public hearings. We seek to maintain direct contact with important stakeholders such as management, NGOs, fisheries and related organisations, the petroleum industry and more recently with offshore wind and similar parties. MAREANO hosts a biannual user conference, inviting key user groups to attend and contribute. More recently webinars and targeted user workshops have also been held.

We will present examples from MAREANO's communication efforts, highlighting both our successes and challenges. We showcase some of our favourite outreach efforts and reflect to what extent our efforts are succeeding as we look towards future aspirations.

Mapping arctic and Antarctic seas with towed camera systems

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Towed camera sleds are regularly used as imaging platforms in the exploration of deep-sea seafloor ecosystems. A drawback of the majority of towed camera sleds is that the information received on benthic communities and habitats is limited to the field of view of the cameras mounted on the sled, and is typically restricted to images of the seafloor from directly underneath the device. In order to increase our understanding of benthic ecosystems and to identify benthic communities, their structure, biodiversity and ecosystems functioning over extended regions, combining image and acoustic data can be a useful approach to achieve this. One such system is the Ocean Floor Observation and Bathymetry System (OFOBS), developed by the Alfred-Wegener-Institute, used recently to discover and quantify the sponge grounds of the high Arctic and the world's largest nesting fish colony in Antarctica.

In the Weddell Sea, the Antarctic Ocean, a vast breeding ground with millions of fish nests of the Antarctic Icefish was discovered with the OFOBS. The bathymetric, acoustic data collected by the system was used to infer the extended distribution of round fish nest depressions in the seafloor for swathes of 50 m on each side of the device during each deployment tow. In the Arctic, the OFOBS system has been used to assess the state and distribution of deep-sea trawl marks across the Svalbard shelf and the distribution of geological and biological assemblages across the Fram Strait.

In this presentation, we demonstrate how variations in slope and surface structure influence the inhabiting benthic community in the Antarctic as well as the Arctic Ocean, as inferred by the data collected by this combined camera and acoustic towed system.

Where is the carbon? Spatially mapping carbon on the seafloor in the Eastern Shore Islands

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Coastal sediments contain some of the largest stocks of organic carbon on earth and play a vital role in influencing the carbon cycle. Protecting organic carbon hotspots is essential to mitigating climate change since coastal development and bottom trawling can disturb the seafloor, driving the remineralization of organic carbon into carbon dioxide. Terrestrial carbon stocks are well studied and mapped, but our knowledge of standing stocks of marine sedimentary carbon and the role that it can play in minimizing the effects of climate change are poorly understood. One of the challenges in mapping the seafloor environment is the issue of characterizing spatial heterogeneity of different substrata, which is critical in estimating organic carbon standing stocks in the marine environment.

In this study, we use high-resolution multibeam echosounder (MBES) data from the Eastern Shore Islands off Nova Scotia to predict the distribution of percent organic carbon in surface sediments. We applied benthic habitat mapping approaches, utilizing high-resolution continuous coverage environmental variables (bathymetry, backscatter, current velocity, bottom salinity, bottom temperature, ruggedness, slope, Euclidean distance) combined with subsea video and sediment grab sample ground truthing to generate thematic maps of sediment types for the area. We then compared that to the measurements of organic carbon from the sediment samples, which were spatially modeled using different methodologies to estimate organic carbon standing stocks in the area by substrate type. These high-resolution sedimentary organic carbon maps can help determine the best methodological approach for using MBES surveys to spatially map carbon and identify carbon hotspots, which are essential for seabed management and climate mitigation strategies.

Mapping shifting species patterns in a changing climate using a hierarchical approach

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Oceanographic conditions and, consequently, the stability of marine habitats in Atlantic Canada, are changing in response to the warming ocean climate. Knowledge generated through spatial modeling indicates that ocean warming will drive poleward range shifts in regional marine fauna of commercial and conservation importance.

The role temperature plays in influencing suitable marine habitats is prominent because many marine fauna exhibit a narrow range of thermal tolerance. However, model dependence on broad-scale climate-driven parameters, such as temperature, may overgeneralize the geographic extent and distribution of suitable habitats for benthic marine fauna as it misses the often strong, specific-species associations with particular seabed characteristics (e.g., substrate and seafloor morphology). Across benthic habitats, the influence of geomorphology occurs across smaller scales than climate-associated parameters such as temperature; however, existing predictive models that include terrain derivatives tend to be evaluated at the same scale as ocean-climate parameters. Consequently, model performance where only spatially coarse, single-scale model parameters are considered may be limited. This research aims to identify how best to combine environmental covariates measured or observed at different spatial resolutions when projecting changes in the range and distribution of benthic fauna across the Northwest Atlantic.

We present a Random Forest machine-learning framework developed to project benthic habitat suitability using a Hierarchical Habitat Suitability Model (H-HSM) built using a virtual benthic species environment. H-HSMs allow the integration of information observed or measured at different ecological and spatial scales within a multi-layered framework of niche models where each level is trained at a different scale. This framework combines multi-resolution derivatives of geomorphology from bathymetric surfaces (either 200 m x 200 m or 500 m x 500 m resolution) with broad-scale (1000 m x 1000 m) environmental covariates representing water column and current data. The broad-scale data are hindcast across the Northwest Atlantic by the Bedford Institute of Oceanography North Atlantic model (BNAM).

We compare the projected geographic range and distribution of habitat suitability using hierarchical versus single-scale HSMs. Furthermore, using a feature importance assessment, we evaluate which multiscale bathymetry derivatives (e.g., aspect, BPI depth, slope, VRM) are most relevant in projecting the geographic likelihood of benthic habitat for a virtual benthic species.

Understanding the importance of incorporating hierarchy and scale in projecting habitat suitability is key to facilitating progression into climate-adaptive spatial management strategies for benthic habitats.

Spatialisation of coral reef conservation issues in Réunion Island

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The UTOPIAN project, led by BESTRUN association since 2021, aims to map the ecological state of Reunion Island coral reefs using the CORRAM standardized field protocol (COral Reef Rapid Assessment Method – initiated by IFRECOR in 2014) and geostatistical analyses. Twelve ecological metrics and three synthetic indicators reflect benthic structure and vitality and ichtyofauna functional state. To date, only the reef flats have been mapped and the reef slopes (0 to -12 m) are still being studied.

The MOUVE project is tightly related to UTOPIAN since its purpose is to model coastal and fringing reef hydrodynamics. It will allow the study of relationships between the water displacement and residence time within reefs and the ecological state of the latter. *In situ* water quality analyses will be useful to identify potential degradation caused by anthropogenic activities (urbanization, agriculture, etc.).

At the same time, a third project called BioEos aims to define proxies to evaluate and quantify coastal biodiversity from satellite imagery. Combined with data collected on the field by UTOPIAN, this project should lead to robust spatial ecological indicators and simplify the CORRAM method. With such approaches, the cartography of vast coral reefs, such as those of Mayotte or New Caledonia, could be feasible, if the human and financial costs are reduced.

All this information, collected and interpreted in collaboration with the Marine Nature Reserve of La Réunion, is expected to provide unprecedented knowledge on the spatial distribution of the conservation issues of the Reunion coral reefs. It will also be used as a decision support tool to identify candidate zones for the expansion of the sanctuary area (CONSTRUI project).

Multi-scale spatialisation approach should allow the identification and hierarchisation of the local causes of coral reefs degradation. Eventually, an atlas will provide the necessary elements to public authorities to better consider coral reefs in territorial planning.

Towards better backscatter data products by multibeam echosounder systems for improved seafloor mapping: An update from the Backscatter Working Group (BSWG)

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Multibeam echosounders systems (MBES) have become the standard swath-mapping sonar systems in hydrographic surveying. MBES backscatter data (conveniently acquired at the same time as bathymetry data) are an excellent proxy for mapping differences in seafloor properties such as substrate and benthic habitat, and are therefore often used in the production of seafloor thematic maps. However, the quality and consistency of backscatter data remain often less than desirable for this purpose. The Backscatter Working Group (BSWG) (an international group of experts on MBES backscatter data) work on improving this situation. The BSWG was formed in Rome in 2013 at the annual GeoHab conference, and to this day operates under the umbrella of the GeoHab conferences. To date, the main output of the BSWG is a report published in 2015 providing comprehensive guidelines and recommendations on the nature, acquisition, processing, and use of MBES backscatter data. However, significant gaps and challenges remain in the field of MBES backscatter data research, and there is significant interest in the scientific community to continue the work of the BSWG.

To discuss the future direction of the BSWG, a three-day international workshop on multibeam sonar backscatter was held (Nov 25-27, 2022) at Dalhousie University (Halifax, Canada), with 20 international delegates attending onsite and 37 delegates attending online. The workshop served as a reviver for the BSWG activities, aiming to continue to support improvements in the quality and consistency of MBES backscatter data products. Several actions have been decided for the future of the BSWG, encompassing the topics of sonar calibration, at-sea acquisition, data processing and collection of reference data. Here, we provide an update to the GeoHab community on the future direction of the BSWG and communicate opportunities on how GeoHab members can get involved in future activities of this working group.

Earth Observation for Ecosystem Accounting: fine scale, high resolution coastal habitat mapping in localised areas, an African perspective

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Advances in utilising machine learning, satellite data analytics and open region-specific reference data within the Google Earth Engine cloud computing platform has become prominent in ecosystem accounting. Region-wide applications demonstrate progress in this field and point to the need for localised, fine scale, African driven validation of this methodology for more accurate ecosystem extent maps within ecosystem accounting components of ocean accounting frameworks.

Several studies of seagrass beds and other habitats have been advanced to show how smaller scale, high resolution (10m) mapping can aid and improve on broader global or regional products and provide localised products that serve as a monitoring tool to help conserve, protect, educate and appropriately manage sensitive and important habitats within ecosystem accounting models.

This work has focussed on the European Space Agency Copernicus Sentinel-2 surface reflectance image tiles at 10-m spatial resolution through image extraction via the Copernicus Open Access Hub / Sentinel Hub and Google Earth Engine platform. Resultant segmentation and classifications have for example, allowed for the identification of mangrove, seagrass, coral complex, sandy beach, rocky shore, kelp forest; subtidal rock and sand structures; estuary and salt marsh, rocky shore and human developed / modified coastal systems at a level of detail that surpasses, and therefore supports, region based spatial analyses. Focus areas include the Bazaruto Archipelago and Unguja Island (Zanzibar) with details of northern coast and Mnemba Atoll for extents of mangroves, beaches, dunes, exposed banks, seagrasses and coral complexes. Additionally, the Kilifi County coast of Kenya, Nosey Be and Nosey Mitsio archipelagos of north-western Madagascar, and detailed kelp forests extents of the broader Table Bay and Cape with ground truthing of these extents through drone or *in situ* applications are included. This work will help reduce uncertainties in region based spatially explicit ecosystem extent accounts and importantly, promote African expertise for analogous products.

ROV-based mapping of bryozoan-sponge-dominated habitat at lower mesophotic depths occurring in a southwestern Australian submarine canyon (Bremer Marine Park)

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Most of the published information on mesophotic ecosystems of Australian waters refers to the Coral Sea and the northwestern continental shelf where reefs and submerged shoals populated by hard corals, macroalgae, and calcareous algae have been documented in the upper (30–60 m) mesophotic zone. However, other locations and taxa have received significantly less attention to date. In 2020, during the oceanographic cruise FK200126 aboard the Schmidt Ocean Institute's RV Falkor, the first remotely operated vehicle visual surveys and collections were conducted in the deep-sea environments offshore southwestern Australia. The ROV SuBastian's shallowest dive, carried out at ca. 200 m on the head of the Hood Canyon (in the Bremer Marine Park), documented a lush mesophotic habitat dominated by erect bryozoans and sponges. The occurrence of derelict fishing gear on-site suggests that this habitat also attracts commercially relevant fish.

By coupling ROV videos and bathymetric indices, we mapped and quantitatively described the habitat and the associated biodiversity. Our contribution documents, for the first time, the benthic associations in the lower mesophotic zone (>60 m) in SW Australia, which importantly provides a baseline for future explorations and new information relevant to conservation and long-term management strategies.

Marine habitat mapping and archaeological investigation of the submerged Paleo-Suwannee River, eastern Gulf of Mexico, United States

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The coastal waters of Florida are highly valuable areas for economic and recreational use but are also highly threatened by anthropogenic pressures and the effects of climate change. As such, there is a need to produce benthic habitat maps that can assist with the identification and monitoring of economic, cultural, and environmental resources in contexts such as management and conservation. The goal of this project is to create geomorphological and habitat maps of the nearshore submerged Paleo-Suwannee River channel and tidal flats off Florida's Gulf of Mexico coast derived from acoustic remote sensing technologies to enable habitat identification and map habitat distribution and extent while also detecting potential cultural heritage targets given the high archaeological potential of this area.

In September and October 2021, bathymetric data were collected using an EdgeTech 2205 echosounder mounted on an uncrewed surface vehicle. About 187 km of survey lines were run over an area identified from satellite imagery and hypothesized to be part of former tidal flats of the Paleo-Suwannee River before its submersion by the Gulf of Mexico thousands of years ago. A total of 29 sediment cores were collected as ground-truthing data. The bathymetric data were cleaned and referenced to a vertical datum using RTK tide, and a bathymetric grid at 1.5 m spatial resolution was generated. Subsequently, the bathymetry was analysed using two predeveloped models. First, the "MultiscaleDTM" R package was used to extract seven morphometric features defined from the slope and several types of curvatures. Then, the Bathymetric and Reflectivity-based Segments (BRESS) software was used to segment the area into different morphometric features using three different classification schemes. Results from the different techniques were compared.

The processed bathymetric grid covered about 2.4 km^2, with depths ranging between 0 and 5 m (average of 3.8 m deep). Depending on the scale and type of analyses, results showed that most of the study area is relatively flat (>60%) with some ridges (≈14%), channels (≈10%), and slopes (≈9%). However, motion artifacts in the bathymetric data impacted the relative proportion of morphometric features captured in the area. Two main morphological features were identified in the southernmost portion of the study area. The sediment cores suggest that these features have a different sediment composition than surrounding habitats. The presence of chert outcrops and oyster bioherms, known to act as surrogates of early human occupation in the area, were noted in the cores.

Updating bathymetry improves ecological modeling of seagrass communities in Tampa Bay

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Recently, reductions in both seagrass abundance and occurrence were apparent following a series of wastewater discharges from the abandoned Piney Point phosphate mine. These losses are concurrent with declines in overall seagrass coverage in Tampa Bay since 2018. Seagrass surveys are done to monitor local changes and may be conducted across varying temporal and spatial scales. Data consistency becomes a problem when predicting large-scale ecosystem effects. What is needed is an estuary-wide view of the state of seagrass and their intertwined communities, which can be easily updated to reflect the rapid environmental change. This will identify the parts of the system at risk and assist the wide variety of stakeholders with creating management strategies. My work is building a seagrass estuary sub-model which will predict and map seagrass for the purpose of informing large ecosystem models. The Gulf of Mexico Atlantis model is reduced to Tampa Bay. Fisheries independent monitoring data was used in generalized additive modeling to estimate the relationship between functional groups in the model and seagrass cover. This data driven relationship between environmental, community and seagrass occurrence is also being leveraged to fill in gaps about habitat.

Atlantis is a series of linked, deterministic physics and ecology sub models, spatially resolved in 3-D using a map made of user defined boxes and depth layers. The model tracks growth rates of primary producers, decomposition and nutrient uptake using N-tracers, and diet interactions controlled by an availability matrix. Because Atlantis is capable of extending between high and trophic level ecology, it is a good testing ground for hypotheses at the intersection of fisheries and the environment and poised to answer questions regarding habitat loss. However, due to the varying techniques, temporal and spatial scales of benthic surveys, the large footprints of these models underrepresents habitat and loses important detail. In the Tampa bay model, I am defining the dominant seagrass species as new functional groups.

Habitat mapping literature suggests that high resolution backscatter integrated with bathymetry, and potentially additional spectra, is ideal for mapping seagrass, but survey size and cost are substantial considerations. I am gathering multi-beam acoustic bathymetry and backscatter collected via ships and autonomous surface vehicles (ASV) to update bathymetry maps as well as add predictive power –better informing community structure and resulting food-web impacts. Deciding where to map and accounting for uncertainty in the model, benefits from overlapping surveys and technology such as: LiDAR, optical satellite, and yearly monitored in-person survey tracts. The model makes use of all available data while connecting it to the whole estuary ecosystem.

Incorporating environmental DNA for improved benthic habitat mapping

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Complex coastal seascapes harbor high marine biodiversity from which humans derive numerous ecosystem services. Maps of benthic habitats are important tools used to inform coastal development and conservation efforts. Video and still imagery of the seafloor is a common method of collecting information about the occurrence and distribution of benthic organisms. However, imagery data are often limited to low taxonomic resolutions, and may systematically underrepresent local biodiversity. Recent advances in environmental genomics have enabled rapid and accurate detection of taxa with high taxonomic resolution from environmental DNA (eDNA) extracted from water samples. Targeted sampling of eDNA has been conducted to map the distribution of individual species, but to our knowledge broad-spectrum eDNA biodiversity data has not been utilized in nearshore benthic habitat mapping. We combined an eDNA-based biodiversity assessment with concurrently collected high-resolution video ground-truth data to assess the benefit of metabarcoding data for improving benthic habitat mapping in the sub-Arctic coastal embayment of Mortier Bay, Newfoundland, Canada. Features derived from acoustic bathymetry and backscatter data were used to develop full-coverage habitat and biodiversity maps using a joint species distribution-modeling framework. The distribution of taxonomic richness was similar between video-only, eDNA-only, and combined datasets, suggesting diversity patterns were accurately represented by both methods. However, 225 additional taxa were identified using eDNA compared to the 46 detected by video ground-truthing. Averaged over all taxa, the video-only model performed best in terms of discriminating presences from absences, however we found that most sessile taxa were better predicted by the combined data set compared to video data alone. These results highlight the limitations of imagery-only datasets for biodiversity surveys, and demonstrate the utility of metabarcoding data to improve benthic habitat and diversity maps in complex coastal habitats. This study highlights opportunities to fill data gaps that could improve spatial modeling of seafloor assemblages derived from metabarcoding data, including sources and sinks of DNA in the environment, and water column properties that control DNA dispersal.

Multi-scale mapping of changes in tropical reefs

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This work aims at developing a generic approach to monitor the evolution of tropical reef status by providing maps and indicators over time on the different habitats (corals, seagrass, sand, rocks, etc.), the different classes of the Global Coral Reef Monitoring Network (GCRMN scenario 2), and emblematic species (e.g., sea cucumbers, sea urchins, clams, fish species) in the Indian Ocean. To achieve this objective, the steps are :

1/ Collect and annotate images at fine spatial scale and high resolution for habitats, GCRMN classes, and species using data from an automated surface vehicle (ASV) equipped with cameras under visible and UV lights as well as data from a citizen science project. We have already collected data in different areas like Reunion, Mayotte, Europa, Aldabra and Saint-Brandon which ensures a wide diversity of tropical reefs.

2/ Build an original suite of deep learning tools which will recursively be trained by the lower resolution data and to train the higher resolution data, i.e. predictions from the ASV data will be used to train the algorithm using drone data, and predictions from drone data will be used to train the algorithm using satellite data.

3/ Produce indices of the evolution of habitats and distribution areas of GCRMN classes by applying the algorithm trained on satellite imagery to Indian Ocean reefs over different periods.

This multi-scale approach for deep learning means the time-consuming work of annotating images to train a model will be limited to the first fine-scale (e.g. ASV). A first example of the application of the method described above will be shown through data collected at Aldabra (as part of Monaco Explorations' Indian Ocean 2022 mission) with the ASV and a drone. To add more information to the satellite algorithm, we propose to enrich the observation dataset with environmental data (sea surface temperature, salinity, hyperspectral information, etc.). The different layers of data from local to large scale data (georeferenced images, bathymetry data etc) will be in open access for the scientific community to explore them, following the FAIR guiding principles for scientific data management.

Habitat Suitability Model predicts potential solitary scleractinian coral occurrence in southwestern Australian submarine canyons

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The application of a Habitat Suitability Model (HSM) could be of pivotal importance to mapping, managing, and conserving sensitive habitats, especially in data-poor regions. A case in point is the southwestern Australian submarine canyons, which were recently revealed as hotspots of charismatic cold-water corals (CWC).

A HSM has been applied to identify sites potentially available to colonization by solitary scleractinian corals along the canyon heads and slopes of several submarine canyon systems and adjacent environments offshore southwestern Australia. The study areas are the Bremer canyon system (BCS), Mount Gabi seamount, and Perth Canyon. The CWC dataset is based on the analysis of videos acquired by remotely operated vehicles (ROV) on-board RV Falkor during two Schmidt Ocean Institute cruises, FK150301 and FK200126. The points of potential occurrence of scleractinians were obtained by integrating the video information with geomorphological indices derived from bathymetry.

Our integrated approach upgrades previous projections for the Australian canyons by expanding the number of potential locations exploitable by CWC, along with the integration of environmental variables (e.g., dissolved oxygen, temperature, current speeds and directions, salinity) obtained from ship and satellite data. However, the precision in identifying suitable areas could be further improved through the application of environmental layers, especially from satellite data, which must be adapted to the high spatial resolution obtained during the survey campaigns.

Flushed away – nutrient load distribution related to supratidal spring-fed living microbialite ecosystems

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Coastal zones are under bidirectional pressures globally and are expected to become more vulnerable under future development and climate change scenarios. Land-derived nutrients and pollutants entering the marine environment through surface water pathways such as rivers and estuaries are well understood. However, anthropogenic inputs to coastal and marine habitats through groundwater systems, such as submarine groundwater discharge are often overlooked in conservation planning and management.

Numerous and extensive supratidal spring-fed living microbialite ecosystems (SSLiME) are actively accreting along the coastlines of Australia, Ireland and South Africa. These carbonate systems require the influx of fresh groundwater from the coastal interior, as well as seawater input during high tides and storms. The SSLiME are of scientific and societal importance in terms of palaeoscience, heritage, biodiversity and as environmental indicators.

In South Africa, a correlation between coastal human occupancy and nutrient content of the groundwater entering the microbialite systems has previously been reported. It has also been suggested that SSLiME may serve as coastal pollutant buffers through nutrient attenuation. This study quantifies and maps the distribution of nutrient loads to SSLiME along the western coast of Nelson Mandela Bay, South Africa. Preliminary results indicate that SSLiME act as important pathways for nutrient supply to the marine environment. For example, the dissolved inorganic nutrient content of the Nelson Mandela Bay systems is comparable to that of a wastewater treatment works. Furthermore, the inorganic nutrient loads are highest in systems adjacent to coastal urban areas, indicating a linkage to anthropogenic pollutant sources such as septic tanks. It is therefore crucial that SSLiME are included in ecosystem-based management strategies.

Highlighting deep-sea geodiversity as a precursor to fully informed ecosystem-based management: examples from the Norwegian Sea

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Comprehensive and systematic surveys of seabed habitat in the deep-sea, beyond the continental shelf, are few and far between. High costs and operational challenges associated with such surveys are often hard to offset against the greater demand for information in more accessible coastal, shelf and slope areas. It is the latter which are typically prioritized by national seabed mapping initiatives such as Norway's MAREANO programme. Notwithstanding the sparsity of information on deep-sea habitats and ecosystems, interest in exploiting deep-sea resources (fisheries, minerals etc.) is growing and risks developing in an unsustainable manner if management of such activities is not based on more complete scientific knowledge.

MAREANO has made a start on characterizing the deep Norwegian Sea, having completed multibeam and sub-bottom profiler surveys in 2019 in around 40 'representative' areas (guided by unsupervised classification of existing environmental data supplemented by existing scientific knowledge). While follow-up surveys with direct observations of the seabed are presently on hold for MAREANO, there is much useful information we can harvest from the existing surveys which can already help inform and update the scientific basis for management. We show how initial analysis of MAREANO's 2019 acoustic data combined with older multibeam surveys and coarser regional data can support this effort. Terrain attributes and morphological feature classification highlight the topographic diversity of the deep sea, which is extremely high near the mid-Atlantic Ridge. Components of geodiversity from morphometric studies like this contribute to the pool of information required for sustainable management. They are also directly relevant to the Norwegian Nature Diversity Act and are fundamental elements of the associated Nature in Norway classification and descriptive system.

We present a case study showing how the existing data can help overcome the current underestimate of seamounts in Norwegian waters. This is one example of a management-relevant landform acknowledged by OSPAR but for which scientific knowledge, at least in this region, is currently sparse. Further characterization of seabed geology and associated habitats on seamounts and for the remainder of the deep-sea is still required. However, once direct observations from follow up surveys are conducted, the MAREANO dataset will offer an invaluable resource giving insights into geodiversity and biodiversity. This will facilitate a better understanding of the deep-sea ecosystem as a whole, thereby providing a far more solid foundation for informed management and sustainable development.

Fine-scale mapping of coral reef communities in Mayotte: an essential tool for marine park management

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Marine habitat maps are important tools for managers who need updated and accurate data to implement suitable management actions in the marine environment. While shallow-water habitats can be mapped using high-resolution satellite imagery, deep-water habitats are difficult to survey and tend to be poorly mapped, especially over large regions. This project aimed to map the coral reef lagoon of Mayotte, a French island of the Southwestern Indian Ocean, down to 150 m depth and over an area of 1406 km². The entire exclusive economic zone (EEZ) of Mayotte is managed by a marine park. Mapping was carried out by visual interpretation of satellite and aerial remote sensing data for shallow-water habitats. For deeper waters, the bathymetric data were generated by merging aerial Lidar surveys and acoustic data. Historical biological data were gathered through bibliographic review (2164 points) and completed by 659 ground truth points using underwater video, visual census from scuba-diving and snorkeling. Kriging was used as a spatial interpolation method to assess the spatial distribution of living corals cover.

A total of 236 habitat classes were defined and mapped. Analyses revealed that the region around Mayotte consists of 478 km² of bio-constructed reefs, including 83,414 patch reefs (69 km²). In order to better characterize coral habitat – a keystone habitat – spatial community structure was studied with non-metric multidimensional scaling (nMDS) ordination and tested with permutational multivariate analysis (PERMANOVA). Each reef geomorphological feature presents diverse benthic morphotypes. Areas with higher living coral cover (ε50%) are located in the inner lagoon patch reef complex (northeast), the double barrier reef (south) and the western fringing reef. Conversely, the health of the fringing reefs appears to have been degraded in the northeast and east of Mayotte, and in enclosed bays. The composition of benthic assemblages varies significantly among water mass and among geomorphological structures. The best preserved reefs are characterised by Acropora communities and encrusting calcareous algae, while degraded reefs typically include other coral genera (e.g., Porites, Montipora, Echinopora) and present higher proportions of algal turf.

The detailed habitat maps created in this project became an essential management tool for this region, and the approach used in Mayotte could be applied to other similar contexts. Such a detailed mapping of marine habitats in terms of depth range and extent was a first in a French overseas territory, encouraging further research on these ecosystems for conservation purposes.

Surficial geological and biological observations near an upper continental slope cold-seep off Saglek Bank, Northern Labrador, Canada

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Apparent hydrocarbon seeps have been detected using satellite technology along the continental margin of the Northern Labrador Sea and western Baffin Bay, Canada. Nonetheless, very few cold seeps have been directly observed and sampled in this cold and deep water environment, strongly affected by past continental glaciation and glaciomarine sedimentation. Here we present multibeam sonar-derived bathymetry, and ROV-based visual observations of a surficial geology and invertebrate megafauna surrounding a cold-seep off the northeastern edge of Saglek Bank, Northern Labrador. This site lies at the southern edge of the Hudson Strait outflow, the largest Pleistocene trough mouth fan in Atlantic and Arctic Canada. A ~2 km^2 elongate arcuate depression, opening downslope to the northeast, was detected in exploratory multibeam sonar mapping in 2019-2020, the shape of which suggested some sort of slump or subsidence. Sub-bottom profiling (3.5 kHz) yielded incoherent reflections, consistent with ice contact sediments that have been previously described in this region.

Four short ROV dives in July 2021 covering 1.75 km of bottom transect distance allowed field observations of bacterial mats, surficial geology, and invertebrate megafauna of this site. Surficial geology was visually dominated by sand and gravel, with common cobbles and boulders up to several metres in diameter. Sites of apparently active hydrocarbon venting, based upon observations of white microbial mats, were commonly observed on three of the four ROV dives, within most of the 600-800 m depth zone sampled. No previous ROV dives or drop camera deployments in the northern Saglek Bank upper slope had previously observed these microbial mats. Authigenic $CaCO_3$ crusts were observed in the 750-650 m depth range; crusts were commonly up to 1-2 metres in length, and less than 10 cm in thickness. Most carbonate crusts were friable, but some were well-enough indurated for large gorgonians to grow upon them.

Invertebrate megafauna observations indicated a cold-water coral fauna structurally dominated by the long-lived calcified-stemmed gorgonian coral *Primnoa resedaeformis*, with average density of 0.21 ind m^{-2} , but the site was numerically dominated by nephtheid soft corals. Most *Primnoa* corals were observed growing on boulders and cobbles, with only very few directly attached to carbonate crusts or in the immediate vicinity of hydrocarbon seeps. A diverse sponge fauna, structurally dominated by large geodiid sponges, co-occurred with the corals, with sponges almost exclusively attached to boulders and cobbles. The coral and sponge faunas here were consistent with non-seep observations in the same area.

Linking coral bleaching patterns with hydrodynamics, oxygen availability and microbiome variability in coral reefs

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It is well understood that climate-change driven heatwaves induce coral reef bleaching, with bleaching events increasing in both frequency and severity. However, bleaching responses are not uniform, owing at least partially to species-specific responses, and spatiotemporal differences in environmental parameters driven by hydrodynamic regimes. As such, reefs experience daily oxygen fluctuations due to community metabolism and local differences in the natural reef topography. An exposed vs. sheltered zonation has been displayed on a large scale (kilometres), where long water residence times enhance the influence of community metabolism on the water body. Potentially, this may also occur on a microhabitat scale (centimetres to millimetres), i.e., where water may be trapped along coral surfaces within branches or in cryptic spaces. Therefore, certain parts of coral colonies that exhibit hypoxia could be more susceptible to bleaching, whereas other parts of the respective colony may remain unaffected. Furthermore, this micro-zonation might be caused by a combination of oxygen and nutrient availability (modulated by reef topography and hydrodynamic regime), which will ultimately affect the activity of microbial communities. The topographic and hydrodynamic characteristics favour a differential nutrient availability due to a potential accumulation of metabolic exudates that in turn favour shifts in the trophic regime (microbialisation). This could have implications particularly on nitrogen fixing microbes and denitrifiers that rely on anaerobic milieus, whereas nitrifiers depend on aerobic conditions. Hence, the presence and/or activity of these microbes and, therefore, the plasticity of these processes could also be moderated by the reef topography, the hydrodynamic regime and subsequently, the availability of oxygen. Recent research has indicated that both nitrogen availability and hypoxia increase the bleaching susceptibility of corals, rendering the yet overlooked spatial and temporal distribution of oxygen availability and nitrogen cycling microbes within the reef matrix as potential missing pieces in understanding coral bleaching patterns. As such, we here present a project that aims to monitor reef patches and the occurrence of coral bleaching over space and time. We aim to include a long-term assessment of related environmental parameters such as the hydrodynamic regime, small-scale oxygen availability together with the coral's associated microbiome. For this, a particular focus will be laid on nitrogen cycling microbes to identify the hypothesised relationship between low and high oxygen zones around coral colonies, their ecophysiological responses and their link with bleaching occurrence.

WIO-Benth – mapping unknown habitats and communities of the western Indian Ocean

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We describe, model and map primarily unconsolidated habitats and their benthic communities from the seabed of the continental shelf and upper slope (to 500m depth) in the western part of the Western Indian Ocean (WIO). Unlike the inshore critical and vulnerable habitats such as corals, mangroves and seagrasses which are relatively well known in the WIO, little is known about other habitats of the remaining shelf and upper slope, which are important fishery areas and likely biodiversity hotspots.

Using a combination of diverse sources including georeferenced and digitized charts of bathymetry, seabed habitat attributes and geophysical features, as well as information from samples collected over many years by numerous surveys. Maps of the most prevalent bottom type distributions were generated by the dbSEABED programme, a global seabed mapping initiative. The plots were produced by 3D Inverse Distance Weighted interpolation as a spatial analysis technique (incorporating bathymetry) and show the bottom type which most likely occurs according to aggregated classes in a scheme of rock, gravel, sand, mud. WIO shelves are mostly narrow, and gradients are shallow, with a shelf break around 100–150m depth; near large rivers, the shelf is wider and characterized by finer terrigenous-derived sediments. Extensive coral reefs occur along the coasts of Kenya, Tanzania, Mozambique and Madagascar. The vast majority of the WIO shelf and upper slope (ca. 360 000 km^2) is unconsolidated sediments, with sand comprising almost 50% of the area of interest, and the remainder split equitably between gravel, mud and rock. As a novel alternative approach, habitat maps were also produced based on interpolation of broad seabed habitat preferences (soft, hard, mixed) of trawled benthic faunal communities, assigned from the literature.

Trawled faunal communities were dominated by fishes, and distributed according to depth, latitude and habitat drivers, with regionally homogenous communities at depth, and distinct communities associated with muddy habitats off large river mouths. Indications of potential vulnerability of organisms to anthropogenic disturbance were reflected in maps of their relative mobility and distributional extent.

This is an ambitious attempt to map and broadly categorize seabed habitats and their associated communities, on the shelf and upper slope of a very large area in the WIO, which will assist decision-makers with regional marine spatial planning and in critical biodiversity delineations as they pertain to the habitats that support important communities and species.

Mapping macro-litter in deep-sea canyons: the southwestern Australia case

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We quantified marine macro-litter found in deep-sea canyon environments offshore southwestern Australia (Bremer canyon systems, Perth Canyon), during cruise FK200126 aboard the Schmidt Ocean Institute's RV Falkor. Our study couples multibeam sonar system bathymetric records with remotely operated vehicle (ROV, SuBastian) videos. Items larger than 25 mm in their longest dimension were georeferenced and categorized following current classification schemes.

The items identified belong to the following categories: plastic, metal, glass, aluminium, fabric, mixed, derelict fishing gear, unclassified. Derelict fishing gear were observed exclusively at the shallowest site (ca. 200 m depth, Hood Canyon), whilst plastic items were the most abundant in the other, deeper, sites. Our results document that the deep environments explored by us are only moderately impacted by anthropic macro-litter. This is especially true for the Bremer canyon systems that are located within a marine park, which imposes restrictions on human activities, and are also far from obvious land-based sources of litter. The Perth Canyon, also a marine park, is understandably more impacted being situated offshore a major city (Perth) and traversed by commercial and leisure maritime routes, which are obvious sources of litter.

When comparing the quantities of macro-litter found in the Australian sites with other submarine canyons in the world's oceans, the Australian sites are shown to be relatively pristine. Although limited to visible anthropogenic impacts, our results suggest that the rather pristine condition of both the Bremer canyon systems and Perth Canyon is partly due to their national status as marine parks and their successful stewardship. To ensure the preservation of this low level of human impact, the current relatively effective joint management programs shared between State (nearshore) and Federal (offshore) authorities should be continually reviewed, especially in the face of growing demands and intensive tourism.

Seafloor morphological features of tidal channels in the shallow coastal Lagoon of Venice Lagoon, Italy

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Shallow coastal lagoons have a generally complex morphology dominated by tidal networks, which are characterized by bifurcating tidal channels dissecting tidal flats and salt marshes. Tidal channels are crucial for the functioning of coastal lagoons because their morphologies are relevant for seafloor habitats and hydrodynamic flow within the system. However, despite their importance, the submarine morphological features of tidal channels are still poorly documented due to their characteristics, which limits the access of underwater acoustics and aerial remote sensing technology. Therefore, recent morphological studies on tidal channels rely mainly on 2D topographic surveys of channel profiles and cross-sections, seismic records, UAV-based photogrammetry, and satellite images. In this study, we present a detailed documentation of shallow coastal marine bedforms that were mapped in the Lagoon of Venice using multibeam echosounder, which provides high-resolution and three-dimensional characterization of the morphologies. Results of this study provide quantifiable data that are suitable for studying geomorphic evolution, understanding of tidal salt marsh morpho-dynamics and benthic habitats, which are essential in the development of cost-effective monitoring and sustainable management of shallow coastal ecosystems.

Deep-sea Mining: Spatiotemporal seafloor and plume monitoring of *in-situ* trials in Clarion-Clipperton-Zone using hydroacoustic and optic methods

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The first deep-sea *in-situ* trial of the Patania-II pre-prototype nodule collector vehicle was conducted by DEME-GSR in the Belgian contract area for polymetallic nodules in the Clarion-Clipperton Zone (CCZ). The European MiningImpact2 research consortium (Joint Programming Initiative Healthy and Productive Seas and Oceans) conducted independent monitoring using two Remote Operated Vehicles (ROVs) and a dense network of 50 acoustic and optic backscatter sensors (ADCP, ADV, AquaScat, PartiCam, JFE, FLNTU, and Seapoint) at fixed seafloor locations to distances up to 2 km from the trial site. In addition, a deep-sea Autonomous Underwater Vehicle (AUV), running five additional acoustic and optic sensors (MBES, SSS, FLNTU, JFE, Camera) increased the data coverage in distances of up to 5 km away from the source and 50 m above the seafloor.

The images (≈ 1,000,000) obtained within the trial area were used to construct the so-far largest photomosaic from the CCZ, which shows the mining imprints on the seafloor, sediment blanketing, and seafloor fauna in ultra-high-resolution (mm scale). The image-derived Digital Elevation Model (DEM) depicts the mining depth providing insights into the total amount of mobilized sediment parallel to the high-resolution hydroacoustic seafloor and water column mapping with MBES and SSS.

The low-lying plume is distributed down current over long distances. The suspended sediment concentration degrades rapidly, while particle flocculation and fast sediment redeposition occur. The plume is spread perpendicular to the mining tracks as a turbidity flow, which is locally channelized in steep and concave seafloor parts, highlighting the importance of detailed MBES mapping in morphologically complex terrain before deep-sea mining activities. A new 4D visualization tool is used to show the spatiotemporal plume evolution.

This study provides valuable information regarding the fate of deep-sea mining plumes and seafloor disturbance. The applied methods advance deep-sea environmental monitoring and mapping, helping the International Seabed Authority to establish effective environmental monitoring guidelines before any exploitation starts.

Quantitative morphologic investigation of thousands of seafloor pockmarks offshore Vancouver Island

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Pockmarks are crater-like depressions in marine or lacustrine sediments. They are often interpreted as the surface manifestation of hydrocarbon venting but may also result from freshwater flow in coastal regions, compaction induced sediment dewatering, or bottom scouring. New bathymetric data from offshore Vancouver Island, Canada, indicate the presence of a huge pockmark field between 100 – 200 m water depth. Owing to the presence of a large cabled underwater observatory, a wealth of multi-resolution and multi-disciplinary marine data is available from the pockmark field, including multibeam surveys, seafloor video footage, seismic and EK60 echo-sounder profiles, and multibeam water-column information. First results from seafloor mapping indicate that the field consists of several thousands of pockmarks. By automatically mapping the pockmarks in digital elevation models, we are able to quantify their morphologies and spatial distribution. The pockmarks range in size between 100 - 500 m². Their mean depth varies between 0.5 - 2 m. Seepage of gas from the seafloor could not yet been directly associated with the pockmark depressions. Instead, limited seafloor video footage indicates that some depressions host meter-sized boulders within their craters. We will next investigate temporal changes in pockmark morphology and seep activity by individual analysis of datasets that have been repeatedly collected between 2010-2022. By resolving pockmark morphologies and seep activities on an annual time-scale over a decade, the results will help to understand pockmark formation and seep activity within one of North America's largest pockmark fields.

Mapping still to do towards high spatial resolution map of grain size distribution along the Israeli continental shelf based on multibeam backscatter data

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Grain size distribution along the continental shelf has far-reaching implications from the spread of ecological habitats to infrastructure planning and is therefore of interest to academics and governmental agencies. The spatial distribution of the grain size along the Israeli shelf is dynamic and was shown to be affected by activities e.g. the damming of the Nile in the mid-1960s. Conventional methods to map grain size distribution are based on interpolation of grain size analysis from discrete sediment samplings (where these can be obtained). This method is greatly lacking, particularly in areas where there are large spatial variations and where sampling is challenging because the sediments are very coarse or adjacent to hard substrates. To overcome these problems, we used backscatter data of the R/V Bat-Galim multibeam from recent years. For this data, we applied a mathematical correction using the observed backscatter angular response, in locations where grain sizes were sampled and analysed. The normalized backscatter angular response is verified and cross-checked to reliably represent the seafloor characteristics to the extent that we are now able to characterize sediments in the range between silt and clay with the precision of a single Phi value and up to gravel and submerged rock surfaces. Our current goal is to apply this method to existing multibeam surveys from recent years to produce an unprecedented, detailed map of the grain size distribution of the Israeli continental shelf.

Interferometric Synthetic Aperture Sonar for centimeter scale mapping and imaging of seafloor geology on the Scotian Shelf, Canada

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While oceans cover 70% of the Earth's surface, only ~20% of the seafloor has been mapped at resolutions better than 100 m/pixel, through the use of multibeam echo sounders. Mapping at even higher resolution requires the sonar to be closer to the seafloor, thereby limiting coverage. Recent development of high-resolution acoustic survey technology, such as interferometric synthetic aperture sonar (InSAS), enables seafloor mapping and imaging at cm-scale resolution over larger areas. Until now, InSAS-derived imagery and bathymetry of the seafloor have been used primarily for military and commercial purposes. However, numerous new applications are emerging (geological mapping, habitat mapping, marine conservation monitoring, seafloor changes monitoring, etc.). In this study, we identify challenges and benefits of using InSAS for seafloor geological mapping, by characterizing fine-scale geological features and comparing the results to resolutions that would have been obtained if conventional technologies (multibeam, side-scan sonar) had been employed instead.

We use high-resolution InSAS acoustic imagery (3 cm/pixel) and co-registered bathymetry (25 cm/pixel) collected using a Katfish towed sensor (Kraken Robotics) over 70 km^2 of seafloor on the Scotian Shelf, 50 km offshore Halifax, Atlantic Canada. From these data, we are able to resolve large scale folds in exposed basement rocks, which can be correlated with deformation of the corresponding rock formations on land. At the fine scale, the outcrop surfaces display striations, veins, and fractures, which are unidentifiable at coarser resolutions. The multiscale details resolvable from the InSAS data allow for the identification and interpretation of features that are otherwise not discernible using more traditional lower resolution mapping and survey technology, thus opening the door for a significant increase in our ability to characterize geological and biological processes at the seafloor.

Geostatistical mapping of seabed sediment type and benthic communities: Review of common challenges and solutions

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Geostatistics is increasingly used to characterize coastal habitats and macrobenthic communities, which typically involves the quantification and modelling of the spatial variability of a set of parameters (e.g., grain sizes and sediment textures, biodiversity inventories) followed by their mapping. The full potential of geostatistics, however, cannot be achieved through the blind application of off-the-shelf methods. Tools need to be tailored to the characteristics of each site and parameter, in particular: 1) complex coastal geometries might require the use of non-linear measures of spatial proximity, e.g., over-water distance vs. straight line (Euclidian) distance, and 2) the compositional nature of the variables hampers the application of traditional multivariate and kriging techniques, e.g., the variance-covariance matrix is singular while there is no guarantee that predicted percentages of texture categories or benthic classes sum to 100%.

Approaches to tackle both issues are introduced and illustrated using 170 samples collected in the sub-Arctic coastal ecosystem of the Baie des Sept-Îles (Québec, Canada). The dataset includes, for each station, benthic macrofaunal communities (289 taxa combined into six main phyla) and sediment grain size distribution (percentages of gravel, sand, silt, and clay). The matrix of over-water distances between each pair of stations underwent a multidimensional scaling (MDS) to create a new data configuration where Euclidean distances between observations approximate the original over-water distances; allowing the sound application of variogram estimation and kriging prediction. Then, a compositional data analysis (CoDA) was conducted by first transforming each set of physical and benthic parameters, expressed as percentages, into a set of logratios. Geostatistical analysis was performed on these new sets of variables followed by a back-transform of kriging estimates, leading to coherent maps for both sets of parameters. Multivariate outliers for Macrofaunal assemblages were identified based on a spatial Mahalanobis distance and results were visualized using parallel coordinate plots and biplots. Cross-validation analysis illustrated the benefits of a combined MDS and CoDA approach over traditional geostatistical modelling that ignores complex geometries and does not guarantee that predicted percentages will be non-negative and sum to 100%.

Salmon foraging in an Urban Sea – Habitat mapping for fisheries sustainability

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Urban seas generally exist within river mouths, estuaries, bays, and inland seas that border the global ocean and provide refugia and a nexus between marine and terrestrial resources. These seas range from small to large areas, populations, and industry, but they all depend upon their natural environment to sustain an economy. This includes such industries as fishing, shipping, and energy production. We focus on one moderate size, mature urban sea, the Salish Sea of the Pacific Northwest State of Washington, USA regarding one of North Americas' most valuable and revered fish, the Chinook or king salmon (*Oncorhynchus tshawytscha*).

Salmon are a fish of concern in the Salish Sea as their habitats are being disturbed by human activity and their prey are disappearing. Little is known of salmon foraging activities in the ocean. To gain knowledge of salmon feeding behaviours, one needs to follow the fish. We attempted to do this by focusing on one of Chinook salmon's prey, the Pacific sand lance (PSL, *Ammodytes personatus*) and its sub-tidal habitats. To determine what, where, and how salmon are feeding we mapped potential PSL sub-tidal habitats, solicited recreational fishers and charter boat operators to provide stomachs of caught fish, analyzed the stomach contents, and plotted the locations of the salmon caught with PSL in their gut to compare with the potential and known sub-tidal habitats. We identified over 275 bedforms and classified them according to their potential for PSL occupancy with 106 sites rated good or better potential. Of the 109 salmon stomachs examined, including Coho (*O. kisutch*, or silver), and Pink (*O. gorbuscha*, or humpback) the Chinook salmon (N=46) contained PSL. We found in several instances that these fish were not caught near previously mapped known PSL habitats but appeared to be foraging on small banner bank bedforms. From striations along the salmon snouts and sides and the propensity of PSL to burrow into sand, we hypothesized that salmon may be targeting PSL sub-tidal habitats.

The potential for adverse human influences in urban seas, such as the Salish Sea, is increasing and includes, among other activities, oil spills from shipping accidents. Such spills as sinkable heavy (persistent) oil, can cover and smother fish habitat and fish. To sustain salmon fisheries, detailed forage fish habitats need to be mapped and made available for planning mitigation if an oil spill were to occur. We will present examples of such maps for the San Juan Archipelago in the central Salish Sea.

Mapping kelp forests using aerial drones and machine learning: A case study from Norway

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Kelp forests are known for their multiple ecosystem services, including high biodiversity and carbon capture and storage. To be able to conserve and protect these important habitats, it is crucial to know where they in fact are located. Spatial distribution models (SDMs) have taken us far to identify probable areas where kelp forests can be found, but maps based on SDMs are usually not either precise or detailed enough to serve as foundation for management purposes. Recent drone - and sensor technology produce images at centimetre accuracy. Combined with *in situ* ground truth data and machine learning (ML) analyses, remote sensing technology can develop high resolution maps of high precision of biodiversity-rich coastal habitats, like the kelp forests. We will provide recommendations on using drone technology for coastal habitat mapping and research, as critically needed tools to reach the ambitious goal set by the Global Biodiversity Framework (GBF) to protect and conserve 30% of our nature by 2030. (www.seabee.no, www.obama-next.eu)

Utilizing high-resolution seafloor maps to assess habitat recovery in active bottom-contact fishing zones: A case study of the Banquereau Bank Arctic Surfclam fishery

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Bottom-contact fishing methods cause unnatural disturbance to benthic ecosystems, and the rate of population and ecosystem recovery to pre-fishing conditions is site-specific and often unknown. Due to the strong association between benthic species and substrate type, the spatial distributions of bivalve stocks can be relatively well represented by seafloor habitat maps. These maps, combined with geospatial fishery data, have tremendous potential to help assess benthic habitat recovery post-fishing, providing an indication of how physical/biological components of the seafloor recover post-harvesting. Banquereau Bank is a large, sandy, storm-dominated submarine bank located at the outer eastern edge of the Scotia Shelf, offshore Nova Scotia, which has supported an abundant Arctic Surfclam fishery since the mid-1980s. High-resolution multibeam echosounder (MBES) data were collected from 2007-2010 over 65% of Banquereau Bank (multibeam coverage of ~6,600 km2). Since 2014, Clearwater Seafoods Limited Partnership has commercially harvested Arctic surf clams on the bank and has implemented an in-house harvest database that records the location of each dredge tow and associated catch information. Here, we present the results from research utilizing the available MBES data set along with in situ benthic grabs and camera survey data, and the temporal catch information of Arctic Surfclam, to generate a series of thematic maps of the bank (surficial substrate, morphology, and habitat suitability of Arctic Surfclam). These were generated using a variety of machine learning methods (Random Forest (RF), object-based image analysis (OBIA), and Maximum Entropy (MaxEnt)). We demonstrate how the thematic maps of the bank, combined with the temporal, spatially accurate privately held commercial catch data from the harvest database (which determine the time since fishing), are being used to design a post-fishing recovery study. Impacted study sites (500 m x 500m) are being selected and paired with control sites (i.e., undisturbed by fishing) of similar seafloor habitat type. Future research in 2023 is planned to conduct field surveys at these selected sites to assess physical habitat change, benthic community composition and Arctic Surfclam recovery post-fishing. This will offer valuable insight into the processes and time required for habitats to return to their natural state following fishing, and provide information from which sustainable rotational harvest strategies for clam fishing can be developed.

Drones for mapping benthic habitats and the SeaBee infrastructure

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Shallow water habitats provide a wealth of ecosystem services, including feeding and nursery grounds for ecologically and economically important species and blue carbon storage and sequestration. Nevertheless, coastal habitats are poorly mapped and their ecosystems sparsely quantified and understood.

We present a novel approach for coastal ecosystem mapping and monitoring using aerial, surface, and underwater drones, combined with machine learning (ML) for image analysis, with the aim to provide cost-efficient tools for marine research and management. We provide examples of how aerial drones equipped with RGB, multispectral and hyperspectral sensors can deliver high resolution (2-10 cm/pixel) maps of benthic habitats incl. seagrass and macroalgae beds and demonstrate coverage and patchiness that are difficult to constrain with traditional techniques. RGB imagery provides multiple opportunities for identification of species and habitat patterns. Multispectral and hyperspectral data, in addition, provide opportunities for accurate quantification of remote reflectance and facilitate the development of sophisticated ML algorithms for habitat identification based on their optical signatures (or 'fingerprints'). Unmanned surface vehicles (USVs), deliver a unique platform to support aerial drones using in-water, downward mounted imaging, optical, or acoustic sensors. Such approaches can provide high resolution *in-situ* data and support collection of ground truth data for training of ML algorithms, and extend autonomous data collection to water depths beyond what is feasible using optical techniques from aerial drones and satellites.

The talk will briefly introduce SeaBee: the "Norwegian Infrastructure for Drone-based Research, Mapping and Monitoring in the Coastal Zone" (www.seabee.no) and highlight advantages using drones for mapping and assessments of coastal habitats, ecosystem structures, and marine biodiversity.

Ocean acidification of deep-sea habitats – impact of the rising CCD depth in the global ocean

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The “lysocline” is the transition zone in the ocean within which the calcium carbonate mineral “calcite” becomes unstable and begins to dissolve. Its upper limit is the calcite saturation depth (CSD) and its lower limit is the calcite (carbonate) compensation depth (CCD). Above the CSD ocean water is super-saturated with calcite and seabed sediments are calcareous rich. Below the CCD, seabed sediments contain little or no carbonate minerals. Due to burning of fossil fuels, carbon dioxide is being absorbed by the ocean where its chemical conversion to carbonic acid has already caused the surface ocean to become more acidic than it has been for at least the last 2 million years. Global ocean modeling suggests CCD levels have already risen by one hundred meters since pre-industrial times and will rise further by several hundred meters more this century. Potentially millions of square kilometres of ocean floor will undergo a rapid transition in terms of the overlying water chemistry. Depending on their sensitivity to these undersaturated conditions, benthic fauna will either remain and adapt to the changed conditions, or their distribution will shallow as they die out in or move away from areas that they cannot tolerate.

In this paper we report that shoaling of the CCD since the industrial revolution has submerged an additional 12,432,096 km^2 of ocean floor (3.60% of total ocean area) below the CCD. Further hypothetical shoaling of the CCD by an increment of 100 m illustrates that the surface area of seafloor submerged below the CCD rises by 24,947,550 km^2 equal to 7.23% of total ocean area. All categories of geomorphic feature mapped in one global database intersect the lysocline and are impacted by the rising depth of the CCD, with much regional variation. For seamounts, the highest percentages of increase in area submerged below the CCD from pre-industrial times to the present occurs in the Southern Indian Ocean and the South West Atlantic regions (6.3% and 5.9%, respectively). For submarine canyons we find the South West Atlantic exhibits an increase in area submerged below the CCD from 3.9% in pre-industrial times to 8.0% at the present time, the highest percentage of canyons found below the CCD depth in any ocean region.

Marine base maps in the Norwegian coastal zone – contributing to a more sustainable co-existence

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As many other countries, Norway has committed to the Sustainable Development Goals (SDG) of the UN, including sustainable development and use of the oceans. To sustainably develop our coastline, we are dependent upon up-to-date baseline knowledge from benthic habitat maps. The Norwegian pilot project “Marine base maps for the coastal zone” was initiated aiming to provide mapping knowledge to meet this need; to improve coastal resource management, aid in coastal development and decision-making, while maintaining healthy ecosystems. The project used a range of mapping methodologies, including multibeam echosounders, remotely operated video platforms and physical sampling to produce a set of detailed maps of three geographical areas extending from the south to the north of the Norwegian coast; namely Stavanger (59°12' N, 5°47' E), Sunnmøre (62°41' N, 6°20' E) and Troms (69°59' N, 20°55' E).

The map products fall into four categories which successively build on each other; digital terrain models, oceanographic models, geological maps, and biological maps. Biological maps are further categorised to accommodate multiple stakeholders' interests. This includes maps that classify marine nature types based on environmental variables (compliant with the *Nature in Norway* (NiN) framework), maps of nature types of national management interest, and maps of vulnerable benthic habitats. We will present a selection of these maps and demonstrate how new knowledge from our project is being used to update nature classification systems as well as being used by governmental agencies, local fishermen and the industry to support a more sustainable spatial decision-making.

This pilot project is a multi-institutional partnership between the Norwegian Mapping Authority (Kartverket), the Geological Survey of Norway (NGU), and the Institute of Marine Research (IMR). The diverse applications of the maps have demonstrated the ecological and socioeconomic value to coastal communities and form the basis for an application for a full-scale national program aiming to cover nearly 100,000 km^2.

Developing designated anchorages to improve anchor management for ocean-going vessels: a role for habitat mapping and vessel tracking data

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World maritime trade is increasing and expected to double during the current decade (2020-30). Combined with persistent growth in the cruise-ship industry, the international shipping fleet is set to expand with increased vessels and marine traffic placing ever greater pressure on the marine environment. Environmental awareness means shipping companies are having to seek ways to reduce operational impacts from pollution, emissions, waste, and noise. Physical impacts from vessel anchors and anchor chains on benthic environments have received relatively little attention. For many international ports, their anchorage roadstead remains unmapped at high-resolution and subsequently the impact on benthic ecology from anchoring is poorly understood and inadequately managed.

Historically, vessels dropping anchor to await entry to Port Kembla, in Australia's temperate south-east, assumed the seabed to consist of only soft sediments. Even though some early multibeam surveys (2006) established the presence of reef within the harbour approach, consideration of anchoring impacts upon benthic environments has only very recently been prioritised. NSW Department of Planning and Environment and the University of Wollongong have been mapping the region since 2014. The aim of our work has been to 1) map and characterise seabed habitats and diversity in and adjacent to the Port Kembla offshore anchorage area; 2) use vessel tracking system (VTS) data to map (extent, intensity) vessel anchoring activity; and 3) use these data to improve management of anchoring practices and reduce risks to benthic environments within the marine estate.

Multibeam, towed imagery, baited video and sediment surveys now contribute to baseline data coverage across ~50% of the ports anchorable area. In mapped areas, the seabed is dominated by low-profile platform reef (>60%) cut with sediment filled channels. Areas of unconsolidated or intermediate seabed types are in relatively short supply. Reefs within the anchor zone are >35-40m, mesophotic and sponge dominated, with significantly lower diversity in anchored versus control locations. Areas of the brown kelp *Ecklonia radiata* have also been identified in 'deep-water' for the first time and may represent a refugia from the effects of warming waters of the East Australian Current.

Habitat and anchor intensity maps have recently been used to develop a new anchoring management approach. Designated 'anchorages' have been identified through collaboration and agreement between the port and multiple government agencies based on a set of operational and environmental criteria. This has resulted in at least a 60% reduction in the total area of seabed now available to anchoring.

Benthic Habitat Mapping in Soariake MPA, Southwestern Madagascar

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Coral reefs are an essential source of marine biodiversity and the lives of millions of people depend on them. Currently, they are in peril under the effects of climate change and human pressure. In Madagascar, research conducted for coral reef monitoring by in-situ observation is very expensive, and therefore does not allow a complete representation of coral reef systems. Satellite remote sensing is an alternative and complementary approach that allows for larger scale and more affordable coverage. This study uses freely available high-resolution satellite imagery to provide an affordable and effective solution for marine scientists and policymakers to monitor the health of the remaining coral reef systems so that appropriate measures can be taken. The objective is to provide a benthic map for the Soariake Marine Protected Area (MPA). Ground truthing was carried out in the Soariake MPA on 28 transects of 500m in length each. 4833 geo-referenced photos were taken. The photos were analyzed on CPCe (Coral Point Count with Excel extension) to obtain the benthic coverage by assigning to each photo the corresponding benthic class.

The combination of field data and high-resolution satellite images, using the OBIA (Object-based image analysis) method, allowed the creation of high precision maps of the benthic classes covering all the Soariake MPA. The accuracy of the classification was evaluated with the Kappa coefficient. The OBIA method allowed to give a map with a Kappa accuracy of 82% at the Soariake MPA, divided into five benthic classes: Corals and Macroalgae, Debris, Macroalgae and Sand, Sand, and Marine Vegetation. Among the 701 validation points, 575 points were accurately mapped. User and producer accuracy by class exceeds 63% reliability.

This study demonstrated the feasibility of creating high accuracy maps from existing free satellite data such as sentinel 2 by combining OBIA and field validation data.

Mapping the coastal and submarine geomorphology of Norfolk Island

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Norfolk Island is an eroded basaltic volcano formed 2.5-3 Ma in the southwest Pacific, 740 km south of New Caledonia and 1,400 km east of the Australian mainland. Although Norfolk Island lies within an Australian Marine Park, there has been very little work exploring the geomorphic characteristics of the Norfolk Island coastline and its extensive marine shelf.

A geomorphic description of the Norfolk Island coastline and submarine morphology has been completed using various field, geospatial and bathymetric methods. Drone photogrammetry, high-resolution LIDAR, rock resistance testing, and field observations have been used to compile a geomorphic map of the coastline, which is predominantly rocky, made up of cliffs interspersed with boulder beaches, shore platforms, sea caves, offshore stacks and arches. Pockets of the coastline are sandy with carbonate beaches produced by biogenic production in the south and northwest. Lithological, structural and erosional differences around the Norfolk Island coast control variations in morphology, which, in addition to mass wasting deposits and erosional scarps, indicate the efficacy of erosion processes on oceanic volcano landscape evolution.

The Norfolk Shelf seafloor has been investigated by combining high-resolution bathymetry (collected by Ocean Infinity, previously iXblue), LADS and Baited Remote Underwater Video (BRUVs). Using geospatial methods, such as Benthic Terrain Mapper (BTM) in ArcPro, and video footage from BRUVs providing ground truth information, the seafloor geomorphology was classified into unconsolidated and consolidated, as well as plane, depression, ridge, steep slope and hummocks. The offshore morphology shows a flat marine shelf dominated by sand, with localised sand ridges. Outcrops of rock, either volcanic or carbonate, are exposed in some locations to form a rugged seafloor on which isolated corals grow.

Trait-based approaches to biological habitat mapping: a case study of functional biodiversity in the Bay of Fundy, Canada

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Ecological traits, which are defined as characteristics of an organisms that influence their fitness in a system, are known to drive community assemblage patterns, influence how species respond to disturbances and describe species' contributions to ecosystem functioning. In ecology, trait-based approaches have become important tools in delineating assemblages beyond taxonomic criteria and have been applied to multiple systems through the assessment of trait composition, functional diversity and redundancy, as well as joint-modelling approaches. The potential of traits represents a useful avenue for the spatial modelling of biodiversity and for benthic conservation monitoring, however, only recently have they been incorporated into habitat mapping and remote sensing research. Here, we use a case study of benthic invertebrate assemblages in the Bay of Fundy, Canada to investigate trait-environment relationships and explore the effectiveness of different geospatial modelling approaches for trait-based benthic habitat mapping. A general workflow framework is also provided with discussion of benefits and drawbacks of these approaches.

We combine data from drop camera deployments (n=156 stations) and a literature-derived trait database, with high-resolution environmental data from physical oceanographic models, multibeam sonar surveys, and seabed sediment samples to model and predict trait structure and functional biodiversity across the region. Our analysis demonstrates that trait composition is influenced by environmental gradients and benthoscape type (a biophysical classification of benthic habitat) with certain traits associated with different benthoscapes. Multibeam sonar backscatter, a proxy for seafloor hardness, was found to have a substantial influence on functional biodiversity patterns, such as functional originality (the uniqueness of traits in the assemblage) and functional dispersion (the breadth of traits in the assemblage). We also observed low functional redundancy across the bay, referring to the number of species occupying available trait combinations. This result highlights the limited trait breadth of the assemblage, and possibly, low insurance for ecosystem functioning under disturbance-mediated species losses. Finally, using machine learning and Bayesian modelling techniques, novel mapping outputs are provided to support biodiversity management goals in the region. The feasibility of trait-based modelling, as well as the sensitivity of traits to environmental conditions, underscores the need for these methods to be adopted in spatial management, and supports a paradigm shift towards a functional habitat mapping and conservation perspective.

Spatial analysis of underwater comet structures along the Israeli shelf reveals trends in the sediment transport system

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Multibeam and backscatter bathymetry from several sites covering ~110 km along the Israeli shelf (Eastern Mediterranean) at water depths 90-120 m reveal over 90 comet structures: exposed sandstone rocky knolls surrounded by unstable soft-sediment scouring at their base, providing conditions for hard bottom insular habitats, proven to host diverse ecological niches and unique faunal communities. They form comet-like 'head and tail' structures, ranging in diameter from 15-140 m, with relative elevation from their surroundings varying up to 36 m and distinct tail orientation of 8-12 degrees. We observe a correlation between latitude and diameter, as they become smaller in size to the north. However, there is a relatively constant ratio between their tail length and their diameter. We suggest that the constant orientation shows a single dominant sediment transport vector towards the north, which matches well with the Levant Jet System (LJS) currents detailed in literature to diminish northward. The study supports previous suggestions about the LJS having a dominant direction from south to north in these water depths. The reduction in exposed knoll diameter northward leads to infer that the LJS current is stronger in the south and weakens with the latitude further north. However, direct measurements for that are yet to be obtained. A comparison of the above set of comets to a set of dozens of recently mapped comets in the southernmost Israeli shelf shows differences in their spatial appearance and geometry, and is related to the bathymetric difference in shelf width and morphology between south and north.

Located in the zone of coastal shoreline/cliffs of the Eastern Mediterranean during Last Glacial Maximum times (~15 ka), we suggest these structures were exposed to sub-aerial fluvial systems during sea-level low-stand periods. During sea-level high-stands, when the shelf is submerged, the persistent current transports sediment from south to north, forming distinct comet structures in the dominant direction of the LJS. Today, these underwater rocky knolls serve as unique, rich and diverse habitats in the shelf of the Eastern Mediterranean and are being investigated by biologists, ecologists and geologists.

Towards improved spatio-temporal estimation of boating pressure to benthic habitats with Sentinel-2 satellite imagery

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The Archipelago Sea Biosphere Reserve (ABR), located in Southwestern Finland in the Baltic Sea, has been in UNESCO Man and Biosphere program since 1994 for its outstanding value for hosting biodiversity and coupled human-nature relationship. The area is described as a mosaic of thousands of islands, making recreational boating the main means of transport. It is widely known that boating is intense, especially during summer months in the area, creating disturbance to valuable benthic habitats. However, spatio-temporal estimations on the distribution of recreational boating in the area have been lacking, and thus, any robust estimations on the impact of boating to benthic habitats are not available. Such estimations would be vital for targeting different management measures (such as prohibiting anchoring or placing speed limits) in the marine conservation areas to minimize the impact of boating pressure to benthic habitats.

The freely available Sentinel-2 twin satellite constellation of the European Space Agency, launched in 2015 and 2017, has significantly increased available high-resolution observations of the globe. The 10m resolution bands of the sentinel-2 satellites make an interesting data availability for near real time monitoring of the human pressure on the global oceans since the resolution is tight enough to distinguish small recreational boats and the temporal revisit time is frequent enough for monitoring.

In this study we present the results of our study for detecting small boats in the Archipelago Sea Biosphere Reserve during summer of 2021 using Sentinel-2 satellite imagery and simple, repeatable modelling approach. We will discuss the potential of the open Sentinel-2 satellites for detecting the small boats and the ways forward for spatially more accurate assessment of boating pressures on benthic habitats.

Ferromanganese concretion bottoms – microscale geodiversity hotspots in the Baltic Sea?

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Mineral deposits are commonly found in the deep seas, but also in shallow seas such as the Baltic Sea. Ferromanganese (FeMn) concretions are typical mineral deposits found on the Baltic Sea seafloor, and have gained interest as a source of commercially important minerals (e.g., cobalt, nickel, rare earth elements). Despite the widespread occurrence of FeMn concretions in the Baltic Sea and other shallow water areas, their significance to the marine ecosystem has been largely unknown.

To improve our understanding of the distribution FeMn concretions and their contribution to seabed geodiversity in the Baltic Sea, we studied several sites in the Gulf of Finland in the northern Baltic Sea. FeMn concretions were found at almost all studied sites at water depths between 9 — 65 m. The shape and size of the concretions varied considerably, from buckshot to plate-or crust-like concretions.

FeMn concretion coverage of the seabed was ≥ 90 % at about a quarter of the studied sites. With increasing concretion coverage, the total seabed surface area also increases. FeMn concretions therefore increase the microscale seabed heterogeneity which contributes to geodiversity. By providing a 3D environment and hard physical structures on the predominantly soft seafloor sediment, dense FeMn concretion fields support benthic communities, likely increasing biodiversity. A harder seabed surface is also more resistant to erosion than soft substrates such as mud.

Dense concretion fields consisting of plate-like concretions possibly resemble the 'Biogenic Reefs' habitats, of which a representative part should be protected according to EU legislation. However, knowledge of their detailed regional distribution and extent is still incomplete. This is a topical issue now, as the economic interest to exploit FeMn concretions is growing worldwide.

Assessing habitat biodiversity with BIIGLE – new tools for online semantic image and video annotation

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In the exploration and monitoring of marine habitats, image and video data (here referred to as visual data) play an important role. Visual data is used to define ground truth information for the evaluation of backscatter data or to assess and monitor the macro-level biodiversity in a habitat. However, the extraction of qualitative or quantitative information from the data requires a cognitive process referred to as semantic annotation, i.e. the selection of a region of interest and the assignment to a taxonomic category. In the last ten years different systems for marine image and video annotation have been proposed, each one with a different kind of focus. The open source software solution for online visual data annotation BIIGLE 2.0 (biigle.de) has been published in 2017 and has now a user community of more than 2.000 registrations just in the Bielefeld instance plus users in external partner instances in marine research institutes. In this talk, we will show how BIIGLE 2.0 has evolved over the past few years to address the challenges in underwater visual data analysis. First, underwater visual data analysis software must be easily accessible so institutes with less IT infrastructure and less IT support personnel can use it and are enabled to analyse their data efficiently. Second, the annotation of the data must be aided by machine learning. However, the success of any machine learning approach to automatic detection and classification depends on a training data set of labelled examples. Third, data management and analysis should follow the FAIR data principles (Findability, Accessibility, Interoperability, and Reusability) to make marine visual data analysis efficient, effective and sustainable. Fourth, the interpretation of the annotation results should be supported with easy to use straightforward visualizations so users get a quick feedback for their annotation efforts, can manage their annotation efforts and are able to gain a first mental model for the biodiversity displayed in the visual data. We will show in our presentation how BIIGLE addresses these four challenges by 1) offering a data upload into cloud storage and enabling SSO (single sign on), 2) improving BIIGLE's MAIA object detection and classification tool and supporting fast semi-automatic training data collection with BIIGLE, 3) supporting iFDOs (image FAIR Digital Objects) and 4) offering a new rich information visualization dashboard for BIIGLE projects.

Using machine learning for predictive mapping of ferromanganese crusts (Fe-Mn) in the oceans

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There is an increasing demand for minerals and metals in the context of decarbonizing societies, and is pushing mineral exploration into new frontiers. Mineral prospectivity mapping is a complex multi-criteria decision task aimed at delineating prospective areas for exploring undiscovered mineral deposits. Expansion of digitised regional geological and geophysical surveys, and abundance of high-resolution remote sensing data has sparked the development of a GIS-based solution for this type of mapping. The applicability and efficiency of the random forest algorithm has been recently evaluated and concluded that random forest models are stable and reproducible, using a variety of dataset sizes and subsets that outperform other methods in terms of success and prediction-rate.

A compilation of known occurrences of ferromanganese (Fe-Mn) crust deposits was used for presence data, together with non-deposit locations, such as sediments and other samples acting as absence data.

Several predictor datasets were utilised. All had global coverage (excluding the polar regions) but had varying resolutions from 2 arcminutes (~3.7km) to ¼ arcminutes (~0.5km). The predictor variables trialled included: Geomorphological classifications, seafloor kinetic energy, current surface productivity, crustal age, depth, slope and sediment thickness. It was found that several predictor datasets had strong correlations ($r > 0.8$) and were removed. Once removed, all r values in the Pearson correlation matrix of predictors on the training data set were $-0.5 < r < 0.5$, except for the “Bathymetry” and “Lithic sediments” variables, correlated at $r = 0.59$, and considered acceptable for use in a predictive model.

Relatively high probability of occurrence for Fe-Mn crusts are usually associated with geomorphological features (such as seamounts, ridges, cliffs, rift valleys, abyssal mountains) that generate important bathymetry gradients, or slopes. The findings of the random forest model corroborated the generally accepted model of occurrence of Fe-Mn crusts.

Gradient maps of predictive occurrence of Fe-Mn crusts will be shown and discussed, and compared with ISA (International Seabed Authority) licenced blocks. The model predicts that 34 million km^2 of seafloor has a probability > 50% of hosting Fe-Mn crusts, of which just under half are in countries’ exclusive economic zones (EEZ).

Where has the Suwannee Reef gone? Mapping historically significant subtidal oyster habitats in Florida at multiple scales

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Eastern oysters (*Crassotrea virginica*) provide numerous ecosystem services to coastal ecosystems and human communities and are considered a Species of Greatest Conservation Need in Florida. Along the central and northwestern Florida coastline, offshore subtidal oyster reefs have experienced an estimated net loss of 88% since 1982 because of a combination of environmental and anthropogenic stressors. This loss highlights the importance of frequent and comprehensive monitoring of these critical habitats to inform management and restoration, yet there is currently a lack of spatially-continuous baseline data.

The Suwannee Reef was so extensive over 50 years ago that it created an enclosed bay. Today, however, the reef is mostly subtidal and only fragments remain. This work aimed to update the information we have on the distribution and extent of the reef by mapping oyster habitats along the historical footprint of the Suwannee Reef. In October 2021, bathymetric and sidescan data were collected using an EdgeTech 2205 echosounder mounted on an uncrewed surface vehicle. The surveys were designed to follow the latest available data on oyster beds along the reef, which were recorded in 2001. The processed bathymetric grid, produced at a 25 cm resolution, covered an area spanning about 1.7 km^2 in depths ranging from about +0.49 m to -4.41 m relative to the lowest astronomical tide datum. Vertical uncertainty on the bathymetry averaged 8 cm.

The 2001 data showed 20 individual beds distributed along a six-kilometre stretch and covering about 47,000 m^2. These beds were not visible anymore in the 2021 bathymetry and sidescan data, and no clear evidence of oysters could be found except in one particular area where the data suggest that there may have been a 45 m migration of shell material toward the coastline. However, this will need to be validated with upcoming ground-truthing.

The broader-scale morphology of the seafloor suggests that the former oyster beds played a key role in shaping the seafloor. To confirm this, the bathymetric data were used to inform an empirical satellite-derived bathymetry process using Sentinel-2 data (10 m resolution). The resulting regional bathymetry, which had an R^2 value of 0.59 and a standard error of 4 cm, highlighted the important contribution of oyster resources, past and present, in shaping the seafloor in the area. Current work tests semi-automated classification methods to characterize the area's geomorphology quantitatively and will add to the story about the role of the Suwannee Reef in shaping its environment.

Large polygonal patterns of western Rio Grande Rise

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Kilometer-scale polygonal structures were recently revealed in bathymetric and shallow seismic data of western Rio Grande Rise (RGR). Separated by troughs on the seabed, up to 20 m deep and 500-1000 m wide, these patterns resemble mud cracks. However, while the typical desiccation cracks are associated with basins and depressions, where fine-grained sediments contract due to pore water expulsion, the flat mapped area in question is actually shallower than its surroundings, in depths about -2000 m. The presence of a 4 km diameter crater in an enclosed sector, far from canyons or ravines, denotes that the seabed is not only eroding, but also collapsing.

Sediment samples were gathered only in the adjacent abyssal plain, composed of calcareous nannofossil ooze and foraminifera sand, the same material found on 517 and 518 DSDP holes. The topographic landscape of RGR is highly complex and has undergone an intricate geological evolution, characterized by uplifting and subsidence episodes and the development of numerous faulting systems. In addition, several canyons and plateaus were shaped by wave action during times when the region was above sea level.

Processing of magnetometric data acquired in the same campaign reveals anomalies along slopes at define bathymetric level: -2050 m to -2200 at the northern part; -2400 to -2600 m to the southern portion. Anomalies to the northern part are shallower, some are less than 200 m below the sea bed. These patterns can unveil layered mafic intrusions.

Hence, there are some potential mechanisms that could create the polygonal patterns observed in RGR. A possible mechanism is the gravitational force exerted on sediments of varying degrees of compaction, where lighter, unconsolidated sediments located at the base of the sedimentary column may undergo Rayleigh-Taylor instabilities and cause the upper layer to crack. The existence of pockmarks in the northern RGR indicates the likelihood of gas leakage, microbial biostabilization and the development of habitats that rely on chemosynthesis. To acquire more comprehensive knowledge about the processes causing the polygonal features, it is necessary to conduct an investigation focused on sediment properties. Additionally, deep seismic acquisitions could provide a better comprehension of faulting systems, which are accountable for the seepage of fluids or gases.

The discovery of geomorphological features in the deep southwestern Atlantic Ocean can indicate the presence of fluid seepage and chemosynthetic habitats.

Palaeo-estuarine seafloor features create biodiversity hotspots and offer insights into coasts past and future

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Several unusually well-preserved relict seafloor features are found off Durban, South Africa that were stranded by abrupt rises in sea level since the Last Glacial Maximum of 18,000 years BP. Two shorelines are found at -60m and -100m, adjacent to the No. 1 Reef complex on the mid-shelf, underlain by incised river channels representing palaeo-estuaries that formed as sea levels rose. The relict seafloor features mirror contemporary segmented estuarine coastal lakes such as found some 400 km north on the Maputaland Coastal Plain. Indeed, many of No. 1's extant marine macrobenthos including Callianassidae malacostracans and their infauna associates, closely resemble and dominate those of the interconnected Kosi estuarine lakes.

Our study is the first to document the inhabitants and habitats of this palaeo-estuarine complex, a muddy lagoon-type environment surrounded by highly bioclastic and medium to coarse sands and gravels. The feature was revealed using a suite of past and recent surveys. Multibeam bathymetry at various resolutions, side scan sonar, high- and very high-resolution seismic coverage with a specific focus on the palaeo valley, and three dated cores that constrain the palaeo estuary age, form the physical basis of inspection. These were followed by grab sampling for sediment biophysical attributes in each of the palaeo lagoon segments, and along a habitat/bathymetry continuum to the uMgeni Estuary shoreline, with which this system shared a palaeo-connection.

We propose that this drowned feature, although relatively imperceptible at a regional scale, has created a unique environment on this shelf region, triggering a remarkable infauna diversity across many Phyla. Local shelf studies have revealed a rich macrobenthos with many unique habitats of conservation importance. These are however eclipsed by this species hot spot. Particularly the Amphipoda have flourished, including endemic fauna (e.g. *Unciolella spinosa*, *Basuto stimpsoni*) and those sensitive to disturbance (e.g. *Ampelisca* spp.).

The study also provides evidence that these ancient systems can provide valuable information about the functioning of modern estuarine coastal lakes and offer insights into the evolution of marine ecology. Further, such studies of marine palaeo-estuarine habitats are testing grounds for the physical evolution of coasts, for example to better understand changes in response to climate, including sea-level rise.

Mapping Ogak/Greenland cod (*Gadus ogac*) habitats in nearshore Nunatsiavut waters using community identified fishing locations

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In Canada, northern coastlines are undergoing significant environmental change in response to the rapidly warming climate. Warmer conditions coupled with changes in ocean circulation and ecological processes (e.g., migration periods, prey availability) continue to cause profound changes to the ranges and ecology of northern fish, benthic ecosystems, and ecosystem services. These changes impact the social, cultural, and physiological well-being of Labrador Inuit within Nunatsiavut (Newfoundland and Labrador, Canada) whose livelihoods are intrinsically linked to the coastal marine environment.

Ogak (Inuktitut for Greenland cod (*Gadus ogac*)) is a highly valued demersal marine fish species within the subarctic communities of Nunatsiavut and has been designated as a research priority in a local marine management plan, *Imappivut*. Ogak have traditionally been a large part of Inuit subsistence, yet the distribution of benthic habitats in Inuit Nunangat (Inuit homeland in Canada) and how these habitats support the species is poorly understood. This research uses nearshore community-identified Ogak fishing locations to map the distribution of benthic habitats in Nain, Nunatsiavut in support of managing one of the most important marine resources in this rapidly changing region.

Residents of Nain who fish for Ogak year-round disclosed important locations near the community. These 5 fishing locations, and 70 additional locations within Nain's nearshore benthic environment, were surveyed with 5-minute drift videos. Sites were spatially balanced and distributed to encompass a broad range of seabed environments based on the stratification of acoustic bathymetry available in the region. Continuous environmental layers found to influence faunal distribution were derived using a multiscale approach from available bathymetric data. Random Forest was used to model the presence of species assemblages against the acoustic data and derivatives to create a full-coverage habitat map. A total of 68 morphospecies comprised of 29,734 individuals were identified within 75 video drops. Preliminary community analyses revealed four faunal assemblages and fishing locations were represented in three of them. The only assemblage without a fishing location was entirely composed of fine sediments and was characterized by dense fields of tube-dwelling anemones (*Cerianthidae spp.*). Results suggest that Ogak tend to be caught in more structurally complex habitats represented by the other assemblages. By pairing community expertise with habitat mapping, this project supports Inuit research interests, and provides a baseline on the distribution and structure of benthic habitats in Nain. Moreover, this research will aid in conservation and management strategies under the pressures of climate change in Inuit Nunangat.

High resolution mapping before and after seafloor macrolitter removal by an innovative robotic solution in the Venice lagoon, Italy

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Recent studies indicate that a large percentage of marine litter accumulates on the seafloor. However, the seafloor marine litter is hard to identify and, once found, even harder to remove in an efficient and eco-sustainable way. For this reason, it is crucial to develop new techniques for the mapping and the removal of the seafloor marine litter. Within the EU co-founded H2020 Smart technology for Marine Litter SusTainable RemOval and Management (MAELSTROM) project, we carried out repeated multibeam surveys associated with video inspections for ground truthing to map the presence of seabed macro litter in a highly impacted area close to the historical city of Venice, Italy.

In September 2022, an innovative robotic system, i.e. a floating platform combined with an underwater cable-driven robot, was successfully tested for the first time in this area of the Venice lagoon. During this first test, the robotic solution, using a gripping device, removed several macro litter items identified by the high-resolution multibeam system in an efficient and selective way.

In this study, we present how the high-resolution mapping and classification have helped to fine-tune the operations of the innovative robotic system for the marine seafloor litter removal. Finally, we show the first results of the cleaning operations by comparing the data collected before and after the cleaning, useful to evaluate the efficacy of the removal technology.

Modeling the local distribution of hydrothermal vent assemblages and megafauna from the surrounding habitat in relation to topographic variables and fluid influence

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Since their discovery in 1977, hydrothermal vents have been extensively studied, shedding light on the link between environmental conditions and faunal distribution. Active hydrothermal vents host endemic fauna in a well-defined and small-scale zonation following the fluid influence. Faunal assemblages in vent peripheral areas are expected to be similar to those found in the background deep-sea environment. Indeed, peripheral habitats are mainly composed of deep-sea sponges, cold-water corals or other megabenthic invertebrates and their distribution are driven by seafloor topographic features and sediment characteristics. Moreover, those species rely on photosynthetic organic matter sinking from the surface, but they can also benefit from the local chemosynthetic production from hydrothermal activity. However, at the local scale, the transition between active and peripheral communities and the role of environmental factors driving faunal distribution remain poorly understood.

In this study, we computed Species Distribution Model (SDMs) on different faunal assemblages (i.e. vent communities, corals, sponges and other cnidarians) to characterize the predictors of their distribution at the Lucky-Strike vent field, located on the northern part of the Mid-Atlantic-Ridge. Maximum entropy (MaxEnt) models were fit to fauna presence records and spatial-explicit environmental predictors, including seafloor topographic variables and proxies of fluid influence derived from the distribution of fluid outflows mapped over the 5 km^2 area around the vent field. We also implemented different cell sizes in the models to explore the best results for each taxonomic group. Overall model performance was high and the drivers of species distribution appear to be different between all assemblages. As expected, vent communities are highly dependent on the distance from low-flow venting and only slightly affected by topographic features. Conversely, non-vent species are predicted to occur mainly on hard substrates with high rugosity and within slopes facing the dominant currents. However, model results reported no evidence of fluid influence on those taxa. In this work, we also provide predictive maps of the distribution of the different species on the overall vent field, beyond the extent of faunal surveys. This approach provides good support for cruise planning and represents a powerful tool for management and marine spatial planning in the context of biodiversity conservation.

Multispectral backscatter applied to seabed classification: a case of study examining the acoustic response of rhodolith beds

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Although technological and methodological advances have achieved a high level of detail and accuracy in seabed classification based on backscatter data, there are still some gaps to be investigated. One challenge is the difficulty in distinguishing acoustically similar marine substrates, such as mixed sediments and rhodoliths. Although rhodolith beds have a global distribution, the scientific research on these nodules is still relatively limited compared to other coastal vegetated habitats. In this context, one of the recent advances that has great potential to enhance seafloor differentiation and more detailed characterization of rhodolith beds is multispectral backscatter.

This work is based on a dataset comprising multibeam bathymetry, multispectral backscatter, and drop camera images collected on the offshore portion of the Costa das Algas marine protected area (Southeastern Brazil). The three-band mosaic was input to a support vector machine (SVM) classifier to detail the acoustic response of rhodoliths observed in underwater video for the first time using multi-frequency backscatter data. The goals were to investigate the benefits of multifrequency backscatter compared to a single frequency for supervised classification of rhodolith beds, and to analyze the difference between the three frequencies.

Backscatter mosaics showed the general trend of lower values for the frequency of 170 kHz, especially in valley bottoms. In areas where backscatter differences were visually difficult to detect in the single frequency mosaics, the RGB mosaic was useful for visualizing changes in multifrequency backscatter. These analyses, including quantification of the images and supervised classification achieved, suggest that multispectral backscatter is a valuable proxy for identifying biogenic substrate, such as rhodoliths. The SVM classifier provided increased discrimination of rhodolith beds using multispectral backscatter compared a single frequency, enabling their mapping across the Costa das Algas marine protected area.

Mapping macro- and microliter distribution in the Venice coastal area (Italy)

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Marine litter, in particular plastics, is a significant and growing marine contaminant that has become a global problem. Macro-litter is subject to fragmentation and degradation due to physical, chemical and biological processes, leading to the formation of micro-litter, the so-called microplastics. The purpose of this research is to assess marine litter pollution by using remote sensing tools to identify areas of macro-litter accumulation and to evaluate the concentrations of microplastics in different environmental matrices: water, sediment and biota (i.e. mussels and fish) and to contribute to the European project MAELSTROM (Smart technology for MArinE Litter SusTainable RemOval and Management). The aim is to monitor the presence of macro- and micro-litter at two sites of the Venice coastal area: an abandoned mussel farm at sea and a lagoon site near the artificial Island of Sacca Fisola; both sites are subject to strong anthropogenic pressure. The results showed that both study areas are characterised by high amounts of marine litter. However, as they are different contexts, the type of observed litter is also different. In fact, in the mussel farm area, most of the litter is linked to aquaculture activities (ropes, nets, mooring blocks and floating buoys), whereas in the Venice lagoon site the litter comes more from urban activities and from the city of Venice (car tyres, crates, wrecks, etc.). Microplastic is present in both sites and in all the analysed matrices. Generally, higher microplastics concentrations were found in the Lagoon site (i.e. in surface waters, mussels and fish). Moreover, some differences were also observed in shapes and colours comparing the two sites. These differences are related to the different types of macro-litter that characterised the two areas. The distribution of marine litter is therefore related to the main anthropogenic activities of the two areas such as fishery, aquaculture, tourism and waste management.

Multivariate mapping of seabed sediment properties in the Bay of Fundy using artificial neural networks

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Spatially continuous estimates of seabed surficial substrate properties are commonly used to support scientific, ecological, and conservation ocean mapping objectives. Physical oceanographic models, species habitat maps, and spatial management plans may all benefit from high resolution substrate information, which is often obtained from bulk physical substrate samples. These provide compositional data with non-independent properties (e.g., mean grain size, sorting, size fractions) that present challenges for geospatial modelling.

Here we investigate opportunities for addressing these challenges using multi-response neural networks. Historical grab sample data were obtained from the Bay of Fundy, Canada, along with spatially continuous measurements of depth, terrain, and oceanographic variables. Using multi-response neural network regression, parameters describing the mean grain size (xa), sediment sorting (a), skewness (Ska), kurtosis (Ka), and proportions of clay (Cp), silt (Sip), sand (Sp), and gravel (Gp) were jointly modelled as a function of environmental predictors. Compared to multiple univariate models, this is an efficient approach that enables spatially continuous and thematically consistent estimates of the full grain size distribution. Through a combination of softmax activation and mean squared error (MSE) loss, the compositional parameter predictions (Cp, Sip, Sp, Gp), are constrained to an appropriate scale, summing to 100%. Linear activation is applied to the non-compositional parameters (xa, a, Ska, Ka) to simultaneously obtain unbound predictions. Outputs were validated using a spatially explicit design based on measured autocorrelation, and spatially continuous predictions of each substrate parameter were mapped over the extent of the Bay of Fundy.

Results from this study demonstrate the utility of a multivariate approach to modelling seabed substrate parameters. Neural networks are best known for their application in classification contexts, yet the flexibility of their configuration appears to present a robust solution to several of the mapping challenges presented by multivariate and compositional substrate data. The joint modelling of parameters, efficient simultaneous prediction, and appropriate data scaling are three of the primary benefits afforded by this approach. These are demonstrated and discussed in detail.

A review of three decades of benthic habitat mapping

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The field of benthic habitat mapping has advanced tremendously over the past three decades, with improvements in mapping technologies, increases in data resolution, and fundamental changes taking place in how data are analysed, interpreted, and modelled. We queried the published literature to compile data and synthesize the results quantitatively to provide a comprehensive review of the field over this period. Out of a total of 1316 publications reviewed, 47.4% met the criteria for quantification in this study. Four categories of benthic habitat maps are differentiated unambiguously by the response variable (i.e., the subject being mapped): 1) abiotic surrogate; 2) single species; 3) benthic community; 4) benthoscape), rather than the approaches used to produce the map, which are manifold in the literature. Additional terminology in the literature is clarified and defined based on provenance, statistical criteria, and common usage. Mapping approaches, models, data sets, technologies, and a range of other characteristics were reviewed based on their application in the literature. We show clear trends in the adoption of high-resolution remote sensing methods such as multibeam echosounders and hyperspectral cameras for mapping sublittoral environments, and the increasing use of machine learning methods for modelling and classification of data sets. We present a summary of these findings along with insights into the future trajectory and challenges of this field of research, and a reflection on how these advances have been supported through the GeoHab community.

Spatial distribution of coral communities in the northern part of the great reef of Toliara, Madagascar

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Coral reefs support millions of people around the world. However, the effects of climate change and the increasing frequency and intensity of disturbances are leading to accelerated degradation and decline of scleractinian coral communities. Current concerns are focused on the resilience of these vulnerable ecosystems. In this context, it appears essential to improve the understanding of the distribution of coral communities in order to help conservation and management of reefs. The study was conducted in the northern part of the Great Reef of Toliara, Southwestern of Madagascar. The objective was to analyze the benthic cover; determine genetic distribution and define the geographical distribution of living corals in the northern part of the great reef of Toliara. These data were sampled using nine transects of 500m each, three of which are located at the external slope and six at the reef flat. Eight types of substrates were studied: hard corals, soft corals, other related organisms (sponges, starfish, anemones, sea urchins), calcareous algae, macroalgae, seagrass, dead corals and abiotic substrates (sand and rubble).

The results show that hard corals, soft corals, macroalgae as well as calcareous algae dominate the cover at the level of the external slope compared to that of the reef bed, on the other hand, seagrass and abiotic substrates (sand and rubble) are more concentrated at the level of the reef bed compared to that observed at the level of the external slope. The observation of the genetic distribution of hard corals on the two habitats (external slope and reef flat) showed a heterogeneity between the genetic distribution of hard corals on the two habitats. Indeed, the genus *Acropora* dominates on the external slope, while the genus *Porites* dominates on the reef flat. In the northern part of the great reef of Toliara, the spatial distribution of hard corals gains ground at the external slope level compared to that observed at the reef flat level.

Predictive modeling of seafloor surficial gravel distribution within a windfarm concession area in Belgian waters

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To ensure that marine offshore renewable energy can help reach the European ambitious energy and climate targets, a strategy has been formulated targeting an installed capacity of at least 60 and 300 GW of offshore wind infrastructure by 2030 and 2050 respectively. This inevitably implies seafloor sedimentological and ecological impacts. In this context, the national energy production in Belgian waters targets to soon reach 2 GW of renewable wind energy. The Belgian Maritime Spatial Plan in vigour has reserved an additional area of 240 km^2. This concession zone partly overlaps with the Habitat Directive (2012/EC 92/43/EEC) area wherein conservation-priority natural gravel bed biotopes are present. The fundamental prerequisite to scientifically inform the construction of wind energy infrastructure at sites potentially conflicting with environmental conservation objectives, is to map and characterise in detail the habitat distribution. Mapping at spatially explicit and ecologically relevant spatial scales is achievable via multibeam echosounding and ground truthing data, integrated in the framework of acoustic seafloor classification.

This project presents an extensive geophysical (MBES 300 kHz) and ground truth (underwater video and grab sampling) surveying effort, followed by the production of a state-of-the-art seafloor map depicting the continuous (i.e., $\%/m^2$) seafloor surficial cover of ecologically important gravel. A machine learning methodological routine, based on Random Forest for regression was set up. Three different models were tuned and built, and the best performing one selected for further analysis. The selected models were subdued to statistical accuracy assessments communicating the “goodness of mapping”, including corroborating the results with qualitative analyses aiding the interpretation, use and misuse of the final model output. The model quantifies an unforeseen degree of spatial detail for the distribution of gravel in this area and provides an adequate base-map to scientifically inform various aspects of maritime spatial planning, including offshore infrastructural development and policymaking, preventing conflict, and avoiding environmental impact.

Deep-sea benthic classification using structure from motion 3D point cloud and machine learning classifiers

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Deep-sea benthic classification can help with the management and monitoring of marine habitats and resources. The use of 3D point cloud with millions of points is currently emerging in deep-sea benthic classification as it allows for high-resolution representation of the 3D shape (i.e., geometry), texture and composition of complex benthic habitats. Benthic classification at high resolution can help decision makers develop appropriate conservation and management policies. However, these applications require automatic classification approaches with reasonable accuracy to ensure efficiency and robustness for accurate long-term monitoring. Machine learning (ML) classifiers are well suited to this task.

In this context, this research used ML classifiers for deep-sea benthic classification from 3D coloured point clouds. Underwater footage of two vertical walls was collected using a high definition camera mounted on a remotely operated vehicle at the Charlie-Gibbs Fracture Zone (CGFZ), a prominent topographic feature dividing the Mid Atlantic Ridge horizontally. Frames were extracted and used for structure-from-motion 3D point cloud reconstruction. The CGFZ consists of two parallel fractures which create a highly variable seafloor bathymetry, causing a heterogeneous environment, optimal for the colonization of cold-water corals and sponges. One of the walls exhibited a high abundance of corals, while the other exhibited a dense sponge aggregation.

Nine geometric features, such as linearity, planarity, and verticality, among others, were derived from the 3D point clouds. These features, in addition to the RGB values, were used to feed five ML classifiers trained on manual annotations of three categories: bare seabed, sponges, and corals. Results from Decision Trees (DTs), Random Forest (RF), Linear Discriminant Analysis (LDA), Quadratic Discriminant Analysis (QDA), and Gaussian Naïve Bayes (GNB) were assessed in terms of overall accuracy as well as recall, precision, and F1-score for individual classes. RF, LDA, QDA, DTs, and GNB obtained an average overall accuracy of 84.24%, 82.83%, 79.58%, 78.66%, and 76.50, respectively. The RF classifier outperformed the other classifiers in terms of overall classification accuracy as well as F1-score of individual classes with an average of 91.19%, 57.78%, and 56.55% for the bare seabed, sponges, and corals, respectively. Results showed that the incorporation of geometric features with RGB values are applicable for deep-sea benthic classification at high resolution. This can help improve marine protected areas management and contribute to ecosystem conservation.

Sen2TimeFusion: a remote-sensing image processing chain to improve deeper seafloor feature extraction using Sentinel-2 time-series imagery

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Coastal ecosystems are facing increasing environmental pressures and anthropogenic disturbances, leading to a worldwide degradation of their health. This situation generates an urgent need to improve methods used to study and monitor those ecosystems and their vulnerability to different stressors. Optical remote sensing (RS) is commonly used to map and monitor coastal benthic habitats. Because of limitations brought by water characteristics on individual satellite images (e.g., surface reflection, water column absorption, turbidity), RS images are often only useful to map clear shallow waters when light conditions are the most favorable. With rapid improvements in RS sensors and the acquisition of images over longer time series at high spatial and temporal resolutions, large collections of images acquired at a same site can be processed together to improve the ability to extract useful information on marine environments.

To deal with such large time-series of satellite data, we have developed processing chains that allow different levels of processing (data download, pre-processing for atmospheric and cloud effects, and production of indices and temporal statistics). In addition, the possibility of automating the various steps reduces human intervention and processing time, allowing computation over large regions and long periods of time.

Seafloor information was derived from a time series of selected cloud-free images in the blue spectral band, less sensitive to disturbances related to water characteristics (e.g., surface states and water quality and absorption). The signal to noise ratio was improved by averaging pixel values, revealing information on the seabed at greater depths than using traditional analyses of individual images. The number of images used (up to several hundred) determines the maximum depth up to which the seafloor can be perceived (beyond 70m in places). This novel method has been applied to remote areas of several islands of the Southwest Indian Ocean region (i.e., Reunion Island, Madagascar and Seychelles deep banks) that remained poorly mapped until now, providing important baseline data at these locations.

With the guarantee offered by the European Space Agency (ESA) that the Sentinel satellites will be maintained and the data will be available for many years to come, long time series will make it possible to carry out temporal analyses to highlight and quantify spatial and temporal changes in benthic habitats over large areas. Such analysis can greatly help inform management strategies for the conservation of many types of shallow benthic habitats, such as coral reefs and seagrass beds.

Towards a global shallow water habitat mapping of French overseas territories in Indian ocean

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Since the publication of the handbook for producing coral reef habitat maps (2016) the French overseas territories of the Indian Ocean have launched several programs to produce marine habitat maps on their territory. The maps were produced in Mayotte and Zélée, in the French Eparses Islands in Geyser, Europa, Glorieuses, Juan de Nova and Tromelin and in Reunion. Most of them have been carried out on shallow water (0-30m). Thus, 2249 km² of reef habitats (including the lagoon) were mapped between 2015 and 2023, ie 96% of coral reef. Concerning non-reef habitats like basaltic coasts, present almost exclusively in Reunion, more than half of them have already been mapped and the rest should be published in 2023. These habitat maps were produced from Pleiades satellite images, aerial images (spatial resolution 2m/0.5m) and bathymetry data from aerial Lidar surveys (spatial resolution: 1m) and acoustically data. In Reunion, the mapping of basaltic habitats, not visible on satellite images, was made possible by the use of bathymetric data. The habitat maps were produced by processing images, either by visual clipping, supervised classification or by processing bathymetric data (3D bathymetry, calculation of roughness, slopes, slope variance, etc.). Ground truthing was also carried out in most of the territories (underwater video, visual census in scuba-diving and snorkelling) to describe the dominant benthic communities in order to have a precise description of the communities assemblages corresponding to each island. In addition to habitats and coral cover maps, remarkable habitats (hot spot diversity, geomorphology), and the main substrates characterizing the surface available for the fixation of the sessile benthic fauna and flora, are also produced. In parallel with the production of the maps, the National Museum of Natural History and the French Initiative for Coral Reef are producing the typology of habitats for all the territories. The typology of habitats thus created will be referenced at the national level in the Natural Heritage National Inventory. A detailed sheet of each habitat has already been produced (description of the geomorphology, substrate, dominant and characteristic species, sensibility and pressures exerted on the habitats). It will thus be available and will make it possible to harmonize the habitat maps produced, in particular within the framework of the impact study. The maps are essentials for management and used for various purposes, like implementation and boundaries of Natural area of Interest and MPAs, large-scale coral reef health monitoring programs (like bleaching monitoring).

Preliminary development of standard reference areas for multibeam echo-sounder backscatter

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The Geophysical Survey and Mapping group, as part of the CSIRO, has determined a number of seafloor areas for the purpose of calibrating multibeam echo-sounder systems outside of the port of Hobart, Tasmania. This talk presents preliminary work caried out to investigate the suitability of the proposed referenced areas, consistency of data collected between different surveys and potential workflows to be used.

Resolution of Vulnerable Marine Ecosystem maps of the SW Atlantic deep sea – what do we miss if we cannot use shipborne bathymetry data and what are the consequences for Marine Spatial Planning?

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Deep-sea environments face increasing anthropogenic pressure and require mapping to support marine spatial planning that underpins ecosystem-based management and area-based conservation strategies, as called for by the UN 2030 sustainable development agenda goal 14. However, deep-sea environments remain poorly mapped, due in part to technological limitations and high costs of deep-sea sampling. Consequently, decisions regarding spatial coverage and resolution of mapping data often reflect associated deep-sea exploration costs that are inhibitive to broad-coverage detailed sampling. Yet, marine spatial planning routinely requires maps covering regional extents for which only broad-resolution model-derived data exists. Understanding the associated variability in map precision and accuracy from data of varying resolutions is important in informing management and monitoring strategies. Here, we build and compare Vulnerable Marine Ecosystem (VME) distribution maps from a complex slope environment in the SW Atlantic, using broad-resolution open-source data versus fine- resolution shipborne derived data.

Presence/absence matrices of VME indicator taxa were compiled from benthic imagery and fisheries bycatch data. For the broad-resolution mapping a suite of terrain derivatives were calculated from GEBCO bathymetry (400 m) and ocean chemistry extracted from global models (8 km). For the fine-resolution mapping terrain derivatives were calculated from seismic derived bathymetry (25 m). Environmental data coincident with megafauna location data were used to build Random Forest and MaxEnt ensemble models of key VME indicator taxa distribution. Predicted VME distribution maps derived from broad- and fine- resolution environmental data are compared in terms of precision and accuracy plus cost – benefit of maps when applied at scales of spatial management, to answer the question - are maps based on fine- resolution ship acquired data cost effective for deep-sea marine spatial planning purposes?

Automatic detection of fluid emission echoes in water column acoustic data using Deep Learning approaches

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Fluid emissions from the seafloor affect ocean chemistry and are involved in various geological processes, at active and passive continental margins. Precipitations from these sources (e.g. metallic sulfides) are potential mineral resources. Fluids emitted from the seafloor are involved in various geological hazards including earthquakes, sedimentary instabilities, and massive methane releases. For these reasons, detecting and locating the sources of fluid emissions is crucial. Hydrographic MultiBeam EchoSounders (MBES) dedicated to seafloor mapping can be used to record water column acoustic backscatter during surveys. Gas bubbles form so-called “acoustic plumes” in the echograms due to the impedance contrast between gas and seawater. Acoustic data is used to guide underwater exploration of seeps and associated geological structures. However, the volume of data generated by these sounders is colossal and involves considerable processing.

The data used in this work come from two surveys carried out by Ifremer, GAZCOGNE1 (Bay of Biscay, Aquitaine Basin) and GHASS2 (Black Sea). The water column data from GAZCOGNE1 was acquired using a Kongsberg EM302 MBES (transmission frequency of 30 kHz). The GHASS2 was completed using a Reason Seabat 7150 MBES (transmission frequency of 24 kHz). These sounders have shown their effectiveness and potential for indicating the presence of fluid emissions.

Recently, the deep learning approach has made significant performance gains in automatic signal and image analysis. These improvements are the result of the joint use of a large volume of labelled data and GPUs for fast processing. This work aimed to implement a deep learning algorithm that automatically processes acoustic data recorded by MBES, to detect fluid emissions in the water column. We tested two architectures based on a Convolutional Neural Network (CNN); networks particularly adapted to image analysis. We applied the technique known as transfer learning and used these networks to detect and localize boxes in the images.

Our preliminary results demonstrate the potential of this kind of algorithm for fluid emission detection. The results of training on Ifremer datasets were cross-validated and show promising results surpassing the state-of-the-art methods whichever MBES is used for training and validation. The algorithm is able to perform detections over the entire water column, including the region with acoustical artefacts (e.g. specular side lobes, various emission sectors). Moreover, operational tests on a recent survey carried out offshore Mayotte show that this method is easy to implement for almost-real-time monitoring or even exploratory purposes, in both industrial and research fields.

Mapping submarine vertical walls (cliffs) around volcanic Islands along the Mid-Atlantic Ridge using structure from motion

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The Azores archipelago landscape is a diverse topographic environment, forged by volcanic and tectonic activity. Vertical walls, cliffs and overhangs can be found on steep sided Island slopes and seamounts, forming unique habitats. Traditional remote sensing techniques from a nadir angle are not sufficient to map large vertical structures, and instead a horizontal looking approach and a 3D analysis is required.

The crewed submersible, Lula 1000 (Rebikoff-Niggeler Foundation) was used to collect images in a vertical boustrophedonic pattern (lawn mower pattern), with a forward facing camera. Using Structure from Motion, five 3D reconstructions of vertical walls were created (2 from the Island of Pico and 3 from São Jorge), with the largest reaching 40 x 10 m. In addition, transects from the dives were analysed to detect the frequency of vertical structures and their faunal assemblages, in order to detect how unique and common these habitats are.

The walls around Pico were characterised by pillow lava which formed localised overhangs and heterogeneity, whereas the walls around São Jorge had a flatter surface with frequent overhangs and incising crevices. To map important species and quantify how vertical, structurally complex and locally exposed the wall surfaces were, various terrain metrics were created from the 3D point clouds. Training point clouds were extracted from the wall to reflect the walls geological characteristics and presence of prominent structure forming taxa (often Vulnerable Marine Ecosystem indicator taxa): basalt rock, sediment, black coral, structure forming sponges (*Forrea occa* and *Aphrocallistes* sp.), encrusting sponges, reef forming scleractinians and bivalve aggregations. A supervised Random Forest classifier model was used to create a classified 3D point cloud which had an accuracy of 98% on subsampled cloud independent data and 80% on true independent data. The classified point clouds revealed an extremely heterogeneous environment, with habitat preferences for certain species, indicating niche partitions. Important habitat-forming species such as black corals (*Leiopathes sp.*), scleractinians (*Desmophyllum pertusum*) and sponges were observed in high densities on the walls but were generally sparser in the surrounding horizontal habitats, indicating that vertical walls, which were frequently found at some sites, support a diverse and abundant benthic community. We discuss our results in the context of the regional biodiversity patterns and how classified point clouds can progress our understanding of heterogeneous environments.

Developing high-resolution point cloud and 3D modeling for the application of marine growth monitoring on ecological concrete infrastructure

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ECOncrete has developed and validated a nature-inspired solution for both thriving ecosystems and high-performing concrete structures. The science-based innovative technology provides fully structural, bio-enhancing concrete solutions designed to encourage the development of rich and diverse marine life as an integral part of Coastal and Marine Infrastructure (CMI) such as seawalls, breakwaters, and urban/industrial waterfronts. ECOncrete blends extensive and continuous R&D efforts, including biological and environmental monitoring of multiple installations. To date, biological monitoring to determine marine growth, live cover, and biodiversity has required the effort of several divers collecting data on-site followed by data analysis. ECOncrete and ID OCEAN have partnered with the aim of developing a more efficient monitoring scheme, setting a new standard for the biological monitoring of CMIs.

The SEABIM® numerical process, patented by ID OCEAN, automatically finds the position and orientation of a repeated known 3D shape with a centimetric accuracy in a high-resolution point cloud generated by a multibeam or photogrammetry survey underwater. This particularly applies to concrete units shaping the armour of a breakwater or revetment. Since the 3D model of the whole armour is generated, one can create a differential point cloud between the model and the original point cloud. A proof-of-concept was done on a project in La Réunion in 2021. By doing so, the outcrops appear distinctively on the blocks. They can thus be analysed with quantified marine growth development indicators.

The aim of the ongoing project is to apply this technology to current ECOncrete projects previously installed. On-site measurements and data processing will take place from February to April 2023. The main objectives will be to define the biological indicators and to compare the accuracy, application, and limitation of both underwater photogrammetry that can easily be applied on a small scale and close-range multibeam scanning that can be generalized to large structures with high efficiency and at a lower cost.

Whales cause millions of seafloor pits

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Seabed pockmarks are among the most prominent morphologic structures in the oceans. They are usually interpreted as surface manifestation of hydrocarbon fluids venting from sediments. However, in many places the geological setting does not support fluid venting. Here we suggest an alternative hypothesis of pockmark formation based on latest shallow water multibeam echosounder data with a centimeter range resolution. In the North Sea, >40,000 enigmatically shaped shallow depressions or ‘pits’ with a mean depth of only 0.11 m were documented, that do not resemble known pockmark morphologies. Combining the new echosounder data with information from behavioral biology, physical oceanography, satellite remote sensing and habitat mapping, we conclude that harbor porpoises excavate significant amounts of sediments during benthic foraging within a large sandeel habitat by poking the seabed, thereby initiating pit formation. Time-lapse data reveals that the initially small feeding pits serve as nuclei for scouring and eventually merge into larger scour-pits. Given the immense number of bottom-feeding vertebrates in the ocean, such megafauna-driven macro-bioturbation reshapes the seafloor, modulates sediment transport, and ultimately impacts associated ecosystems on a global scale.

Seafloor morphology mapping in the Gulf of St Lawrence, Canada, using machine learning approaches

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Detailed seafloor morphology maps can be strong predictors of benthic community patterns and are valuable for guiding conservation activities. The increasing availability of multibeam echosounder (MBES) data has facilitated the production of continuous-coverage maps of seafloor geology, but these data can be cost-prohibitive to collect and as a result are not always widely available in coastal regions. Legacy bathymetric datasets - often collected using single beam echosounders and combined with seafloor sediment samples – can be used to train machine learning algorithms to generate broadscale morphology and substrate maps. Blending MBES datasets with these bathymetric legacy datasets can produce a more complete coverage of a given region. Here we discuss the use of a classification random forest on legacy sediment grain size data to generate broadscale maps of sediment distribution. We have also tested a novel blended machine learning method of applying k-means clustering to a principal component analysis output to convert bathymetry data into seafloor morphology classes. Bathymetry was acquired from the General Bathymetric Chart of the Oceans (GEBCO), which is compiled from many different data sources using multiple methods of acquisition. The morphology classification identified most morphological features (e.g., footslopes, shoulders, channel floors, planes) but could not discriminate valleys and canyons from other classes. Overall, these methods prove useful for generating seafloor maps from legacy datasets.

A multi-disciplinary approach to assessing reef-scale drivers of biotic communities on Blood Reef (Durban, South Africa)

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A fine-scale understanding of the complex dynamics of marine ecosystems and the natural drivers of ecosystem structure and function are needed to better understand the impacts of human pressures on these systems. Further, there is a need to understand the relationship between environmental and habitat characteristics and biological communities, to make predictions of species distributions for conservation planning. However, very few studies merge geology and biology. The aim of this paper was to conduct fine-scale biophysical and geological mapping of Blood Reef (Durban, South Africa) to determine reef-scale drivers of fish and benthic communities. Fish and benthic community data, collected with baited underwater remote stereo-video systems, were combined with hydroacoustic and geological survey data, which were used to calculate physical characteristics and bathymetric derivatives of Blood Reef. These data were also combined using a unique and novel machine-learning algorithm to produce a biophysical benthic habitat classification of Blood Reef. Biotic communities were associated with different benthic habitats, mostly related to depth and substrate type, but fine-scale differences in bedrock and geological characteristics did not appear to drive fish community assemblages, as expected. Derivatives such as slope and rugosity appeared to affect fish and benthic assemblages, but broad-scale habitat types were better predictors of biotic communities. This is one of few studies to apply a truly multi-disciplinary approach to assessing an integrated structure of rocky reefs, considering biological and geological elements of the ecosystem and we demonstrate the value of this approach through results that are useful to both disciplines.

Production of an updated coastal resource atlas and marine spatial planning tools for the British Virgin Islands

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The British Virgin Islands have an extensive and varied marine estate. The updated Coastal Resource Atlas (CRA2) is the first full-coverage marine map for the entire Exclusive Fisheries Zone of the BVI. The preparation for this product included making a harmonised bathymetric surface (merged from both LiDAR and multiple deep and shallow water multibeam echosounder surveys) and the collation of additional environmental layers (predictor variables) such as optical satellite imagery (Sentinel 2), mission composites for turbidity (MODIS Aqua), high resolution modelled seabed hydrodynamics (U and V combined with seabed aspect to calculate total exposure), temperature and salinity. Given the importance of episodic hurricanes on coral habitat, historical storm tracks were used to estimate an extreme storm wave base, which was also used as a predictor variable.

For training data, over 500 historical observations and 340 additional stations, visited during fieldwork in 2022, were combined before being randomly allocated to either a training (75% of the observations) or validation dataset (the remaining 25%). Random Forest models for substratum (a classifier model of sand, fine sand/mud, coral rubble and rock/accreted rubble surface) and regression-type models for hard corals, soft corals, seagrass (three assemblages include the invasive species *Halophila stipulacea*) and several macroalgae. The predictor variables were used for estimating the ‘disturbance’ and ‘scope for growth’, which are the two composite variables considered necessary to build an ‘ecological template’ (a 2-dimensional state-space) that could predict the diversity, body size, sensitivity (to ecological and anthropogenic pressures), and certain life history characteristics of benthic assemblages (estimated within this study).

To accompany the new CRA, a toolbox of Marine Spatial Planning tools (produced in conjunction with the Ministry of Natural Resources and Labour (BVI), the Joint Nature Conservation Committee (UK) and WSP Global Inc.), that has been calibrated for marine habitats (as included in the new CRA) and human activities in the BVI. These tools will allow local policymakers to exploit fully the new Coastal Resource Atlas, quickly draft marine spatial plans and bring about a step-change in marine management capabilities locally.

Using AUVs for sediment, habitat and object mapping – prospects and challenges

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The MAREANO programme acquires a wide range of seabed data, including ship-based multibeam (bathymetry, backscatter and water column data), videos, sub-bottom profiles and samples. We are now investigating whether the use of autonomous underwater vehicles (AUVs) can improve the quality of our seabed mapping and make it more efficient.

NGU has sporadically used HUGIN AUVs from Kongsberg Maritime in cooperation projects with the petroleum industry, mainly focused on identifying gas seeps and surficial structures associated with the seeps, such as carbonate crusts. Some AUV test surveys using Hugin for Mareano were done in 2015 and we have also used AUVs in coastal projects for identifying UXO. In 2021 two Munin+ AUVs were acquired by our MAREANO partner the Institute of Marine Research, and these are now available to the Mareano programme. The Munin+ is smaller than the Hugin AUVs, but is still well equipped, with sensors such as EM2040 multibeam echosounder, HiSAS2040 synthetic aperture sonar, Edgetech SBP, Cathx still image system and environmental sensors.

Mareano test-surveys using Munin+ started in summer 2022 off mid-Norway. The plan was to investigate different settings, including a challenging slide terrain on the slope, and coral reefs on the shelf. Technical issues reduced the number of successful dives, but nevertheless demonstrated the potential for establishing an observation pyramid, starting at the base with ship-based multibeam data at full water depth, then AUV-based multibeam and HiSAS data flying 15 to 25 m over the seabed, and finally still photos combined with acoustics flying 4 to 5 m over the seabed.

Further testing with Munin+ will be done in 2023 in the North Sea complementing traditional surveys. Some of the primary targets will be tobis (sand eel) habitats, assessment of seabed disturbance caused by bottom trawling and possible anthropogenic objects or gas seep features identified from multibeam data.

One of the important prospects for using AUVs is to replace the current methodology with towed video platforms recording 200 m of seabed, with much longer lines where georeferenced still images are recorded in a format suitable for automatic classification using AI. We also expect that the acoustic information provided by the EM2040 and HiSAS2040 will improve our capability to link the detailed seabed observations of both geology and biology covering small areas, to the complete area coverage provided by the ship-based multibeam data. The biggest challenge is probably that AUVs are not well suited for rugged terrains.

Combining drone and underwater camera photogrammetry to map coral reef complexity at centimeter resolution over large extents

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Underwater photogrammetry by Structure-from-Motion (UWP-SfM) allows high resolution mapping of physical and ecological characteristics of coral reef ecosystems. However UWP-SfM is resource and time consuming, precluding the mapping of large areas. Aerial surveys using Unmanned Aerial Vehicles (UAVs, also called *drones*) allow to map large extent of reef ecosystems but at a lower resolution. Combining these two technologies could provide a significant boost in our capacity to understand and preserve the functioning of coral reef ecosystems. Here, we investigated the relationships between habitat descriptors: fractal dimension (FD), surface complexity (SC) and slope (SL) derived from UWP and UAV-based Digital Elevation Models (DEMs) at two sites around Mayotte island (Western Indian Ocean). We first asked how do DEMs descriptors obtained via UAV and UWP relate to each other ? Then we investigated how far one can use these relationships to: i) bias-correct UAV-based descriptors and ii) downscale UAV-based DEM descriptors to the resolution attained by UWP.

At 2 sites Île-Blanche (IB) and Surprise (SU), photogrammetry sampling were conducted by two acquisition techniques: underwater protocol on SCUBA-dive (small scale and high resolution) and drone surveys (DJI-Mavic2-Pro, large scale and low resolution). UWP-DEMs and UAV-DEMs have been warped using the UWP sampling extent and UAV sampling resolution. We then subdivided the DEMs in the same tiles ($1m^2$) and calculated physical descriptors (FD, SC, SL) for each tile at each site. We used linear models and non-parametric ANOVAs to investigate the relationships between UAV-based and UWP-based values. First, we used simple linear regressions to test "tile by tile" relationship. Second, we use Wilcoxon-tests to compare the distributions of UAV-based and UWP-based descriptor values. Third, we used polynomial regressions using ranked descriptors values (lowest to highest values) to investigate the relationships between the spread of UAV-based and UWP-based descriptor values.

We show that "tile by tile" relationships are week for all descriptors and across all sites (all $R^2 < 0.2$) Further, Wilcoxon-tests revealed that UAV always underestimate significantly the descriptor values However, for all descriptors and across all sites the relationship between ranked descriptor values is strong and provide substantial predictability (all $R^2 > 0.9$). These strong and predictable relationships between ranked descriptors were then used to bias-correct and map UAV-based descriptor values over the full extent of UAV surveys. Finally we used statistical downscaling to exemplify the mapping of habitat descriptors at the UWP sampling resolution over the UAV sampling extent.

Photogrammetry temporal monitoring in the deep sea reveals the fine-scale variability in hydrothermal vent assemblages

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Imaging the seabed is an efficient approach for identifying the scales of spatio-temporal dynamics of deep-sea benthic assemblages. However, the lack of resolution in 2D images has long prevented the characterisation of the drivers of change at fine scales (i.e. from cm to dm scales). Hereby, we make use of 3D annotations performed on a pioneering pluri-annual time series of photogrammetric reconstructions obtained in 2015, 2018 and 2020, to acquire a fine-scale comprehension of the environmental drivers of vent fauna dynamics at the active Eiffel Tower sulphide edifice (Lucky Strike vent field, Mid-Atlantic Ridge).

Over the 5 years of monitoring, microbial mats underwent an overall decline, possibly in relation to magmatic events. In contrast, mussel cover was highly stable, extending our observation of this climax population to 25 years. Despite high stability of the vent edifice, environmental variability occurred at specific locations. It predominantly consisted in infra-metre scale changes in vent activity, resulting from the opening or closure of vents or linked to the progressive accretion of sulphide material on spires and flanges. Vent mussels seemed to respond to these changes by adapting their position in the immediate vicinity of vent exits. As a result, the overall mussel population was able to maintain itself and cope with the fine-scale variability of vent activity. Furthermore, consistent successional patterns between time steps of observation suggested the dynamic equilibrium of the ecological system. Those results confirm the low regime of disturbance and high stability of vent assemblages at the Lucky Strike vent field and potentially at the scale of the MAR slow-spreading ridge. They question the resilience of the vent ecosystem towards large-scale disturbance that could arise from anthropogenic activities such as deep-sea mining.

Deciding where to sample – the 'science' behind selecting abyssal sampling sites using multifaceted mapping support

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Benthic sampling and equipment deployment at abyssal depths is a specialised and complex undertaking. Supporting these operations using modern remote sensing techniques is challenging, yet critical, for deep-ocean research, however the 'science' behind the science can be taken for granted. Here we present a technical overview of the mapping intricacies involved in abyssal research and how Australia's leading Science Agency, CSIRO, and its Marine National Facility (MNF), supports this aboard Australia's blue-water research vessel RV *Investigator*.

CSIRO and the MNF support a range of marine research within and beyond the Australian EEZ. Voyages often require sampling and equipment deployments at abyssal depths (> 3000 m), particularly for biological or geological studies. Conducting research at these depths demands significant ship time, and meeting voyage objectives within specific time and weather constraints can be supported through a well-designed mapping and site selection program. Determining suitable sampling sites to yield positive scientific outcomes therefore involves intricate planning, dedicated onboard resources and the support of specialist technical teams.

Unlike continental shelf environments where multibeam echosounders provide very high-resolution data that enables benthic habitats to be mapped to <5 m, the abyssal region can typically only be mapped at coarser horizontal resolutions of ~50 m to 120 m with current ship-based multibeam echosounder technology. This introduces challenges for focused and fine-scale sampling methods such as benthic trawls, rock dredges, sediment coring and towed camera work, particularly in previously unmapped regions and in rugged seafloor topography. The integration of multiple data types through reconnaissance mapping, significantly increases available information for characterisation of the benthic environment for successful targeted sampling and instrument deployments. CSIRO uses various specialised tools to facilitate this, including operating a suite of systems such as mapping echosounders, biological echosounders and a sub-bottom profiler. Processing workflows for bathymetry, backscatter, water-column, and sub-bottom data are tailored to specific deployment types, and typically a 3-D integrated visualisation of the benthic environment is created, on-the-fly, to support critical decisions for optimal sampling locations to meet the scientific objectives.

We present CSIRO's operations model and provide examples of the support to science teams for several abyssal sampling programs, including successful and non-successful deployments, to highlight the challenges and risks associated with site selection in deep water environments. With continually advancing technologies, we also discuss our adaptations for future improvements, through the MNF 2030 strategy, to continue supporting vital deep ocean research in and around Australia.

Ecological Coastal Units: a global ecological classification of 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 landside, waterside, 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.

The data allows for the visualization, query, and rigorous comparison 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) primarily 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.

This presentation will review the resource, describe how it can be accessed, and present brief analytical vignettes of coastal and marine applications.

A glance at the seafloor with multibeam bathymetry; within and outside the uThukela Banks MPA region in South Africa

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The preserved shallow seafloor reef complexes and palaeoshorelines of the uThukela Banks Marine Protected Area (MPA) of South Africa have varying structures that are yet to be revealed and documented in literature, due to poorly resolved resolution of earlier data acquisition techniques. South Africa has a sizeable exclusive economic zone (ca. 1,547,576 km^2) but only very limited portions of this have been mapped in high resolution. The relative lack of detailed hydroacoustic data is perhaps due to matters of funding, but also an underrepresentation of skills required to collect, process and interpret multibeam echosounder (MBES) data and communicate the value that can be derived.

In this project, surveyed areas of ~200 km^2 include palaeoshorelines, consolidated reef complexes and unconsolidated shelf sediments at depths between 10 and 100 m on the East coast of the South African shelf. MBES data have enabled us to explore resolved seafloor geomorphology of high spatial detail and to regionally define its substrate. The rugged geomorphological character of the reefs has the capability to influence the flow path of bottom currents which leads to sediment processes forming various types of bedforms in the area as well. The analysis of these reef complexes and palaeoshorelines shows variation in structural surface appearance and relief above the seabed. The observed variations suggest that they likely provide several biological niches for a range of species. The mapping of the uThukela Banks MPA's palaeoshorelines is important for quantifying the interplay between the rate and nature of sea-level rise and depositional characteristics of those shorelines when they were active. These investigations provide a preview of how modern coastlines may respond to current and future sea-level fluctuations, since sea-level rise is a certain consequence of global warming.

This contribution aims to discuss 1) the results and value of the seafloor mapping (with MBES) within the uThukela Banks MPA, at different levels of protective restriction, and 2) the geomorphological variations and preservation of these reef complexes and their possible contributions to shelf biodiversity and ecosystem functioning.

The footprint of anchoring on the seafloor

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With the SARS-CoV-2 coronavirus came what media has deemed the “port congestion pandemic”. Since it began, thousands of ships have been reported waiting outside heavily congested ports relying on anchoring gear to hold fast. While the shipping industry is known to contribute to air, water and noise pollution, the physical impact of shipping practices, such as anchor use on the seafloor, has received much less attention. With a regional survey using high-resolution (1 m) bathymetry data of a comparatively low congestion port in New Zealand-Aotearoa, we demonstrate that high-tonnage ship anchors excavate the seabed by up to 80 cm and the associated impacts are preserved for at least 4 years. This is the first characterisation of the intensity and extent of damage to the seafloor and benthic environment caused by high-tonnage ship anchoring. We demonstrate that the observed seabed damage is attributed to high-tonnage passenger and cargo vessels. Anchor use in port regions has significantly changed the structure of the seafloor, with downstream impacts on benthic habitats and ecosystem functions. Extrapolating these findings to a global scale, we estimate that between 6,000 and 20,000 km^2 of coastal seafloor is adversely affected. With the predicted increase in global marine traffic, a less destructive method of managing high-tonnage vessels awaiting port calls is necessary to mitigate the impact of maritime activities on chemically and biologically important shallow marine environments.

A simple geo-acoustic inversion method based on the normalized grain size

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In March 2019 Teledyne RESON and the Applied Physics Laboratory University of Washington (APL-UW) conducted measurements with a T50-P multibeam echosounder (MBES) in Sequim Bay, a sheltered bay in Washington State, USA. Ten sites with different sediment types within an area of approximately 2x2km^2 were chosen. Amongst a variety of ground truth collection types, core samples provided grain size data. At each site the MBES obtained estimates of the backscattering strength (S_b) at frequencies between 200-350kHz in 50kHz steps. The backscattering strength has been plotted as a function of the logarithm to the normalized grain size, i.e., log10(d/λ), where d is the mean grain diameter and λ is the acoustic wavelength. At a 45° grazing angle the results have been compared with results obtained by other researchers (JASA Express Lett. (**3**), 026001). It has been found that S_b increases linearly with log10(d/λ) for d/λ between 0.001-0.1. For d/ λ > 0.1 no data from Sequim Bay exists but results from the literature indicate that S_b fluctuates around minus 15dB for d/λ-values between 0.1-10. Hence, the linear relation only exists when the acoustic wavelength is 10 times greater than the mean grain diameter. Corresponding linear relations have been found for grazing angles between 20°-70°. For grazing angles between approximately 70°-90°, the simple linear relation is not valid (JASA Express Lett. (**3**), 026001), as S_b increases with the mean grain diameter, but also decays with frequency. Finally, in 2021 new surveys were conducted. The surveys were not just limited around the ten sites, but they covered a major part of the 2x2km^2 test area at Sequim Bay. Based on the 2021 data set, a map of the estimated grain size has been produced. Here the map will be compared with a map of the density ratio obtained by model-based geo-acoustic inversion ("Demonstration of a physics-based sediment property inversion algorithm applied to multibeam echosounder data", Hefner et al.,24th International Congress on Acoustics (ICA), 2022).

Restoring a buried reef: using benthic habitat mapping to design, build, and monitor an artificial reef

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Palos Verdes Reef (PVR) is an artificial reef designed to restore rocky-reef associated marine species by directly restoring rocky-reef habitat that has been impacted by scour, sedimentation, and burial in the shallow subtidal portion of the Palos Verdes Peninsula in Los Angeles County, California, USA. Following over a decade of design, planning, outreach, site surveying, and permitting, the reef was built in 2020 as 18 discrete modules using 52,729 tons of quarry rock placed approximately 8–80 m from existing, unburied rocky-reef habitat. This project was a unique endeavour as restoring lost habitat in situ and has not been attempted in a temperate rocky reef and kelp forest community. While the primary design criteria for PVR was fish production in an area where already-limited hard substrate had been lost, it was also designed to be resilient to ongoing sedimentation and turbidity challenges on the peninsula. Bathymetric and side scan surveys were performed once prior to construction and annually thereafter. Using the mapping data, we identified prime locations for reef module placement: areas that are buried in a thin (< 1 m) layer of sediment and adjacent to existing, unburied rocky-reef habitat. Modules were positioned in a formation that followed the natural orientation of existing hard substrate to allow sediment to pass through without settling and were designed to mimic a nearby natural high-relief seafloor feature that has proven to be resistant to burial and sedimentation while also featuring the highest fish biomass of any rocky reef in the region. Rocky-reef associated taxa rapidly recruited to the restoration site, with visible changes occurring within just a few months post-construction. This rapid addition of understory and canopy-forming kelps to the newly added substrate poses a challenge for collecting and processing both bathymetry and side scan data. However, the data showed that there was no significant accumulation or scouring of sediment due to the placement of the reef and the quarry rocks have not moved, subsided, or been re-buried in the following years.

Mapping fish beta-diversity across marine protected areas off Victoria, Australia

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Maps of broad scale biodiversity patterns in marine ecosystems are important to marine spatial management, especially in regard to marine protected areas (MPAs), which are usually set up to protect biodiversity. In this study, we used generalised dissimilarity models (GDMs) that combined fish community assemblages across Victoria, Australia with environmental parameters to determine those factors driving commonalities and dissimilarities in biodiversity. The fish observation data were collated from several Baited Remote Underwater Video Station (BRUVS) surveys conducted across the state at >1200 locations both inside and outside of marine protected areas and provided information on the individual species or species groups and their abundances. Environmental data included seafloor habitat metrics (e.g., depth, reef complexity, distance to reefs) along with temperature, wave environment, oceanic currents, and chlorophyll α. After running the GDMs, we used principal component analysis and a spatially explicit, hierarchical cluster analysis to classify the Victorian coastal waters into unique fish communities. The GDMs explained >30% of the variation in beta diversity with patterns explained by seafloor structure, distance to reef, temperature, waves, and currents. The resulting maps show that there is an east to west turnover in communities that is also driven by differences in habitat and depth. The clustering and principal components analysis revealed 19 distinct communities along the coast. These maps are now being used to determine the representation of fish communities captured across the Victorian MPAs and have the potential to provide guidance for marine spatial planning around offshore energy development.

ABSTRACTS OF POSTER PRESENTATIONS

The submerged karst seascape off the Gargano promontory and their biota (Adriatic Sea, Italy)

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The Apulian shelf offshore (South Adriatic Sea, Italy) is a submerged platform of Cainozoic origin predominantly carbonate. This area suffered several episodes of emersion and drowning during the Pleistocene Epoch, and the rough topography of the study area has been interpreted as relic karst formed during a lower sea level stand. The study area, located 6 km offshore the city of Vieste around 41°59' N – 16°15' E with depths ranging from 50 to 105 m, covers a surface of ca. 220 km^2 whose, the main karstic bedforms are several circular depressions interpreted as drowned dissolution features (dolina). The 'Oyster Pit' is the major one, characterized by a circular funnel-shape of 120 m of diameter with its top at ca. 50 m and its bottom at ca. 75m. The 'Oyster Pit' owes its name to the high density of deep-water oyster, the gryphaeid *Neopycnodonte cochlear* (Poli, 1795), colonizing its rims, flanks and bottom. *Neopycnodonte cochlear* colonize extensively also the shelf with smaller reefs of 1–2 m in length and width, and maximum height of 0.5–1 m. Oyster densities attains at ca. 348±100 ind·m^{-2} and ca. 200±158 ind·m^{-2}, respectively. Despite intense investigation on littoral oyster reefs (e.g., *Ostrea edulis*), information on intermediate (mesophotic) *Neopycnodonte cochlear* reefs is still comparatively scant. However, as their shallower counterpart, they represent a biodiversity hotspot and their ecosystemic value call for the enforcement of adequate protection and management measures to ensure their survival. This approach would be in line with European recommendations for "H1170 Reefs" in the Annex I of the Habitats Directive 92/42/EEC on the conservation of natural habitats and of wild fauna and flora and in the recent the Convention on Biological Diversity and the EU Biodiversity Strategy for 2030. The inclusion in protected areas of the site of Vieste would ensure the preservation of these important bioconstructions in the mesophotic zone of the Mediterranean Sea.

Spatial predictive modelling of coastal habitats of Norway

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Mapping marine seafloor biodiversity and habitat structure is pivotal for determining ecological status of coastal habitats and understanding the main drivers of spatiotemporal variation in benthic communities. These are essential steps for management and conservation of coastal ecosystems and such mapping products are currently in demand for aerial planning to achieve sustainable development goals on the Norwegian coast. To quantify seafloor habitats and macroepifauna species composition we conducted geological and biological mapping surveys on 670 sites along three areas of the Norwegian coast, Stavanger (59°12'17.5"N, 5°47'32.9"E), Sunnmøre (62°41'20.3"N, 6°20'20.0"E) and Troms (69°59'44.7"N, 20°55'03.9"E). These surveys are part of the Norwegian pilot-project “Marine base maps for the coastal zone”, which is a collaboration between the Norwegian Mapping Authority (Kartverket), the Geological Survey of Norway (NGU) and the Institute for Marine Research (IMR). The dataset is based on interpretation of 50 m video transects collected by ROV, drop camera and underwater drones, depending on depth. Habitat classification followed the *Nature i Norway* framework (NiN). Occurrence data on species and habitats were correlated with sediment and oceanographic properties to build spatial distribution maps using predictive multivariate generalized linear models (MGLM). Models predicted variation in seafloor major habitats with an accuracy of 75%. Bathymetry, median wave bottom impact and the percentage of mud, gravel and hard substrate were the most important covariates. Further analyses will test potential relationships between heterogeneity of habitats with variations on beta-diversity and community structure at local and regional scales.

Mapping of benthic foraminifera: an application to soft bottom benthic habitat (Laizhou Bay, China)

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This study proposes to use benthic foraminifera collected from bottom sediments to map foraminiferal biotopes with the aim of better understanding and quantifying the ecological status of the ecosystems of Laizhou Bay (Bohai Sea, China).

Mapping of foraminiferal biotope allows identification of areas characterized by uniform physicochemical characteristics in which a specific species assemblage lives. Each biotope is defined by a unique combination of foraminifera species with different levels of abundance and diversity. For example, Biotope 1 is characterized by the greatest abundance of *Ammonia beccarii*, a species that tolerates large fluctuations in salinity and temperature and, therefore indicates a particular type of marine habitat. Biotope 2 is dominated by *Quinqueloculina akneriana* and *A. beccarii*, and Biotope 3 by *Porosononion granosum*, *A. beccarii* and *Quinqueloculina seminula*. Biotope 4 and Biotope 5, at the eastern part of Laizhou Bay, have a higher species diversity than the other biotopes and the main species are *P. granosum*, *Cribroelphidium magellanicum*, *A. beccarii*, and *Q. seminula*. But in Biotope 5 there is a significant content of sensitive species, such as *Triloculina trigonula* and *Buccella frigida granulata*.

The distribution pattern of biotopes highlights the ecological stress caused by pollution and the mixing of marine and fluvial waters in Laizhou Bay. Biotopes closest to the Yellow River delta had few individuals and a low diversity index, while biotopes farther from the river mouth had a higher abundance and species diversity. This pattern is consistent with the Foram-AMBI (Marine Biotic Index based on Foraminifera) values, calculated using the main benthic foraminiferal taxa. The Foram-AMBI values indicate that the ecological quality of the marine soft-bottom habitats is better in the areas farthest from the mouth of the Yellow River. The Foram-AMBI value varies between 1.5 and 2.5, indicating a good ecological quality status of the analyzed habitat.

In summary, this study highlights the usefulness of benthic foraminifera as ecological indicators for environmental monitoring by providing a detailed picture of the distribution and ecological quality of marine soft-bottom habitats in Laizhou Bay. Mapping foraminiferal biotopes provides information on the specific characteristics of different marine habitats and the temporal changes in these habitats, which can be used to support conservation and management decisions.

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The Development and Implementation of a Methodology For the 3D Monitoring of Steep Coastal Cliffs

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Despite cliff environments comprising more than half of the world's coastlines, few studies have used an extensive timeseries of a steep coastal cliff to investigate morphological change across the entire extent of a cliff face through time. To gain a full perspective of a steep cliff face, analysis must use a 3-Dimensional model. However, methods of collecting 3D data in the past have utilised LiDAR sensors which are associated with limitations around cost and user skill requirements that restrict the temporal resolution of datasets. Unmanned Aerial Vehicles (UAVs) have provided an alternate avenue to collect 3D spatial data that overcomes the limitations of LiDAR. This has allowed the generation of high spatio-temporal resolution datasets for coastal cliff environments. However, a timely workflow that analyses change detection across a high quantity of 3D datasets for steep coastal cliffs is yet to be established.

This study utilised a timeseries spanning over four years (N=30) for the Demons Bluff cliff located on the Great Ocean Road, Victoria, Australia. Data was collected every 6-8 weeks with a UAV flown by citizen scientists as part of the Victorian Coastal Monitoring Program. This permitted the development and implementation of a methodology that was able to identify patterns of change across the cliff face. In regions where the timeseries was complete, precursory deformation was identified prior to high magnitude (>300 m^3) collapses with high success (89%). Deformation was found to occur from the expansion of tension cracks several meters behind the cliff top or from rock slabs fracturing and cleaving away from the cliff face. 14 additional instances of deformation yet to result in collapse were also identified. Cliff retreat was shown to be initiated by cliff-top collapses, often exceeding 1,000 m^3, that terminated mid-way down the cliff face. Below this point, several slab detachments would follow, that overtime, reinstated the cliff's steep slope.

This study highlighted the potential offered from the use of UAVs in coastal cliff monitoring through their cost effectiveness and ease of use that permits the generation of high spatio-temporal resolution timeseries. This permitted the identification of precursory deformation preceding collapse, which to our knowledge, is yet to be observed in coastal cliff data collected by a UAV. This could facilitate the development of an early warning system that detects regions where collapse is likely and aid in the management of volatile cliffs areas that post threats to infrastructure and public safety.

A new GIS tool to classify Mediterranean benthic habitats

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Nowadays any accurate production of benthic habitat maps should respond to the growing need for spatial management of the marine environment and resources. As such, international agreements often require marine habitats catalogs/classifications easily applicable to the conservation and management of marine ecosystems. For instance, European countries are asked to provide lists of marine species and habitats distributed in their waters in order to meet the Marine Strategy Framework Directive (MSFD - 2008/56/CE).

Several habitat classification systems and/or mapping protocols, developed by governmental institutions and international mapping programs, are available to date. Cases in point are the scheme proposed by Greene et al. (1999) for deep sea habitats, the ("A classification scheme for deep seafloor habitats." Oceanologica Acta 22.6 (1999): 663-678) e Coastal and Marine Ecological Classification Standard (CMECS: https://cmecscatalog.org/cmecs/), or the Collaborative and Automated Tools for Analysis of Marine Imagery (CATAMI), based on marine imagery, developed for Australian benthic substrates and biota (https://github.com/catami/classification). Regarding Europe, the most widespread schemes are the European Nature Information System (EUNIS; https://eunis.eea.europa.eu/) and the Mapping European Seabed Habitats (MESH).

Considering strengths and limitations of most of available classification schemes, often of impractical or difficult use in the GIS environment and at multiple scales, we have generated the CoDeMap Habitat Classification Scheme, a new hierarchical and multiscale classification tool. CoDeMap focuses on Mediterranean and Black Sea benthic habitats from coastal to bathyal depths, and takes into account three main components driving the habitat distribution, geomorphology, substrate and biology. This new classification scheme allows the user to map the different components of a benthic habitat separately, at different scales and keeping the possibility to integrate them into a single map to get a full picture of a marine habitat. Applications to different study areas from the Mediterranean Sea and at different scales are presented here.

A multiple-model machine learning approach with increased interpretability for spatial prediction of polymetallic nodules using hydroacoustic and optic data

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Deep-sea polymetallic nodules are of high interest as they contain metals (e.g., Ni, Co, Cu) that are needed for green and decarbonized technologies, such as electric cars and wind turbines. Within the contract areas in the Clarion-Clipperton Zone (CCZ), high-resolution predictive spatial mapping has a key role in mining-block prioritization. Moreover, it significantly contributes to ecological studies as the varying abundance of polymetallic nodules is associated with the abundance and biodiversity of deep-sea benthic fauna.

The first deep-sea *in-situ* trial of the Patania-II pre-prototype nodule collector vehicle, which was conducted by DEME-GSR in the Belgian contract area for polymetallic nodules in the CCZ, provided the unique opportunity to study in detail the spatial distribution of polymetallic nodules in morphologically complex terrain using hydroacoustic, optic and ground-truth data. Two different platforms (ship and autonomous underwater vehicle) and three different MBES and SSS frequencies were used (12kHz, 230kHz, 400kHz) to extract the backscatter response in areas with a varying abundance of polymetallic nodules. These data, combined with bathymetric and backscatter derivatives and ≈ 30,000 training samples, were used to train 5 different machine learning models (GLM, GAM, SVM, RF, ANN). The training samples were derived from HD seafloor images that were analysed with the H^{2}SOM algorithm to return, among others, the polymetallic nodules number (#), bin sizes (cm), and seafloor coverage (%). All models were trained considering the spatial autocorrelation and feature space clustering, while the geographical areas of feature space extrapolation were detected. State-of-the-art techniques were used to increase the model's interpretability, including multidimensional partial dependence plots, k-means++ clustering, and Shapley values parallel to eyeball and statistical tests. The model outputs were confirmed using set-aside data and physical samples such as box corers.

The results show that the used backscatter frequencies can clearly discriminate the areas with different abundances. The ensemble modeling provides a detailed mapping of the spatial distribution of polymetallic nodules, overcoming each model's limitations. The interpretable machine learning offered valuable insights into the drivers behind the distributional patterns and the advantages and disadvantages of each model. These results enhance our knowledge of the spatial distribution of polymetallic nodules and the techniques that can be used for interpretable, high-resolution spatial predictive mapping.

A possible Paleolithic stonewall in the southwestern Baltic Sea

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The Bay of Mecklenburg (southwestern Baltic Sea) is known for an exceptional high density of well-preserved submerged archaeological sites. The different findings, that locate between the present-day shoreline and water depths of about 10 m, date back to about 8000 years BP. During a high-resolution multibeam echosounder survey in autumn 2022, we discovered a curious stonewall in a water depth of 21 m, which had escaped resolution in previous studies. The wall stretches over a distance of 983 m and elevates up to 1 m from the surrounding seafloor. Video observations from scientific research diving and a portable ROV show that the stonewall is formed by a succession of decimetre-scale boulders that are also resolved in side-scan sonar data. Its straight orientation, size, sorted structure, and location suggest that the wall is not of natural origin. We are testing the hypothesis that the wall was constructed during the Paleolithic, possibly functioning as a hunting structure. If constructed by the early Hunter-gatherer that roamed the region after the retreat of the Weichselian ice, we would expect to find an unaltered paleo-soil and possibly also hunting artefacts in the surroundings of the wall. For spring 2023, we plan an AUV survey, additional multibeam campaigns and ground truthing by means of scientific research diving to evaluate the ancient function of the wall. There are a few additional sites in the Bay of Mecklenburg where basal till from the Weichselian glaciation crops out at the seafloor in water depths beyond 20 m. These sites may provide crucial but yet missing information on the development of the Late Paleolithic culture in the western Baltic Sea region.

Enigmatic seafloor depressions around the globe – one process to create them all?

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Seafloor depressions have been documented by means of hydroacoustic data from a range of marine and lacustrine provinces including deep ocean basins, fjords, marginal seas, estuaries, continental shelves and slopes, and lakes. They vary in diameter from less than 1 m to more than several hundreds of meters with depths ranging between some centimetres, to hundreds of meters. Often these seafloor depressions are referred to as pockmarks and interpreted to result from focused fluid escape from fine-grained sediments. Other processes that are sometimes invoked to generate seafloor depressions include freshwater flow in coastal regions, compaction induced sediment dewatering, bottom scouring around natural or anthropogenic objects, or benthic macrofauna interacting with the seafloor. In this contribution we review seafloor depressions across scales and around the globe in order to identify: (1) morphological similarities between different cases; and (2) endmember morphologies in terms of sizes and structural complexity. Subsequently we evaluate whether certain formation processes can be tied to certain morphologies. Finally, we discuss workflows and interdisciplinary approaches that could help to shed light on the genetic origin of different seafloor depressions.

Multibeam bathymetry mapping in False Bay, Cape Peninsula, South Africa

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False Bay is a large marine embayment situated in southernmost South Africa. It is bounded by Cape Point in the west and Cape Hangklip in the east. The local geology is made up of Neoproterozoic to Silurian aged granites, sandstones and shales of the Cape Supergroup, and Quaternary sediments overlie the bedrock. Broadly, this region is where the Atlantic and Indian oceans converge. The bathymetry of False Bay is known from gridded legacy data, acquired up to the 1970s by the South African Navy, with intermittent small commercial surveys carried out more recently near the Simon's Town harbour. The low-resolution dataset covering the bay showed where areas of reef cropped out and these popular recreational diving and fishing areas have provided the basis for detailed marine biological investigations which have been carried out over several decades.

In the last year, Wreckless Marine and the South African Council for Geoscience have initiated a high-resolution seafloor mapping programme that uses R2Sonic 2026 and 2024 multibeam echosounders, respectively, to map False Bay in its entirety. Up to February 2023, we have collected over 300 km^2 of data. We have also acquired boomer sub-bottom profiles to contextualise the extent of surface outcrops beneath the draping marine sediment. These new surveys have focused first on prominent reef areas, and previously unchartered outcrops have been discovered as the survey coverage has increased. Through Wreckless Marine's technical scuba diving programme, spanning depths of up to 100 m, ground-truthing operations are being undertaken to reveal distinct biological habitats that may be associated with different rock types and depth zones.

As this project develops further, our observations will be correlated to multibeam backscatter data towards generating seafloor habitat maps.

Geomorphology and slope analysis of the Tasmantid Seamount Chain

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The Tasmantid Seamount Chain, off the east coast of Australia, comprises at least twenty age-progressive oceanic volcanoes. The chain is associated with the northward migration of the Australian Plate over a stationary hotspot extending from the youngest volcano in the south (~6.5 Ma and 37°S latitude) to the oldest (~33 Ma and 21°S latitude) in the north.

Using bathymetric data collected from the research vessel, R/V *Falkor*, and open-access bathymetry from Geoscience Australia's AusSeabed data depository, geospatial analysis was completed on nineteen volcanoes in the Tasmantid Seamount Chain. Bathymetric derivatives were explored via 3D visualisation to describe the geomorphology of each volcano. Geomorphic features such as terraces, scoria cones, ridges, marine blocks, mass wasting chutes and depositional lobes have been identified and, where possible, corroborated with dredge and seismic survey data.

Bathymetric transects were extracted along the longest and shortest axis of each volcano to identify patterns across the chain. Using the profile data, slope and curvature (2nd derivative of slope) were extracted to identify terraces, reef summits and marine erosion.

Five primary morphologic types of volcano in the Tasmantid Seamount Chain have been defined based on geomorphic mapping and profile slope analysis; seamounts, flat-peaked seamounts, carbonate reefs, guyots, and reef-capped guyots. Each represents a distinct morphology and evolutionary process, and collectively, they demonstrate a north-south latitudinal pattern running south to north along the chain. Volcanoes with active reef growth at their summit are found north of 23°S latitude. Guyots (115–252 m summit depth) formed from wave erosion exist south of 33°S latitude, while drowned carbonate-capped guyots can be found between the two. By combining new high-resolution bathymetry and geospatial analysis, the latitudinal variation of carbonate reefs, seamounts and guyots has been captured and interpreted as a spectrum of evolutionary pathways that oceanic volcanoes can progress.

Study on integrated management of marine environment and ecosystems around Saemangeum in South Korea

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The Saemangeum Reclamation Project, which was carried out from 1991 to 2020, is a national project with a completed area of 409 km^2 and the world's longest seawall of 33.9 km. Although research and policies have been promoted since 2002 to minimize the marine environmental impact of this project, there were still limitations in managing the Saemangeum offshore area. Therefore, the purpose of this study is to establish a comprehensive marine environment management system in order to preserve the offshore environment and promote resource sustainability.

A comprehensive management system, which consists of diagnosis, evaluation, prediction, and reduction-management, has been developed since 2014. The goal of the evaluation is to establish a system to monitor the deposition and topographic changes of the offshore area following the development of the Saemangeum basin. Accordingly, the marine environment was periodically observed and various socioeconomic impact evaluations were conducted to secure observational data capable of time series analysis.

The goal of the prediction field is to predict environmental change caused by the Saemangeum development project by establishing a flow model, a sediment movement and water quality model, and an ecological model. To this end, real-time flow, wave, deposition, and water quality modeling were performed for a period of more than one year.

In the field of reduction-management, the goal is to establish a comprehensive Saemangeum management plan and inspection system. Related measures and governance were established, and the Saemangeum database (DB) was formed to help decision making. Saemangeum DB's metadata was collected from each research institution, and a data catalog map was designed and visualized in four ways. A total of 44 types of data were collected from research institutes, and a storyboard design for each data was completed in consideration of the connectivity between the data. Based on the design optimized for data inquiry, the Saemangeum Marine Environment Socio-Economic Integrated Information System was established.

The results of this study can be used to predict the impact of development projects and derive optimal reduction alternatives based on technological, economic, political, and social feasibility. In the future, management technology is expected to be greatly utilized in East Asia, where coastal development is rapidly progressing.

Cold water coral habitat monitoring with a multisensor platform: a data science approach

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Fixed underwater observatories (FUO) can be used to record different kinds of data for long-term (> 6 months) time series of high temporal resolution (< 1 hr). Here we present results from collection of multi-dimensional and multi-modal data that provides valuable information for describing and characterizing marine habitats. The Lofoten-Vesteralen ocean observatory (https://loveocean.no/) is such a FUO in the north east Atlantic. One component of the FUO (Node 1, 258m depth) is equipped with multiple sensors (current, turbidity, water depth, temperature, chlorophyll and conductivity) and cameras. Cameras were oriented towards one or two cold water coral colonies (*P. arborea* or “bubble gum coral”). In two campaigns (C1: November 2017 - June 2018 and C2: December 2018 - June 2019) the status of the habitat was recorded with LoVe sensors and cameras on different temporal resolutions. The data sets of the two campaigns comprise a great source of information about the ecological dynamics in the habitat (i.e. the corals together with other fauna and the physical conditions measured with the other sensors) but the data cannot be analysed using a classic straightforward standard statistical approach. While the sensor data time series feature the standard problems of missing values, noise and saturation effects, the images must be processed so the coral and fauna features can be related to the environmental physical parameters. In our collaboration we have developed and successfully applied two special computational approaches to extract two special coral features from the images. In the first approach, a U-net coral segmentation is combined with a ResNet50 image patch classification (both deep learning models) to estimate the average polyp feeding activity for two coral colonies visible in the images in both campaigns C1 and C2. So for each campaign and each coral colony we obtain a specific new time series a(*t*) describing the polyp feeding activity. To estimate the relative branch thickness (or branch diameter) at 14 selected anchor points in a coral colony, we have developed a new special two-stage deep learning method. With this method we can compute a relative coral branch thickness b(*t*) for each selected anchor point in a colony for each time point *t*. These new image based measurements together with the sensor data provide a new data basis for a data science approach to describe and monitor coral colonies in a selected habitat. A statistical analysis showed interesting similarities these time series computed for two corals within one campaign and dissimilarities for corals from different.

Seabed acoustic mapping revealing a never-seen-before habitat of circular depression at a marine protected area in Brazil

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Initiatives are promoting seabed mapping throughout the world. In Brazil, especially on the Espírito-Santo Continental Shelf, high-resolution seabed mapping has revealed a complex seascape unknown so far. Circular depressions were mapped for the first time on the Costa das Algas MPA. The MPA outer shelf is characterized by a complex morphology dominated by shelf incised-valleys and flat bottoms, with the presence of rhodolith beds. Our objective is to present the depressions and discuss their origin. A total of 3660 depressions were mapped and they appeared as sparse features on a flat bottom (5-10 depressions/km) to abundant/concentrated features on high slope areas (10-60 depressions/km). They are predominantly V-shaped and occur between 46 and 85 m deep. Their area ranges from 50 to 460 m², and vertical relief varies from 0.9 to 5m. Unsupervised analysis, based on acoustic data, spatially grouped the depressions into 6 groups that were gathered in two main categories: inter-valley (flat bottom) and valley-edges portions. Eleven depressions were directly investigated by scuba-diving with video images and sediment samples collection. The inter-valley regions and the features closer to the valley flank have a finer matrix that upholds structure with many bioturbation indications. The videos show an entanglement of depressions in multiple scales (bioturbation holes, mm; fish holes, cm; depression system; m) making it hard to limit the in and outside part of the feature. The deeper central parts of the circular depression appear to function as a sink, presenting aggregations of rhodoliths or other carbonate fragments such as coralline algae and algae. Depression edge and margin usually follow the same background sediment content as inside. The origin of these features is a work-in-progress discussion. We did not have any indication of gas seeps and there is no clear sedimentological or morphological control on their occurrence. We first hypothesize that their origin is the result of combined multiple temporal scale processes. The circular depressions that were mapped on a metric scale could be related to processes acting during the last glacial period and shelf exposure, i.e., relict features. These depressed areas may be responsible for biomass aggregation and then fish bioturbation, forming holes and rubble mounds, which represents a modern process occurring on a centimetric scale. The research will continue, but data collected so far indicates that this metric scale feature is an important habitat for different fish species.

Comparing manual and semi-automated methods for deducing geomorphometric characteristics of miniature biogenic reefs in a shallow land-locked gulf of the Aegean Sea

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A very large number of small biogenic reefs lie in the Gulf of Gera, Lesvos Island in Greece. Previous studies have used single-beam bathymetry, geophysical prospecting (side-scan sonar and sub-bottom profiling) and ground-truthing methods (sediment sampling and drop camera) to describe the geomorphology of the gulf and map the distribution of the miniature reefs, found to be constructed by oysters and associated benthic assemblages. More than 4000 mounds were recorded, developing in the generally soft, muddy sediments of the gulf. However, their mapping was implemented using only side-scan sonar backscatter data, since interpolation methods on single-beam bathymetric information could not provide reliable morphological evidence. A preliminary geomorphometric analysis was accomplished trying to describe these features. The subbottom profiles also revealed the presence of fluids in the sediment pores as well as buried reefs formed within the marine transgressive and high-stand palaeo-deposits of the gulf.

This study presents the results of a high resolution (1m cell size) multibeam echosounder (Teledyne Reason Sea-Bat T20-R) mapping exercise, used to define the precise bathymetry and morphology of the gulf. The study was carried out during spring and autumn 2022, managing to map about 75% of the gulf (deeper than ~10-11 m). The aim of this study is to (i) precisely delineate the reefs using a selection of manual and semi-automated methods, assessing and comparing the accuracy of each method and (ii) extract geomorphometric attributes and statistically analyse the reef population, in order to observe potential relationships between spatial distribution and morphology that could aid in the evaluation of the environmental drivers and formation mechanisms.

More than 6000 reefs have been manually digitised on the new dataset, using both bathymetric derivatives (slope and curvature) and backscatter. Trimble eCognition software and the CoMMa Toolbox (GIS-based) were also employed as semi-automated delineation methods for the detection of the miniature reefs. To assess the accuracy of all mapping methods, we compared the spread in extracted reefs statistics. The preliminary results didn't show significant differences between manual and semi-automated methods, suggesting that the latter methods are an efficient and time saving tool for mapping this kind of habitats.

Seamounts habitat mapping and characterization of faunal communities using a non-intrusive and multi-scale approach with an AUV on Mediterranean Sea (Corsica, France)

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Seamounts are considered as biodiversity hotspots and usually host habitats and species of special interest, such as cold-water coral reefs, deep-sea sponge aggregations and abundant fish assemblages. Their management is crucial for conservation, and it has been hypothesized as effective ways to protect numerous species. Several methods can be considered for seamount surveys, but slow approaches with high data resolution acquired by low-speed vehicles (e.g., Remotely Operated Vehicles, submersibles of camera sleds) are preferred in most studies. Yet, these approaches are not compatible with large-scale monitoring purposes, required in the context of MPA management. In this study, we applied a multi-scale approach using an Autonomous Underwater Vehicles (AUV) to study two contrasting seamounts situated 30 kms away from Corsica's coast (France) and laying on a 2500 meters depth seabed. The first step consisted in obtaining an extensive bathymetry of the seamounts, from the ground to the summit by using the multibeam echosounder and operating the AUV at an altitude of 60 meters. This allowed us to get a high-resolution bathymetry (2 to 3 m) of a significant part of the seamount within a few days and to define appropriate areas for sonar image acquisition. Next, we operated the AUV at 15 m of altitude and recorded high-resolution digital images (few centimetres) using the synthetic aperture sonar (SAS) to detect notable topographic structures which may constitute suitable habitats for benthic species. Finally, we compiled the whole data to identify specific targets where the AUV could navigate around 5 meters above the seabed, and to record optical camera images for the characterization of faunal communities.

The results of this approach were conclusive as we increased the resolution of the previous bathymetry obtained thanks to hull-mounted multibeam from 100 to 2-3 meters using an AUV. We also identified notable geological structures thanks to the SAS mosaic and obtained a coarse taxonomic resolution within targeted habitats thanks to optical records. In conclusion, this approach appears to be a good way to get both extensive bathymetric data and some punctual high-resolution information on some targeted areas. This method represents an ideal preliminary work for programming a complementary study, in which the use of slow vehicles such as ROVs will be optimized by the global knowledge of the area.

Reducing uncertainty in seafloor fluid vent localization

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Modern water-column-imaging multibeam sonars have been shown to be effective tools for a variety of ocean mapping applications but can generate immense amounts of raw data when recording acoustic backscatter over the entire water column. High raw data rates during acquisition can pose logistic, economic, and technical challenges for processing, analysis, and archiving of the data. These limitations in multibeam water column imaging often provide unique challenges in commercial marine seep hunting surveys that routinely acquire large basin-scale high resolution multibeam datasets that require rapid processing and interpretation required for selection of coring targets for geochemical sampling of seep sediments. Interpreting the seafloor position of gas emissions in multibeam water column data using common commercial software packages is hindered by slow processing due to these large file sizes, a manual “by eye” qualitative assessment of each sonar ping searching for acoustic anomalies, skill and experience of the interpreter, fatigue of the interpreter during field operations, and environmental or acquisition artifacts that can mask the precise location of gas emission on the seafloor. These restrictions over regional basin-scale surveys create a qualitative data set with varying inherent positional errors that can lead to missed or incorrect observations about seep-related seafloor features and processes.

By vertically integrating or midwater multibeam amplitude samples over a set range of depths, a 2D midwater backscatter raster can be generated and draped over bathymetric data, providing a quantitative synoptic overview of the spatial distribution of gas plume emission sites for enhanced seafloor interpretation. We reprocess multibeam midwater data set from NOAA Cruise EX1402L2 in the northwestern Gulf of Mexico using a vertical amplitude stacking technique. Constructed midwater backscatter surfaces are compared with digitized plume positions interpreted during EX1402L2 for a comparison into assessing uncertainty in mapping approaches. Our results show that the accuracy of manually digitizing gas emission sites varies considerably when compared with the midwater backscatter amplitude maps. This quantitative plume mapping technique offers multiple advantages over traditional geopicking from cost effectiveness, offshore efficiency, mapping repeatability, and ultimately improving the detectability of gas plume emission on the seafloor. Datasets generated from this method can be used as a geophysical proxy for locating chemosynthetic and related benthic habitats.

A pragmatic at-sea solution to comply with the multisource multibeam backscatter *conundrum*

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Detailed and accurate information of the spatial distribution of seafloor sediments is of great relevance for several marine management applications. The use of MBES backscatter has drastically improved the quality of traditional sediment maps. Increasing volumes of data becoming available imply the need for objective, repeatable and accurate mapping methodologies. This includes the utmost importance of assessing the feasibility of comparing datasets acquired by different sounders and carrier platforms. In this study, a ~150 km^2 300 kHz multi-source MBES backscatter dataset and a set of 163 ground-truth samples, acquired in Belgian waters over the period 2015-2018, were integrated to predict seafloor sediment type. Based on survey overlap on a natural reference area, a pragmatic strategy to merge the disparate data into a seamless backscatter map was implemented. This pragmatic at-sea cross-calibration-propagation solution enabled the production of a single dataset exploitable for manyfold scientific applications.

Here we present results on exploratory data analyses of sediment-acoustic relationships; predictive modeling of sediment distribution across the merged backscatter dataset; and a comparative assessment of the thematic accuracy of unsupervised and supervised classification approaches, including the identification of trade-offs between thematic accuracy and resolution of the prescribed sediment classification schemes.

A two-part seabed geomorphology classification scheme: Part 2 – a geomorphic classification framework and glossary

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Maps of seabed geomorphology provide foundational information for a broad range of marine applications. To be most effective, geomorphic characterisation of the seabed requires standardised, multi-scalar and interjurisdictional approaches that can be applied locally, regionally and internationally using the best available data. An ongoing collaboration between geoscience agencies in the United Kingdom (BGS), Norway (GSN), Ireland (GSI and UCC) and Australia (GA) has focused on developing a new standardised approach to meet this need. Dove et al (2016) first described a two-part approach for mapping the geomorphology of the seabed. Part 1 was subsequently published as an open access glossary that includes an illustrated list of terms and definitions that primarily draw on the International Hydrographic Organization standard (https://zenodo.org/record/4071940#.Y7tURodBxPY). Morphology maps are created by applying Part 1 Morphological terms to bathymetry data. Part 2 classifies these mapped shapes with their geomorphic interpretation; geomorphic unit terms are structured within 11 geomorphic Settings (Fluvial, Coastal, Marine, Glacial, Hard Rock) and Process (Current-induced, Biogenic, Mass movement, Fluid Flow, Karstic, Anthropogenic) categories. Consistent with Part 1, Part 2 terms are primarily sourced from established literature. The application of Part 2 requires further seabed data and/or contextual information and expert judgement, and is intended to constrain the uncertainty that is inherent to subsurface facies interpretation and prediction to this step. A draft version of Part 2 was the focus of a well-attended (>50 participants) workshop at the IAG's International Seafloor Geomorphology Conference in Malta (July 2022). Feedback from that workshop and from the broader community was integrated into a revised version of the report, which will be released in February 2023. We will demonstrate the application of this method to worked examples from coasts, continental shelves and the deep marine, and thereby demonstrate the utility of the two-part approach for the mapping the distribution of sedimentary facies that form in these diverse marine environments.

Using underwater photogrammetry for mapping and monitoring seafloor habitats: case studies from Western Australia

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The use of underwater photogrammetry for seafloor habitat mapping has been ever growing, particularly in the last 10 years. There are, though, various challenges to overcome and important strategies to adopt for successful creation of accurate image-based 3D reconstruction and georeferenced mosaics. This talk will present some results and lessons learnt from case studies carried out off the Western Australian coast, including: monitoring coral reef growth in turbid waters, and mapping deep-water mesophotic reefs. They will highlight and describe the camera characteristics and strategies best for deep or turbid environments, the benefit of collecting auxiliary data, and methods developed for camera calibration and control points in remote locations.

Seascape Mapping: Defining levels of detailed information

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Oceans are under pressure and fisheries, oil and gas industry, mining, navigation, etc. are few examples. In the last decade, marine spatial planning (MSP) became critical for ocean management and protection and knowledge of the ocean floor is a baseline for MSP. Brazil has one of the largest EEZs in the world, but despite that, only small parts of its continental shelf have been mapped. Thus, we present here a regional seascape mapping of the Espírito Santo continental shelf (ESCS - eastern/southeastern Brazilian margin). We aim to use existing data to produce regional seascape maps applying different levels of input of detailed physical information. The study uses bathymetric data compiled from the Brazilian Navy and surface sediment data from existing databases. The ESCS morphology is characterized by changes in sedimentary regimes, from terrigenous to carbonate, but also by post Last Glacial Maximum shelf evolution processes. The combination of these processes led to a heterogenous seascape, forming a complex mosaic of benthic/physical marine habitats.

In terms of seabed types, the ESCS seascape is marked by soft bottoms (terrigenous and carbonate sediments) and hard bottoms (carbonate – reefs, carbonate crusts and Rhodoliths). Seabed morphology is characterized by flat, regular and lobate features and by irregular and rough bottoms. A variety of habitats are associated with soft bottoms, for example, muddy, sandy and gravel beds and for hard bottoms (rhodoliths on flat bottoms and shelf valleys, and biogenic crusts). Thus, in order to develop different levels of seascape complexity, we generated maps using distinct levels of input information. The first level is a map showing the distribution of benthic habitats associated with soft and hard bottoms and with flat/regular and irregular/rough surfaces. This map produces a general idea of potential benthic habitat distribution. The second, discriminates the seabed types, i.e., sand, mud, gravel and rhodoliths, reefs, crust, etc increasing complexity in terms of potential habitat distribution. The third roughness, slope and BPI and the fourth map uses detailed sedimentary facies description for example, terrigenous mud, carbonate sandy gravel combined with the terrain attribute classes.

Adding information increases complexity on the mosaic of potential benthic habitats. However, considering different strategies, experience shows that the final product must be of easy understanding for decision makers and analysts, especially where no official habitat classification is available. Producing distinct levels of detailed seascape information is an interesting approach for local managers and decision makers.

Comparing microplastic pollution in marine reserves and urbanised areas

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Microplastic particles (< 5mm) have been observed to be widely distributed in all the oceans, however little is known about their distribution and accumulation on the seafloor, particularly in marine protected areas. The delimitation of marine protected areas frequently follow jurisdictional or political boundaries, however the distribution of species, habitats and ecosystems do not strictly follow these same confines. Likewise, pollution in the marine environment does not have boundaries

This study aimed to compare microplastic particle concentration between areas in close proximity to urban built environments, with those more distal in Aotearoa / New Zealand. We assess the microplastic content in sediment cores from two sites: an urbanised area, near the coastal township of Picton; and a site distal from the township (~30 km), adjacent to the Kokomohua Marine Reserve, in the region of Queen Charlotte Sound/Tōtaranui.

Microplastic particles were identified throughout the sediment cores from both locations, reaching depths of ~45 cm below the seabed. Our findings revealed that marine sediments adjacent to the marine reserve had four times the microplastic accumulation of marine sediments from near the coastal township. The abundance of microplastics across the sediment depth profiles also varied between the two sites, suggesting differences in the spatial and temporal accumulation of microplastics on the seafloor.

Our results suggest that the lesser seafloor disturbance in the marine reserve may also lead to increased microplastic burial in marine sediments, with the urban-proximal site favouring more resuspension through other human activities such as ship anchoring.

Our study demonstrates the extent to which human stressors such as microplastic pollution proliferate and concentrate in the environment, particularly areas considered to be near-pristine with strict environmental protections. Further to this, we recommend further research into understanding the drivers of spatial and temporal distribution and accumulation of microplastic particles in the seabed; and exploring the severity and impact of microplastic pollution in benthic ecosystems.

Drone photogrammetry and autonomous surface water prospectors to investigate the morphology of super-shallow seabed: the buried marshlands of the central Venice lagoon exhumed by ship wake erosion

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UAV photogrammetry and surface-water autonomous prospectors were used to map the morphology of a shallow water area located alongside an important waterway in the central basin of the Venice lagoon (northern Adriatic Sea, Italy). The channel, opened in 1970 after dredging lagoon tidal flats and marshlands for a total length of 15 km, connects the industrial port of Marghera (2 km west of Venice) to the Adriatic Sea through the inlet of Malamocco. During the excavation of the channel (100-120 m wide and 12 m deep) millions of m^3 of dredged material were used to reclaim a marshland area to an elevation of about 2 m above mean sea-level (msl), in order to make space for an expansion of the industrial zone. The area was later abandoned and became colonised by vegetation, while the artificial shoreline facing the navigation channel was exposed to erosion by ship wake for decades. This began with the demolition of the rip-rap protection through the removal of the sandy substratum, and continued with the progressive removal of the artificial deposits with the shoreline currently retreating by about 4 m yr^{-1}. Recently the erosion processes exposed the original salt marshes which were buried under the artificial fill for 40-50 years. Salt marsh deposits form the upper part of the natural lagoon sedimentary record mainly consist of dark grey clayey silt, containing mollusk shells and a diverse population of benthic foraminifera. The base of the lagoon sediments, dating back to 4500 years before present, is located about 4 m below msl.

These “ghost” marshes have been mapped at centimetric resolution using drone photogrammetry, performed during an exceptionally low tide, and a single-beam echosounder mounted on an OpenSwap surface-water prospector operating at mid-to high tide. The elevation of the top of these marshes, measured in the field with a GPS-RTK rover, is about 18 cm below msl, while the top of pristine marshlands in the proximity is commonly found at elevations of more than 25 cm above msl.

It is likely that a combination of factors is responsible for the difference in elevation between the original and pristine salt marshes. For example, sea level rise over the past 50 years and compaction induced by the load of dredged materials may have contributed in part. Additional factors such as the lack of sedimentation above the once-buried marshes or a partial erosion after exhumation could have played a role.

Seamless opto-acoustic mapping of coastal waters – a case study from the Baltic Sea with seagrass mapping

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Coastal vegetated ecosystems provide valuable habitats and offer a wide range of ecosystem functions and services. Their contribution to biodiversity and carbon sequestration on annual and millennial timescales is massive. For example, recent evidence suggests that seagrass meadows are much more efficient at sequestering carbon than tropical rainforests over the same area.

Plants feed on photons, so remote sensing methods are well suited to detecting submerged vegetation. However, the accuracy of remote optical sensing degrades with distance and depth, ultimately failing to detect the deepest stocks of vegetation.

In this study, we present an opto-acoustic approach that allows seamless mapping. We fuse multibeam echosounder (MBES) data with LIDAR and satellite imagery and show how a seamless map along the coastline, including submerged aquatic vegetation, can be produced. We focus on *Zostera marina* seagrass habitats, which we have extensively studied for their opto-acoustic detectability by aircraft and ships during the EU BONUS ECOMAP project in the Baltic Sea and within the ongoing CDRMare sea4oCiety project, which assesses carbon dioxide sequestration through the maintenance and potential expansion of coastal vegetated ecosystems. The resulting maps will also serve as a monitoring baseline study and support ongoing and future reforestation plans.

Mapping seagrass and rockweed habitats using UAV hyperspectral imaging and machine learning

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Seagrass and rockweed are important parts of the “blue forests” found in marine shallow waters. They provide several ecosystem services, including primary production, carbon sequestration, and forming structures that are habitats for a plethora of marine animals. The blue forests are subject to several stressors, including climate change and human activity, and in some parts of the world, the extent and health of the blue forests is rapidly changing. Current methods for monitoring changes in the blue forests are mostly limited to manual sampling (using diving, “drop cameras” etc.) and remote sensing from satellites or airplanes. Sampling is inherently limited with regard to area coverage, satellite images generally have poor resolution, and airplane imaging is costly. However, unmanned aerial vehicles (UAVs) have recently been introduced as alternative remote sensing platforms. UAVs are low-cost, easily deployable in the field, and produce high-resolution images.

In the “MASSIMAL” research project we aim to develop new tools for monitoring the blue forests, using hyperspectral imaging performed from UAVs. Hyperspectral cameras have higher spectral resolution than regular RGB cameras and are thus able to capture more detailed measurements of the reflectance of blue forest species.

The hyperspectral images are converted into habitat maps by machine learning algorithms. Ground truth observations are used to manually annotate hyperspectral images which in turn are used to train the machine learning models. We show initial results based on datasets collected at a beach along the coast in northern Norway. The beach forms a mosaic of sand, seagrass, rockweed, filamentous algae, and clusters of blue mussels. We train multiple machine learning models, including “traditional” models such as random forests, and deep learning models based on convolutional neural nets, and compare their performance. The results are promising, but also highlight that annotation of images of complex marine habitats can be very challenging, and that using single “habitat classes” can be an over-simplification.

Two decades after: reoccupancy of cold-water coral habitats of the southwestern Adriatic Sea

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One of the most emblematic Mediterranean live cold-water coral (CWC) hotspot is located offshore the Apulian coast in the southwestern Adriatic Sea. The Bari Canyon CWC site was firstly imaged in 2006 by a remotely operated vehicle survey (ROV *Quest 4000,* RV *Meteor* cruise M70-1), disclosing abundant scleractinian (dominantly *Madrepora oculata*, *Desmophyllum pertusum*, *D. dianthus*) and sponge life. The Bari Canyon CWC site was, therefore, selected by the Italian project GLIDE (Global Change Impact on Deep Sea Ecosystems) to evaluate its ecological status after 16 years from their discovery. In summer 2022, we reoccupied a small target area at 41.29 Lat N, 17.28 Long E during mission ITEM aboard MV *Fox*, in collaboration with Eni Mediterranea Idrocarburi (Enimed). We explored the site by means of ENI *Clean Sea* AUV/ROV and the survey reveals no appreciable change on the good ecological status of the resident CWC communities. This information provides a robust argument for maintaining the current situation, but also to recommend measures for the safeguard of the Bari Canyon CWC into the future.

A new standard in seamless on-offshore geological mapping for South Africa

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In 2022 and 2023 the Council for Geoscience, South Africa, completed and published a series of onshore-offshore geological maps of the Cape Town sheet (3318CD) at 1:50 000 scale. The series consist of 4 maps: Bathymetry, Surficial texture and hydroacoustic facies, Seismic setting, and seamless On- offshore Geology. The data to achieve this were multibeam bathymetry and backscatter, side-scan sonar, marine magnetics and shallow sub-bottom profiling and covered an area of 380 km^2 offshore. In some challenging areas data were ground-truthed using SCUBA diving, grab sampling or drop cameras. When the hydrographic and geophysical surveys and processing were complete, these data were used to inform the offshore geology which was then merged with existing onshore geological data to produce the seamless on-offshore geology map.

The seafloor geology is made up of Neoproterozoic metasedimentary basement rocks of the Malmesbury Group, which were subsequently intruded by the Cape Granite Suite during several phases of granitoid emplacement. Interspersed between the basement rocks are pockets and channels with more recent Holocene sediment accumulations.

Through this onshore-offshore geological map production, an unexpected challenge was to classify offshore sediments into stratigraphically accepted units in South African geology nomenclature. It illuminated a need to first consider that previously unmapped (terrestrially) geological units should follow the same scrutiny and acceptance criteria as their onshore equivalents as recognised stratigraphic formations.

Utilizing benthic habitat mapping and biological surveys to determine the physical status and ecological function of artificial structures offshore California, USA

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Marine infrastructure from offshore energy development can change the distribution and abundance of local marine habitats and species via the introduction of artificial hard substrate. This “artificial reef” effect potentially modifies a variety of local and regional processes, including those that drive the ecological dynamics of managed, sensitive, or non-native species. Artificial reefs may also enhance certain human activities such as fishing or diving. Decision makers must therefore understand how offshore projects that add significant amounts of hard substrate into the marine environment may be evaluated, managed, and potentially incorporated into an artificial reef program. On the west coast of the United States, these habitat issues are of particular importance due to: 1) the imminent decommissioning of oil and gas platforms and their associated subsea structures such as pipelines, power cables and wellheads, which may remove important habitat for managed fish species; and 2) the introduction of new marine infrastructure from offshore renewable energy facilities which can affect local biodiversity and food web structure. Consistent with California’s goal to achieve 90% clean energy by 2035, the Biden-Harris Administration recently launched initiatives to deploy 15 GW of floating offshore wind capacity on the west coast of the United States by the same year. However, in southern California, it remains unclear to what extent platform habitat and other similar man-made structures contribute to regional-scale ecological dynamics. Understanding how artificial habitats interact with regional drivers will improve forecasts about the consequences of decisions related to marine infrastructure and support environmental review.

Bathymetry and side scan sonar data collected via an Edgetech 6205 MPES is being used to confirm location and determine the physical state of known artificial reefs offshore southern California. Biological characteristics are assessed using visual surveys via SCUBA (for depths < 30m) or remotely operated vehicles (> 30m). Similar data on nearby natural habitats is also being collected to provide a basis for comparison. Human use is evaluated by summarizing recreational fishing data, direct observations, and by collecting new data via guided discussions with stakeholders. The goal is to determine what physical, biological, or geographical features are important for productivity of planned and de-facto artificial structures and what criteria should be used to evaluate future artificial reef proposals and projects at a regional scale to maximize environmental benefits and ecosystem services.

Mapping seafloor erosion induced by ship wakes in in the lagoon of Venice: integrating remote sensing (drone/satellite) and bathymetric data from autonomous shallow-water vehicles and hi-res multibeam echosounders

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Ship and boat wakes generated in the open sea are rapidly attenuated with distance from a moving vessel and have a limited impact on the seabed morphology of nearshore areas and on the related ecosystems. For navigation in shallow coastal waters and inland waterways, however, the wake generation processes, the patterns of propagation and the type of impacts can markedly differ from those typical of open sea conditions. It is widely documented that boat traffic can significantly affect valuable coastal ecosystems and can be the most significant factor for changes in the proximity of fairways, such as on the channel edges and adjacent tidal flats or salt marshes and on the shores of navigable river deltas/estuaries.

The generation, propagation and impacts of ship wakes in the navigable channels of the Venice Lagoon has been extensively investigated in the last decade. Experimental studies and modelling approaches have been implemented and the results are currently in use by the authorities to plan mitigation strategies to limit the loss of benthic and riparian habitat. Within the flagship project Venezia2021, we improved the spatial and temporal resolution in the analysis of morphological impacts by integrating the observations obtained from different platforms. These included remote sensing from satellite (Copernicus Sentinel-2 A/B and Landsat 8-9), drone aero-photogrammetry, and bathymetric data from a single-beam autonomous shallow water prospector (OpenSwap) and a boat-mounted hi-res multibeam echosounder.

Satellite images and derived products show high turbidity plumes generated by ship wakes in the correspondence of more vulnerable hotspots of erosion (sediment type and stratigraphy of the deposits), where fast shoreline changes are identified on a GIS system implemented with the available imagery. From this preliminary knowledge, we focused the analysis on the morphological evolution of the waterway and adjacent habitats by integrating a high-resolution digital surface model of the emerged areas, elaborated from drone photogrammetric data, with bathymetries of the subtidal areas (from 0 to -2 m), from the OpenSwap, and of the deep navigation channel and its margin slopes, from multibeam data.

The results, presented here, permit the estimation of the eroded volumes and represent a reference base for the future monitoring of morphological changes in order to address future actions to limit seabed erosion and to address future management actions for the sustainability of channel maintenance and safe navigation.

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