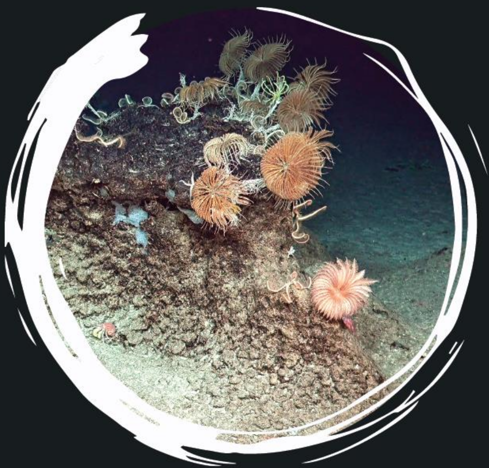

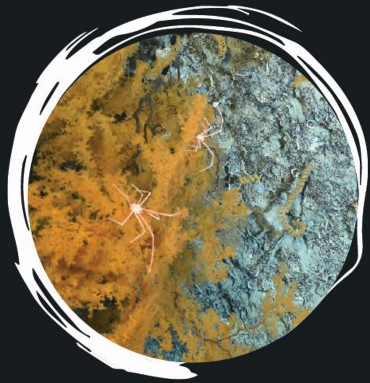

4th Marine Imaging Workshop

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Platforms, optical sensors and (underwater) image acquisition, calibration and preprocessing

Oral presentations

(Inverse) Volumetric Raytracing Methods for Physically Faithful Simulation and Estimation of Underwater Scenes

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The majority of Earth's surface is situated in the deep sea and thus remains deprived of natural light. Such adverse underwater environments have to be explored with powerful camera-light systems. Often, it is not possible to obtain ground truth data, to develop, train and evaluate computer-vision algorithms for underwater usage. To overcome this, we employ physically-based volumetric raytracing to correctly describe and visualize the geometric and radiometric distortions in underwater imagery. However, the technology can also be applied inversly: This allows us to restore the colors in images taken by such systems, after jointly estimating physically-meaningful optical parameters of the light as well as the water column. We present an integrated in-situ estimation approach and a complementary surface texture recovery strategy, which also removes shadows as a by- product. As we operate in a scattering medium under inhomogeneous lighting conditions, the volumetric effects are difficult to capture in closed-form solutions. Hence, we leverage the latest progress in Monte Carlo-based differentiable ray tracing that becomes tractable through recent GPU RTX-hardware acceleration. Evaluations show that we can estimate physically meaningful parameters, which enables coherent color restoration.

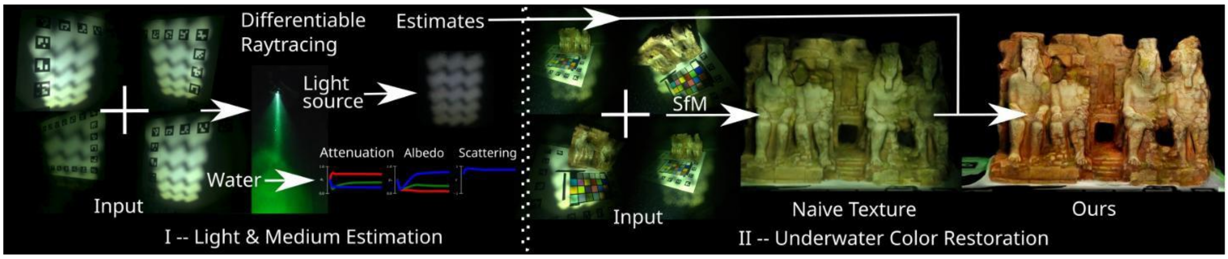

Figure 1: System Overview : Pipeline for estimation of optical propeties of an underwater scene and consecutive color restoration.

Exploring deep-sea benthic ecosystems of the Azores with a cost-effective imaging tool: how much ground have we covered with the Azor drift-cam?

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Deep-sea exploration has significantly increased during last decades due to advances in marine technology. Cutting-edge underwater imaging tools now represent a common approach to study deep-sea benthic habitats, but are only accessible to few research institutions/countries. Current commitments to protect marine biodiversity would therefore benefit from imaging tools that can generate scientific data at reasonable costs. In the Azores, deep-sea exploration historically relied on international research vessels visiting the archipelago. Hence, detailed information about its benthic communities was limited to a few seamounts, island slopes and hydrothermal vents. Aiming to speed up deep-sea exploration, we developed prototypes of low-cost imaging devices until reaching a fully functional model: the Azor drift-cam (https://doi.org/10.1111/2041-210X.13617; Figure 1a). The system, designed to obtain high-quality images of the seabed down to 1000m depth, uses off-the- shelf components, taking advantage of small action cameras. Its design reflects the reality of the Azores: cost-effective, covers large areas in short periods of time, performs well over rough terrains, can be operated from small local vessels and has high chances of escaping if entangled in lost longlines.

In 3 summers, we performed almost 400 dives down to 1000m depth, covering more than 200 km of seabed (~300 hours of new video footage). We collected information on the composition of benthic communities for several unexplored seamounts along the Mid-Atlantic Ridge, as well as seamounts and slopes around the islands (Figure 1b). The versatility of the system, which can be operated from small fishing boats (7-12 m), allowed us to survey close- by areas while keeping operational costs very low. The new knowledge gathered on the diversity and distribution of benthic communities (Figure 1c-f) has increased our capacity to develop area-specific management plans for the Azores, which should lead to a more sustainable use of deep-sea resources and the conservation of its natural heritage.

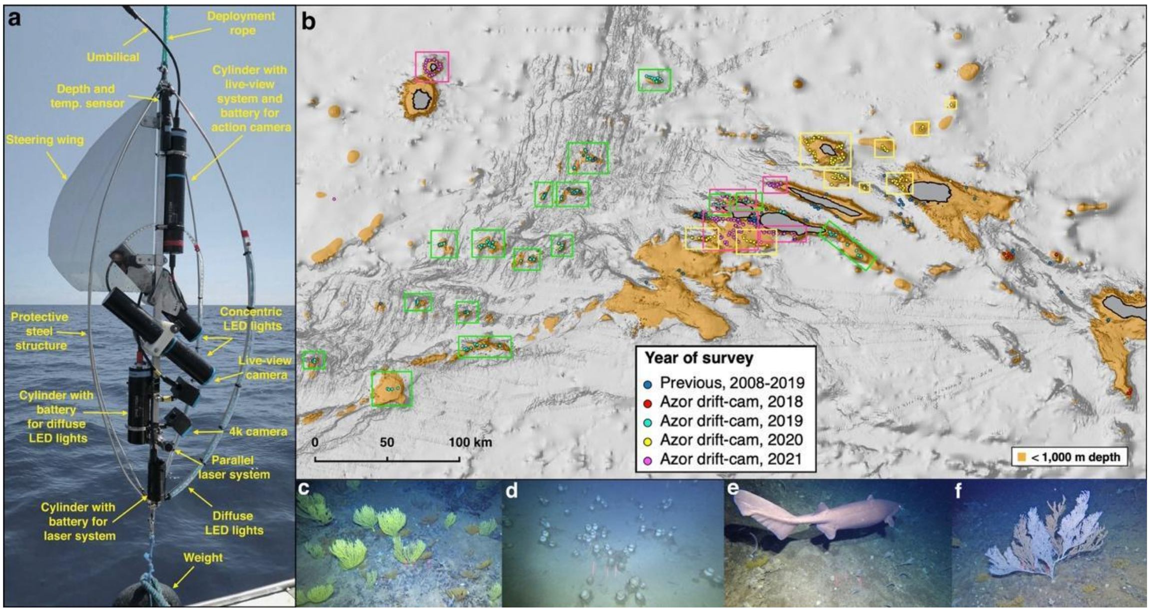

Figure 1: (a) Lateral image of the Azor drift-cam, with all its components mounted on the stainless-steel structure. (b) Areas explored with the Azor drift-cam during the past 3 years along the Mid-Atlantic Ridge and different islands of the western and central group of the Azores. Dive locations and boxes are colored according to the year of the survey. (c-f) Screenshots extracted from the video footage recorded with the Azor drift-cam, showing some of the species and communities found in the deep sea of the Azores. More video footage recorded by the Azor drift-cam can be found at: www.youtube.com/channel/UCrUCCk9866Ym8voq7ZwwZoQ.

Comparing particle spectra across a suite of pelagic imaging systems

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In a field expedition to two Norwegian fjords with a contrasting pelagic food web structure, we used seven different commercially available and custom-made pelagic in situ imaging systems. While all imaging systems were targeting particles (“marine snow”) and planktonic organisms in the water column, they each have their specialized size range and particle and organism types. By combining optical systems with differences in optical resolution, sampling volume and illumination principle, we were able to efficiently and accurately determine a broad range of particles and organisms in the ocean. We combined data sets from the different systems to assess potential added value of multiple optical systems and to identify ideal combinations of in situ observations to target specific research questions. This work is based on simultaneous deployments of UVP5, UVP6-HF, CPICS and Plankton Imager with Scanning Optics (PIScO) mounted on one platform and parallel deployments of ROSINA, LISST, and ISC on a separate platform at the same locations. We here present a comparison of the respective spectral slopes of the particle distribution as well as abundances of selected pelagic organism and marine snow types, such as appendicularians, copepods, chaetognaths, ostracods, large rhizarian protists (aulacantha), sinking appendicularian houses and fecal strings.

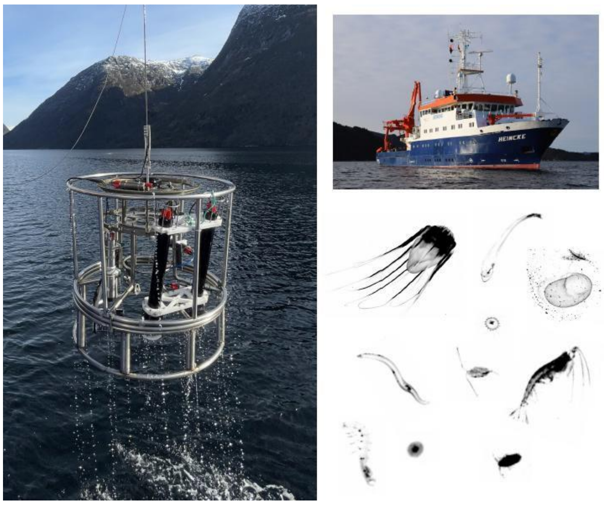

Figure 1: Bio-Optical Platform (BOP) with different imaging systems mounted, research vessel Heincke in Masfjorden and example images of pelagic organisms present.

Imaging Plankton Probe (IPP): an AI-empowered Imager for Underwater Imaging of Marine Plankton

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We report the new development of a novel underwater imager called Imaging Plankton Probe (IPP) and its applications for *in situ* imaging of marine plankton and suspended particles in this workshop. IPP achieves *in situ* darkfield true-color imaging of planktonic particles in the size range of ~200μm-40mm, and features higher quality image yield and effective avoidance of underwater organism phototaxis during static deployment, thanks to its patented orthogonal shadowless laminar white light illumination. In addition, IPP has also been demonstrated very successful in biofouling control for protecting its underwater optics and housing with a record of more than six-month deployment in sub-tropical coastal waters without manual maintenance. IPP is not only equipped with machine learning-based algorithms for autonomous big image data analysis, its imaging capability is also greatly enhanced through a series of novel deep learning-based methods including image super-resolution, depth-of-field extension and greyscale image colorization technologies. It has been tried to deployed on platforms including coastal rafts, surface buoy, and sea-bed landers along the East and South China Sea coast for long-term, high-frequency, continuous, and *in situ* monitoring of harmful plankton blooms and biodiversity in the past two years. We expect this novel technology can be widely applied to enable various marine observational platforms for better supporting more comprehensive *in situ* plankton monitoring-based scientific research and marine eco-disaster early-warning.

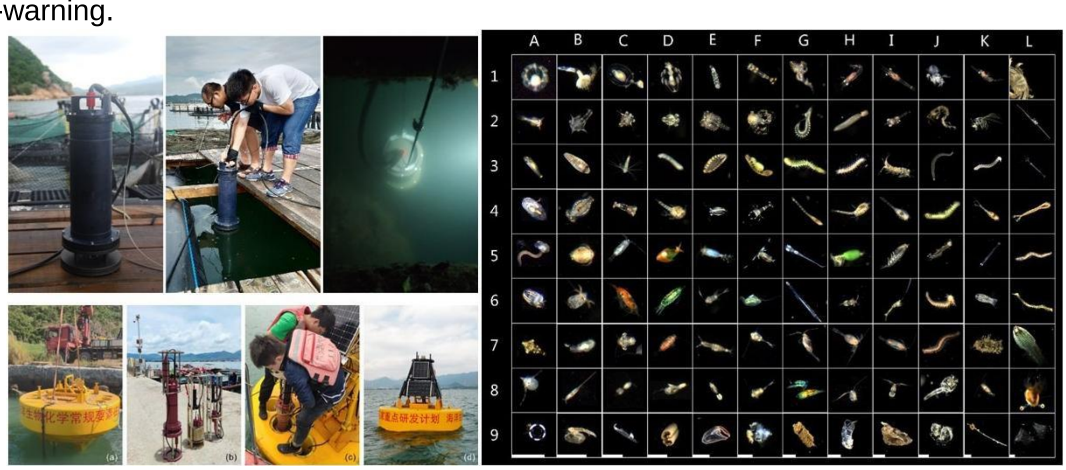

Figure 1: Raft and surface buoy tests (left-top and left-bottom) of Imaging Plankton Probe (IPP) and representative plankton and particle images acquired by IPP. Scale bar 1mm.

Autonomous and Intelligent Underwater Video Monitoring: the GUARD1 Approach

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The marine science community is engaged in the exploration and monitoring of biodiversity dynamics, with a special interest for understanding the ecosystem functioning and for tracking the growing anthropogenic impacts. The accurate monitoring of marine ecosystems requires the development of innovative and effective technological solutions to allow the remote and continuous collection of data. To achieve this goal, novel technologies for the continuous monitoring of natural ecosystems are urgently needed and video-based observations are increasingly being considered among the most promising tools for a non-invasive environmental monitoring. Within this context, the GUARD1 intelligent imaging device has been specifically conceived for long-term deployments as equipment of mobile platforms (e.g. AUV, USV, Argo Float, drifter buoys) as well as stand-alone and wired observatories (e.g. oceanographic moorings, landers, cabled observatories). The imaging device is capable of acquiring underwater images at a programmable time rate, provides on board content-based image classification based on customizable software and communicates the information extracted from the acquired images, discarding not relevant data. A summary of the past monitoring experiences performed with the autonomous intelligent imaging device GUARD1 will be provided and the new device architecture, together with the ongoing and forthcoming applications, will be presented focusing in particular to the autonomous onboard detection and classification of fishes and to the transmission of image-content relevant data to a land station.

PISCO - An extended depth-of-field imaging system for improved observations of plankton in the ocean

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A major limitation of microscopic imaging is the seemingly inevitable trade-off between magnification and depth-of-field (DOF). One of the applications, where this challenge becomes most prominent is *in situ* plankton imaging: Taxonomic identification of plankton species requires high image detail (=magnification), leading to drastic decreases in DOF and image volume. However, large sample volumes are necessary due to usually low plankton concentrations (often < 1 organism L^{-1}), especially for larger species (as organism abundances decrease with body size). Consequently, the trade-off between magnification and DOF inherent to conventional optical systems prevents exploiting the full potential of imaging systems for *in situ* plankton observations.

To solve this problem, we have developed a novel "extended depth-of-field (EDOF)" underwater imaging system, combining "telecentric shadowgraphy" (a special illumination technique) with varifocal "Electrically Tunable Lenses" (ETL), a new opto-electronical technology that allows for rapidly changing the focal plane (at 70 kHz) during image acquisition, thereby axially integrating over all focal planes in an extended sample volume during a single exposure. Using this "focal sweep" approach, we can substantially enhance the DOF and image volume while maintaining the desired optical resolution for identification of plankton. Our current prototype provides a pixel resolution of ~12 µm and can image plankton over a distance of 500 mm (DOF), thus exceeding comparable instruments (based on conventional optics) by 10- to 50-fold. This greatly increases the size range of plankton organisms than can be examined in a quantitative manner. Preliminary data suggests that organisms between 200 µm and 10 cm can be detected and classified.

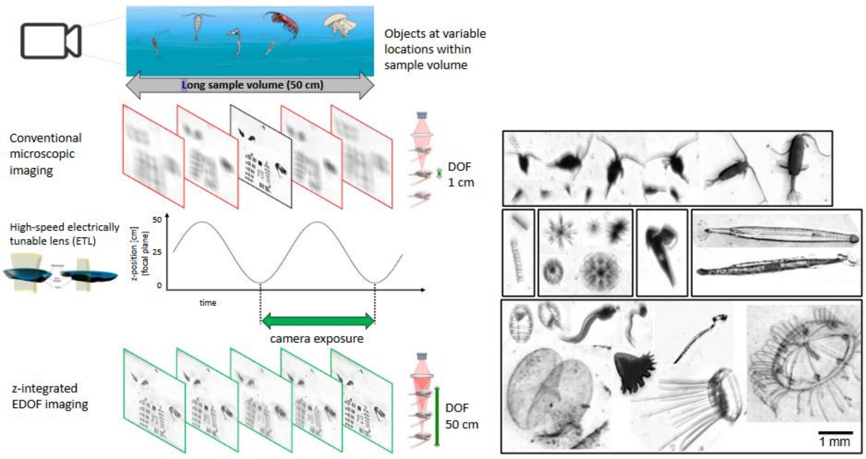

Figure 1: Principle of the EDOF imaging approach for plankton imaging to enhance the image volume for a given optical resolution (left). Examples of *in situ* images of different organism groups (right).

Large-scale photogrammetric survey and immersive visualization of seafloor outcrops

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Complex biogeochemical studies on the seafloor ranging from bathymetry to habitat mapping may suffer from a lack of situational awareness, especially when it comes to the assessment of morphologically complex areas such as hydrothermal vent sites or (sub-)vertical volcanic outcrops. Such sites are generally surveyed using remotely operated vehicles, with their camera system providing only limited field of view, limiting productivity compared to on-land studies. We briefly report advances of three interlinked projects to improve on this situation:
The Schmidt Ocean Institute funded cruise FK160320 visited the Niua South volcanic field in Tongan waters, photogrammetrically mapping an area 500m x 500m x 80m at “industrial” scales. We comment on the challenges of photogrammetrically processing and visualizing a data set of 220.000 images resulting in billions of 3D points, including the lessons learned regarding survey design.
The consequence of this expedition was the LIGHTHOUSE technology validation project, in which a highly integrated suite of acoustic sensors, cameras and laser scanners are fused to create a real-time 360° model of the seafloor surroundings. This project sported the development of the world’s first commercially available native underwater, deep-ocean capable survey lens in cooperation with Carl Zeiss Jena.
Lastly, we will touch on our efforts to visualize the seafloor in the spatially immersive ARENA2 visualization dome at GEOMAR (Fig. 1), facilitating quantitative visualization and virtual field work on the seafloor in small groups of researchers.

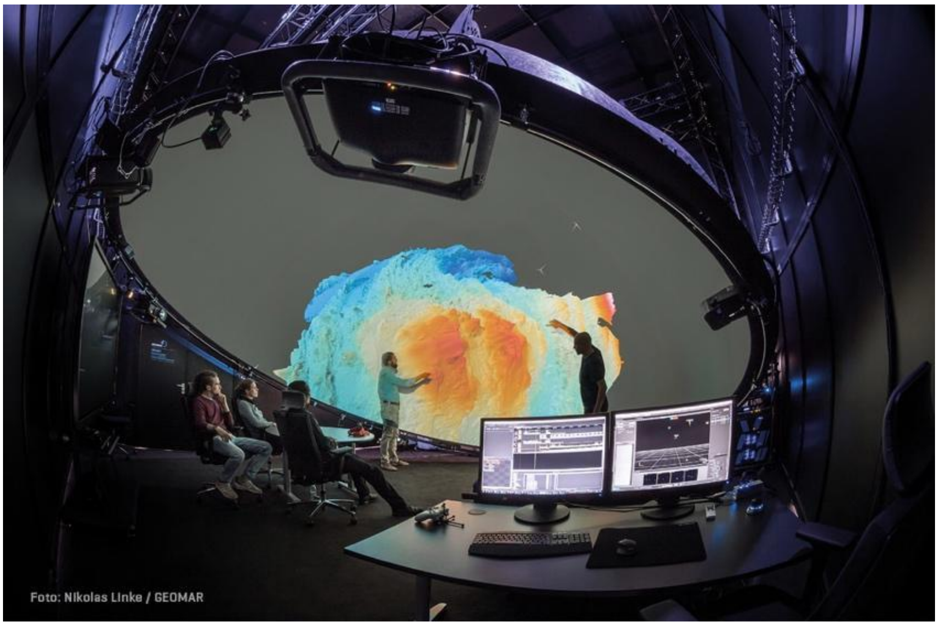

Figure 1: Visualization of seafloor terrain in the ARENA2 immersive visualization lab

A new workflow for space-time continuity and management of data acquired from deep-sea imagery observatory

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The development of deep-sea observatories now provides the ability to acquire long-term infra-annual data to resolve the temporal dynamics of underwater ecosystems. These observatories are often equipped with camera systems that record daily images to monitor the evolution of local habitats and their associated fauna. These imagery datasets allow to resolve habitat dynamics and biological processes that can occur over a wide range of temporal scales, from sporadic (e.g. predation), infra-daily (e.g. tidal influence), infra-yearly (e.g. season) to pluriannual and decadal time scales (e.g. habitat modification/disturbance, succession However, because these long-term systems require regular maintenance, slight modifications in the camera system position often lead to changes in the field of view. The analyses of spatial variations at the centimetre scale requires a flexible workflow, as well as automated in order to explore the large amount of imagery data. To this end, we developed a Python routine using the image sets collected from 2012 to 2019 by the TEMPO ecological module of the EMSO-Azores observatory (Lucky Strike vent field, Mid-Atlantic Ridge). By making use of homography, we developed a pre-processing tool to homogenise the image set and annotations over space and time. Furthermore, the routine is accompanied with the possibility of computing several ecological metrics for investigating spatio-temporal dynamics of the fauna and detecting the underlying processes at stake (e.g. total cover over time, multiscale detection of cover changes within images). While this pioneer routine still needs to be integrated in a single platform, it provides a baseline workflow for long-term imagery monitoring that can be applied to all observatories currently operating or under development.

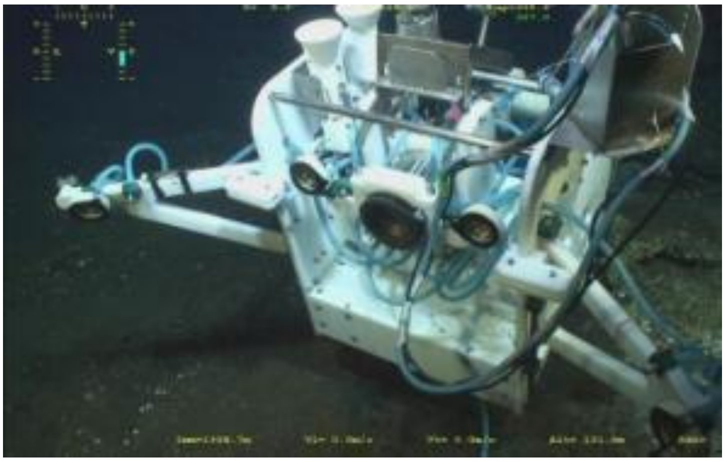

Figure 1: The TEMPO ecological module (EMSO-Azores observatory, Lucky Strike hydrothermal vent field, - 1700 m). The module has collected daily images for 7 years in order to monitor dynamics of the vent fauna. We used this extensive set of images to develop the workflow present in this study.

Posters

A new approach to use marine robotic networks for ecosystem monitoring and management: The PLOME Project

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Our understanding of marine ecosystem functioning and processes relies on adequate spatio-temporal multiparametric monitoring procedures. Over the next 3 years, the Project PLOME (Platforms for Long-lasting Observation of Marine Ecosystems) will implement a spatially adaptive and autonomous network of easy-to-use benthic landers with dockable Autonomous Underwater Vehicles (AUVs)ñ This network will be used to intelligently video-

monitor and map marine ecosystems and their environment from coastal to deep-sea areas. All platforms will be connected via acoustic or optical communication and will operate over periods of weeks to months with real-time supervision. Stations will provide continuous and intensive temporal observations, while dockable AUVs (with battery recharge and data downloading capability) will provide intensive measurements at various spatial scales, using intelligent and adaptive trajectories to explore surrounding areas. Biological, geochemical and oceanographic data will be generated by an array of sensors including acoustic receivers and cameras. Images will be processed in real-time for species classification and tracking, using advanced data analysis and Deep Learning techniques. Metadata will be communicated between landers and AUVs and transmitted opportunistically whenever an Unmanned Surface Vehicle (USV) connects the platform via aerial communications (i.e. GSM and satellite communications, depending on form distance to shore). The unattended operation will also be possible with an innovation of pop-up buoys that will allow data transfer to the surface from landers and UAVs to be relayed once the pop-up buoys reach the surface. Complex ecological indicators for ecosystem management will be computed from the collected data, by applying advanced computer vision techniques to classify, count and size individuals in video images and to generate multimodal maps of the seabed. A pipeline for automated data treatment will be tailored for multiparametric analyses to derive cause- effect relationships between biological variables and the physical habitats.

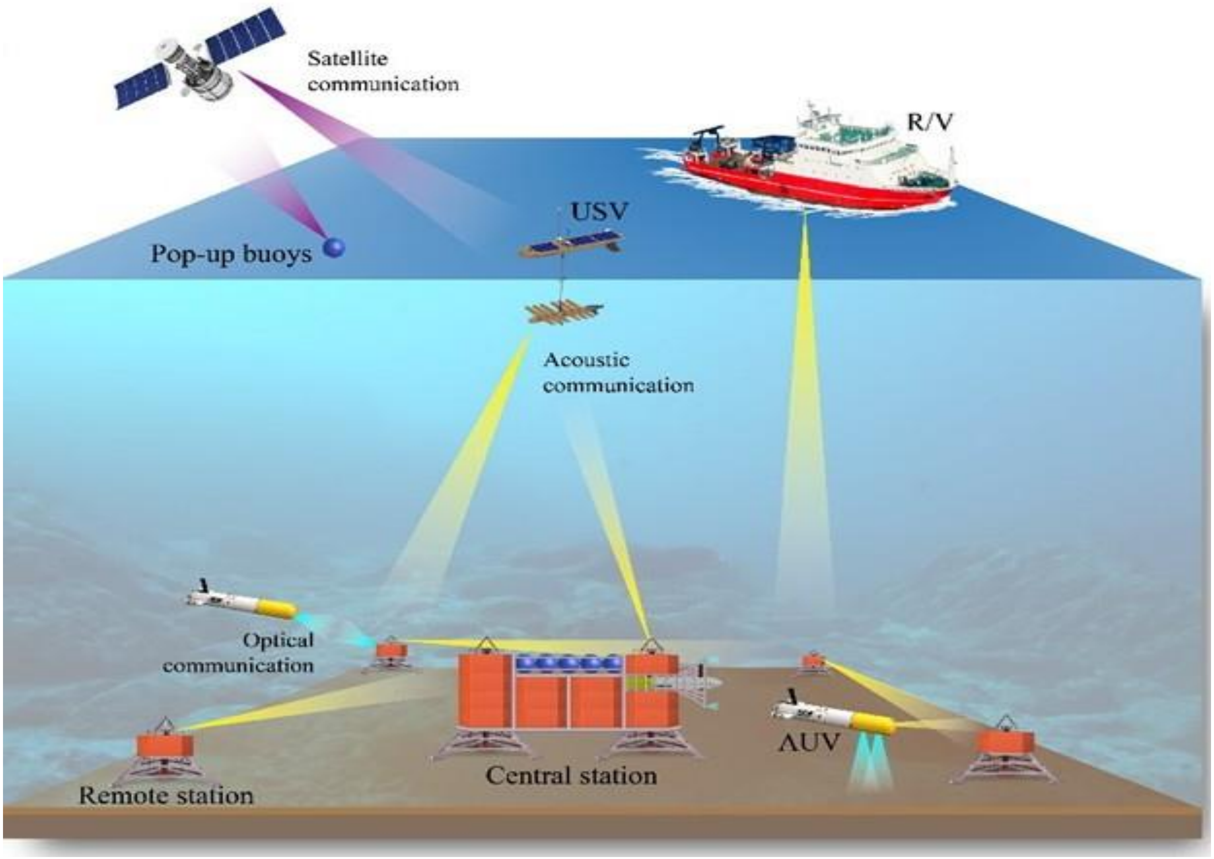

Figure 1. Schematic illustrating the varios scientific and communication platforms that will be incorperated in the PLOME project.

Novel *in situ* Camera System to Quantify Gelatinous Pelagic Community Structures

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Quantifying the role of deep-sea pelagic fauna (>1 cm) in carbon transport in an increasingly changing ocean requires technology that enables documentation of diversity and size of dominant taxa. Gelatinous zooplankton are ecologically important and abundant components of food webs and occur in the deepest ocean regions. Due to their fragility, they are easily destroyed and undersampled in traditional net sampling. This hampers identification and size/biomass estimation. The application of camera systems on ROVs and towed platforms have revealed an enormous diversity of gelatinous taxa in the deep sea. However, still little is known about the ecology, community structures and biomasses of gelatinous zooplankton in the deep sea. With the help of stereo vision, the size of organisms can be quantified *in situ* and their biomass estimated via allometric equations. We used a stereo camera system in midwater during the RV METEOR cruise M182 in the eastern tropical North Atlantic. There, we conducted horizontal stereo camera tows in depths between 25 and 1500 m along a productivity gradient from West to East at 18°N. Furthermore, we collected hydroacoustic and multinet data to support interpretation of the stereo camera data. The stereo camera was equipped with Ximea MX245CG-SY-X2G2-FL built with 24.5 MP Sony IMX540 sensors and DUW Distagon deep ocean metric 4.2mm f4 lenses developed by Carl Zeiss Jena GmbH in collaboration GEOMAR. This system was mounted on the towed platform XOFOS and two synchronized videos were recorded with a 4k by 4k resolution at 25 fps. Gelatinous organisms that we observed were Siphonophorae, Narcomedusae, Cestidae, Beroidae, Coronatae, Lobata (including *Kiyohimea usagi*), *Vampyroctena* sp., *Poeobius meseres,* Chaetognatha, and more. The size of these and other pelagic organisms (>1 cm) were measured via computer vision and photogrammetry methods. We present and discuss preliminary results of this novel approach for deep-sea imaging.

GRASSMAP – A case study on mapping seagrass with Lagrangian drifters

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The traditional way in which marine imagery is processed to identify species and/or habitats involves (1) field deployment of georeferenced imaging systems, (2) extraction of data through a physical connection (i.e. a tether or through the physical recovery of the system), (3) selection of a subsample of images for sparse description by human experts, and (4) use of aggregate statistics to represent the environment/region. This methodology limits the scale of interpretation to just a small fraction of the available data and introduces huge latency (months, years) when generating numerical summaries. Moreover, it needs dedicated research vessels or cabled infrastructure to support observations, which makes these operations prohibitively expensive. To make imaging in marine applications scalable, there is a need to eliminate reliance on tethering and/or recovery for data extraction and develop end-to-end automated workflows (both training and analysis) for information extraction that is robust to different targets and instrument specifications. Lagrangian drifters (LD) can overcome the abovementioned limitations on scalability and support infrastructure by not requiring dedicated support vessels and performing long-lasting missions. LDs have no means of self-propulsion, they drift with seawater currents whilst keeping a constant altitude to the seafloor. But the implications on how LDs data compares to standar AUV surveys was unknown at the time. To this end, the research cruise GRASSMAP studied the viability of Lagrangian drifters (LD) to perform common environmental montitoring surveying tasks instead of Autonomous Underwater Vehicles (AUV) in a case study on seagrass monitoring in the Mediterranean Sea. The cruise took place on Cabrera Marine Protected Area and the presentation will show a comparison on habitat classification for AUVs and LDs.

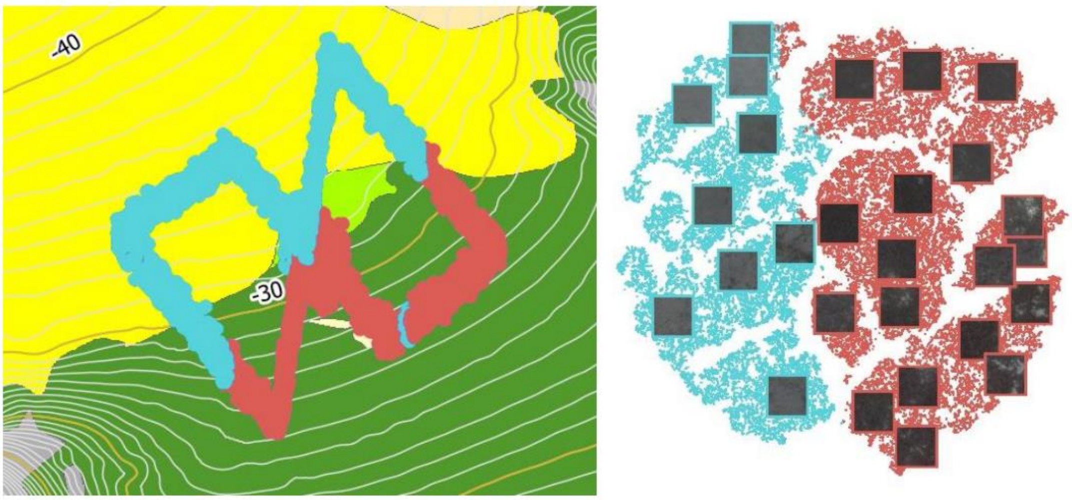

Figure 1: Habitat classification of three image mapping missions performed by Turbot AUV that will be compared to the results of the drifter. Images classified as sand in blue vs images classified as seagrass in red relate to the known biononomy of the area (yellow for sand, green for seagrass). On the right-hand side, the TSNE feature space shows a clear separation between the two classes.

Plenoptic and multi-camera imaging on ROVs and AUVs

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While underwater camera systems continue to become more advanced over time, three-dimensional imaging remains uncommon in high resolution applications across scales. However, this is essential for accurately determining sizing and density of marine organisms and organic particles, as well as studying the interaction of biological tissues with the fluid environment. To address this need, two camera systems were recently developed. EyeRIS is a plenoptic camera system designed for deployment by ROV, allowing detailed imaging of a volume 60 mL - 2 L at 60 fps, with realtime data feedback to the ROV control room, allowing for detailed sizing measurements as well as motion recording. The second system, confusingly named AyeRIS, is a 140 megapixel camera array with integrated strobes and computing capability for deployment by long range autonomous vehicles. Imaged objects and organisms are detected in real-time through traditional computer vision methods, and classified using modern machine learning models. Sample statistics from the imaged volume are then broadcast to the vehicle in real-time to aid decision making and inform targeted sampling strategies. In this talk, we will share instrument details as well as practical examples of data collected from both systems, relevant to key scientific questions.

Figure 1: (left) The ROV-deployed plenoptic imaging system EyeRIS imaging a deep sea coral (right) the multi-camera 3D imaging system AyeRIS integrated into MBARI’s Long-Range AUV in the test tank

Inelastic Confocal LiDAR for localized underwater measurements

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We present an underwater confocal continuous-wave (CW) LiDAR sensor capable of remote fluorescence measurements in a spatially confined probe volume. The system is based on a blue 450nm CW laser diode focused at a distance by a pair of lenses in a telescope configuration. The inelastic signal is collected coaxially and deflected by a dichroic mirror through a lens to be imaged onto an avalanche photodiode. A pinhole placed in the probe's conjugate plane eliminates the out-of-focus light to ensure axial confinement. The Rayleigh length of the laser beam, in combination with the pinhole, set the near-diffraction limited measurement volume. 3D imaging is accomplished through a combination of a dual-axis galvanometer scanning mirror and a linear z-translation stage for one of the telescope lenses. The sensor's spatial resolution is assessed by measuring the Point Spread Function at representative distances in controlled underwater conditions using sub-resolution microbeads as probes. The longitudinal and transverse resolutions are, respectively, around 5mm and 50µm at 0,6m distance, and 14mm and 65µm at 1,2m. A theoretical model describing the spatial confinement through the overlap integral between the transmitted beam and the virtually back propagated pinhole to the target space is also proposed and compared with the experimental results. Optical aberrations induced by the air-glass-water refractive index mismatch at non-normal incidence angles are discussed. Due to the inherent properties of our confocal inelastic LiDAR, superior three-dimensional resolutions can be achieved at distances of up to 5m when compared to ns-pulsed time-of-flight LiDARs. This novel tool can potentially be integrated in a submersible vehicle to enable in situ detection and imaging of sub-mm to mm-sized organisms (as plankton) in the water column.

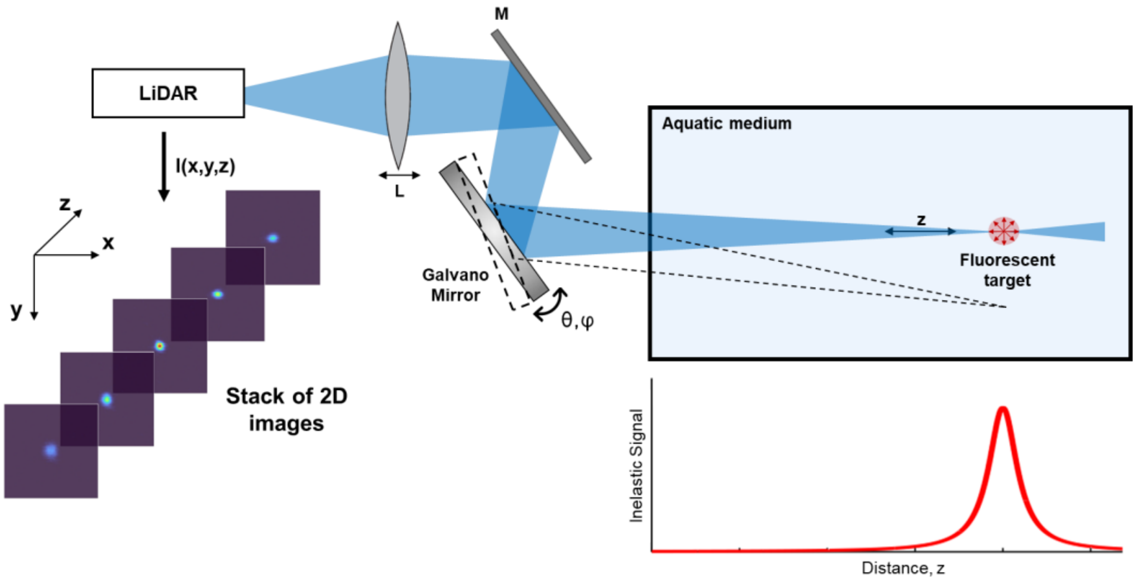

Figure 1: Simplified diagram of the confocal LiDAR system. For a matter of representation simplicty, refraction at the air-water interface is neglected (small-angle approximation). L: positive lens; M: Mirror.

A Guided Camera Calibration System for Underwater Applications

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Camera calibration is essential when calculating real world locations, angles or dimensions from image measurements, for visual robotics, and for optical mapping. For underwater applications, also properly treating refractive effects of waterproof housings is important, where light rays can change their direction at the interfaces between water, glass and air. Besides calibrating the important parameters, another option is avoiding or minimizing refraction during proper mechanical adjustment of a lens with respect to the port. In this work we propose a software tool that integrates state of the art procedures for camera and underwater housing calibration. Several mathematical camera models, dome and flat port housings together with different image acquisition scenarios are supported. The integrated pose suggestion procedure guides less experienced users to an efficient calibration. The software has been validated on raytraced data with ground truth and real imagery and will be made publically available to support computer vision applications in ocean sciences.

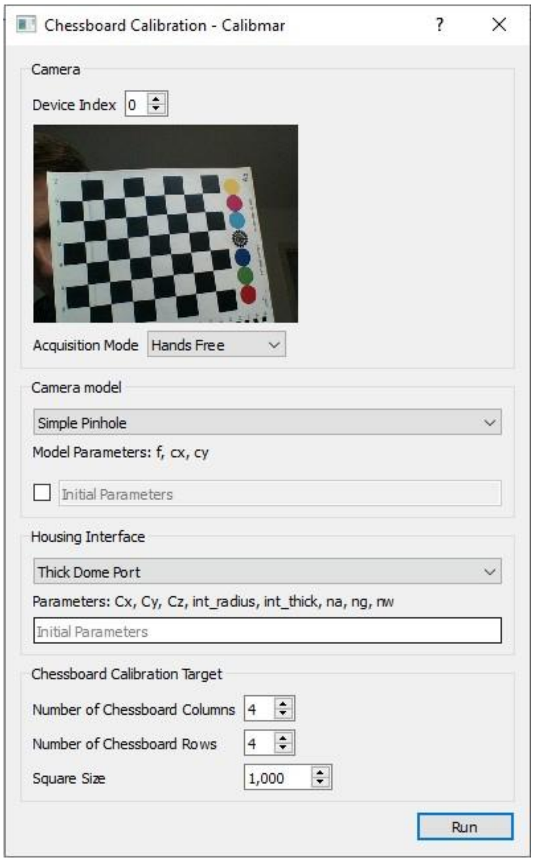

Figure 1: Screenshot of Calibration Software Prototype

Optimization of Lighting Configurations for Deep Sea Imaging Systems

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The deep sea covers more than half of Earth’s surface, most of these areas are still remaining uncharted. Vision systems typically provide high resolution data which is directly understandable by humans. They are being widely applied in deep ocean exploration tasks. However, light is absorbed when it travels through the water body and no natural sunlight penetrates to such depth. To film in the permanent darkness of the deep sea, underwater vehicles require artificial light sources to illuminate the scene. Compared to shallow water imaging, the image quality of deep sea vision systems are more significantly influenced by the lighting configurations. The co-moving light sources project illumination patterns onto the seafloor and create unique light scattering effects . Recent advances in light emitting diode (LED) technology provide more flexible illumination configurations with many small light sources but raise the question of how to arrange multiple light sources in order to achieve good image quality. To improve the image quality obtained by deep sea camera systems with many light sources we proposed a method that works by synthesizing virtual images for different lighting configurations, and analyzing image quality metrics, returning the best lighting configuration visited. Our early work has presented rasterization-based rendering using a coarse-to-fine approach to optimize the deep sea image quality under multi-light illuminations, which has been applied to autonomous underwater vehicles. While this method assumed neglectable scattering, ongoing work is integrating volumetric effects using ray- tracing to the illumination system design.

Tools for image annotation

Oral presentations

Evolving annotations: new tools to supplement existing annotations for machine learning

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Managing and annotating visual data collected by underwater camera platforms is labor-intensive and requires specialized, domain-specific knowledge of habitats and faunal communities. New annotation workflows that leverage machine learning aim to alleviate some of this demand on human experts. In exchange, machine learning models typically require vast amounts of task-specific training data, such as bounding box localizations for object detection. While a myriad of annotation systems exist for reviewing and cataloging visual data, many of these systems do not offer native support for the types of data needed for and generated by machine learning. In practice, working with external, generalized localization tools incurs integration overhead and an undue burden on annotators. Moreover, alternative annotation workflows, such as verification or correction of model-generated bounding box proposals, are not well-suited to existing tools. To enable these emerging workflows, we need interfaces to bridge the gap between existing annotation systems and modern machine learning data. To this end, we have developed two annotation-localization tools with the primary goal of seamlessly integrating with MBARI's Video Annotation and Reference System (VARS). The first, *VARS Localize*, enables rapid bounding box localization of existing VARS annotations on still-frame images that leverages the VARS knowledgebase and flexible association subsystem. The second, *VARS GridView*, provides mechanisms to query, sort, verify, and correct bounding box localizations in batch. These new tools, as adjuncts to VARS, have broadly enabled experts to supplement existing annotations with localization information. As a result, useful machine learning data can be generated and managed rapidly, lowering the burden on annotators and opening the door to new avenues in underwater visual data annotation.

Figure 1: Screenshot of VARS GridView.

Collaborative Exploration and Annotation of 4D geospatial data with the Digital Earth Viewer

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A comprehensive study of the earth system and its different environments requires understanding of multi-dimensional data acquired with a multitude of different sensors or produced by various models. These datasets may need to be analyzed through a collaboration between experts from different disciplines. Here we present a component-wise scalable web-based framework for simultaneous visualization of multiple data sources. It helps contextualize mixed observations, including image data and photogrammetric reconstructions, annotations and offers interactive multi-user capabilities, e.g. for annotating 3D visual seafloor information The Digital Earth Viewer is able to directly load and display file formats commonly used in the earth sciences field, such as GeoTIFF, netCDF, CSV, LAS and many more. Data can also be requested from network resources like WMS servers or OpenStreetMap. Loaded data can get represented both in gridded form as a virtual landscape or as point clouds, with special visualizations available for e.g. animated vector fields. Surfaces can be assigned real world data from photographic surveys (VR-like scenes), synthetic data products like heatmaps or any kind of raster derivatives. The application backend was written in the Rust programming language and features a web frontend using Typescript and WebGL for performant 3D graphics.Its server/client separation enables that multiple users can connect to a shared scene simultaneously to explore and annotate collaboratively in real time. Real-time annotations can be stored and reused later, existing annotations as from OFOP or BIIGLE can be loaded to the scene and displayed on the chosen surface layer.It is distributed as a single executable file for Linux, Windows, or Mac which launches a web application that can be used locally or hosted online. Its source code is openly available under the EUPL license.

Figure 1: Photogrammetric reconstruction of subsea munitions in the Digital Earth Viewer with annotations and measurements

SeaTube V3: Evolution of a browser-based underwater video annotation tool

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SeaTube V3 is Ocean Networks Canada's 3rd-generation, all-in-one, browser-based dive video viewer and annotation tool. Developed in-house and officially launched in 2021, it is the default platform for all dive logging at ONC, and has been adopted by organizations such as NOAA and Fisheries and Oceans Canada. While its predecessors have been in use since 2013, SeaTube's 3rd iteration underwent a complete front- and back-end makeover, updating everything from the user interface, to annotation structure, to the database model. The main focus for STv3 development was twofold. One: improve annotation quality, consistency, and searchability through the introduction of taxonomy structures. Two: provide an enhanced user experience adaptable to the needs of any logger, from beginner through domain expert. This approach led to an entirely new look and feel (see *Figure 1*), with dozens of updated features, including:

- Integration of external taxonomies - WoRMS and CMECS for biological and ecological annotations
- Ability to create user-defined taxonomies for standardized annotations tailored to organizational needs
- Highly configurable dashboard-style logging UI offering a wealth of options to customize layout elements, with preferences saved across sessions
- Synchronized video, annotation, map/bathymetry, and ROV sensor data displays
- Support for multiple simultaneous dive loggers on ship and shore
- Button-based, one-click 'Quick Entry' logging utilizing user-defined button sets

Dive logging with STv3 can be as simple or complex as the user or organization deems necessary, from simple free-text comments to highly structured annotations based on widely-adopted standards and pre-loaded with default attributes for ease of use. STv3 is under ongoing development using an agile software framework, and continues to incorporate feedback and implement improvements. ONC is eager to demonstrate SeaTube V3's capabilities to the broader marine imagine community, and solicit feedback about what our target audience wants and needs in a high-quality, one-stop video annotation package.

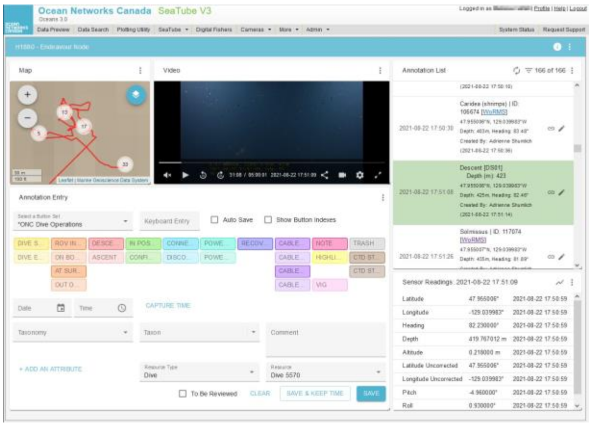

Figure 1: The SeaTube V3 UI

RESTful API plugins for SquidJam - a video annotation ecosystem for multi-camera datasets.

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SquidJam is an ecosystem of API-based tools that integrate with the marine image data management, discovery and annotation platform "Squidle+" (squidle.org) and the Squidle+ plugin, “SquidvidPRO”, a custom local video player. We describe this integrated system, which includes extensions for realtime and post-processing analysis to acquire and annotate video data streams from remotely-operated vehicles (ROVs) with their associated metadata at sea, through to supplying data repositories with the survey results. Rapid re-annotation back in the land-based lab is facilitated by using realtime annotations logged in the field to index into relevant parts the video files, based on field observation timestamps. Such post- cruise annotations for the production of a cruise report can be kept sandboxed from more methodical linear re-annotations through a multi-user login permissions and management system. Organism occurrence data can be exported to DarwinCore format for ingest into the Ocean Biogeographic Information System (OBIS), while localized image annotations can be output to produce training sets for machine-learning applications (eg. COCO format). Tags applied to annotations identify multiple annotations of single organisms to enable both quantitative analyses and the export via restful APIs of within-image object location data for linking with external tracking algorithms. Work has also begun on developing plugins for measuring organism sizes based on stereo camera image pairs.

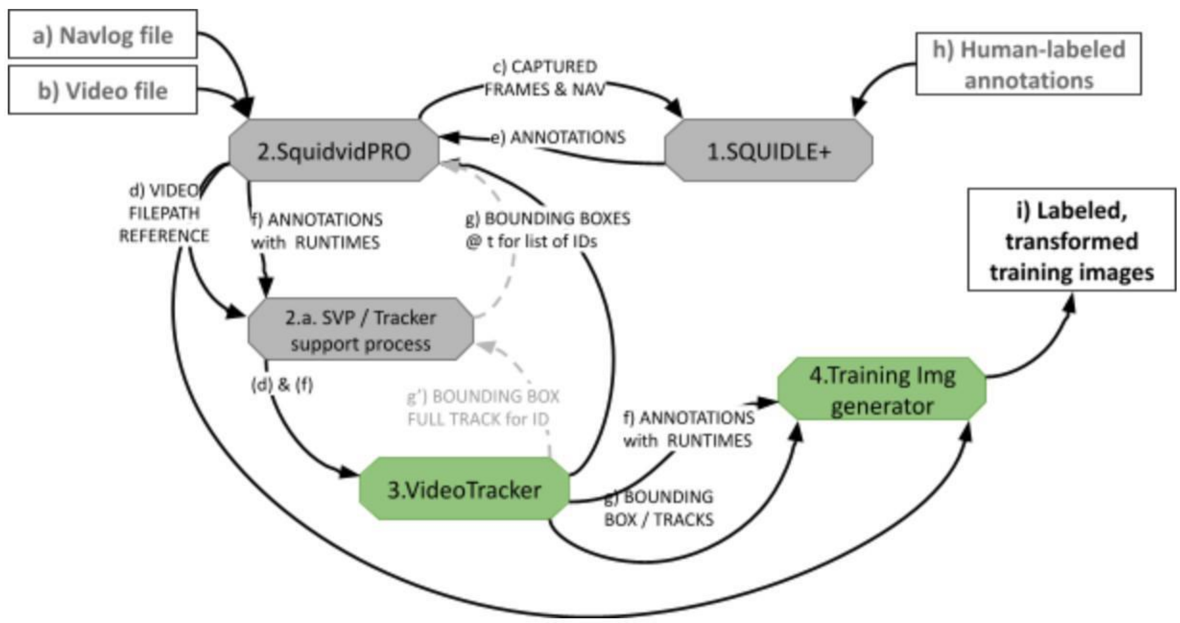

Figure 1: Video annotation system diagram.

An interactive tool for labeling plankton image datasets

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In recent years, convolutional neural networks (CNNs) have gained increased attention for achieving state-of-the-art results in many classification tasks. However, a known challenge for properly training CNNs is the requirement of a big amount of labeled data. Manually labeling a dataset of images may take a very long time and may result in wrong or inconsistent labels due to fatigue or subjectivity. Also, effort is often spent labeling exemplars of most frequent classes, when it would be desirable to direct such effort to label exemplars from less frequent classes. To help dealing with these problems, we developed a browser- based tool for labeling and revising labeled plankton image datasets. Our tool uses t-SNE for projecting features extracted from a set of images onto the 2D plane, where each image is represented as a point in a scatter plot graph. Features are extracted using pre-trained CNNs (usually on other datasets), and they are rich enough to project similar images grouped close together. Users can interact with the projection graph by selecting and analyzing specific clusters or regions in detail. Recent implementations of t-SNE enable stable projections, such that when new images with similar features are projected they will fall approximately at the same sub-region of the graph. We envision different types of uses for this tool, such as (i) bulk labeling of clusters of images, (ii) quick and large scale label verification and correction of manually or automatically labeled datasets, and (iii) quick examination of particular species of plankton, taking advantage of the fact that it is likely that they will be mostly projected to a same sub-region in the graph.

Figure 1: Interface of our tool.

Managing Digital Video at MBARI

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The Monterey Bay Aquarium Research Institute (MBARI) has been recording and archiving underwater video from remotely operated vehicles since 1987. This video is currently managed and annotated using MBARI's Video Annotation and Reference System (VARS). The tenants of VARS—using a controlled vocabulary and a centralized archive of expertly- curated annotations—have proven extremely effective for generating quantitative and qualitative information from images and video. Over 500 peer-reviewed publications have been written using data from VARS. In the last few years, a number of shifts have occurred in how video is managed at MBARI. These include: the transition from recording ROV dives onto video tape to recording digital video files; converting the large existing library of video tapes to digital video files; development of machine learning pipelines and training sets; investigations of tooling to support machine learning generated annotations; and investigations on how to combine and present digital video annotations. This talk will present a high-level overview of video data management at MBARI as well as tools that are being created to tackle the challenges and opportunities due to the emergence of machine learning.

Efficient Annotation of Plankton Images: Progress of the MorphoCluster project

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Marine image data needs to be annotated to make it accessible for further analysis, which is a time-consuming and costly task. However, volume and complexity of marine data have already surpassed the annotation rate of human experts and will continue to increase in the coming years. MorphoCluster is a software tool for data-driven, fast, and accurate annotation of large image data sets. It addresses the problems of conventional, classifier-based image annotation approaches (their limited efficiency, training set bias and lack of novelty detection) by using clustering and similarity search to enable efficient, computer-assisted image annotation. Recently, we performed a deeper analysis of this approach. We find that labeled training data improve the image representations, that unsupervised learning beats transfer learning and that the utility of different clustering algorithms depends on whether completeness, efficiency or runtime is the priority.Here, we also show examples of how we used MorphoCluster in current projects to add new images to existing datasets or detect unexpected patterns in the data like dirty or misaligned optics.1

Past, present and future of the BIIGLE annotation software

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A crucial step in the analysis of marine imaging data (i.e. digital photos and videos) is semantic annotation. Software assistance is nowadays essential to make this task efficient and reproducible. Presented over ten years ago as the first web-based annotation tool, the BIIGLE software has now reached a high level of multi-dimensional functionality and community acceptance. The main application instance on biigle.de hosts an international community of over 1,500 users with millions of image and video annotations. Here, we present a selection of new and improved BIIGLE features for annotation, collaboration and data management that were developed in the recent years. First, a new tool for video annotation already highlights a substantial interest in this area. However, we notice differences to image annotation that are most evident through the time required for each of the tasks. Second, new features for mobile deployment, data synchronization and instance federation support flexible use cases. Third and most recently, the support for the emerging iFDO standard for image metadata and annotations paves the way for better interoperability between software tools. We also present quantitative observations how BIIGLE has been used over the last years by the community. While the software has been developed to facilitate collaboration, most of the annotation tasks are still conducted by individuals. The substantial ratio of registered users without annotations hint to a new upcoming BIIGLE use case for teaching and exploration. We conclude with an outlook on the future development of BIIGLE. One focus will be work towards a more active community of users and developers. Users should be encouraged to exchange experiences, help each other and provide valuable feedback for the developers. At the same time, the development of BIIGLE must become more of a community effort in order to become more sustainable.

Posters

SQUIDLE+: online tool for managing, exploring, annotating and understanding marine imagery

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Squidle+ (SQ+; squidle.org) is a marine image data management, discovery and annotation platform that forms the foundation of the new IMOS Understanding Marine Imagery (UMI) facility. UMI currently contains ~7.4M images, ~12K deployments, >1.2K users and >2.3M annotations (@15MAY22) and is growing rapidly. SQ+ is feature-rich and designed to be flexible, collaborative and enable modern workflows: ● Works by leveraging preexisting cloud-based storage repositories to harvest data in flexible formats. Once a datasource has been defined, a background service can be scheduled to import new datasets upon upload, automatically. This expedites post-cruise data delivery, eliminating data handling and the need to preprocess data for import. ● The centralised repository for annotations maintains links to the underlying survey data, providing tools for map-based exploration, summary/reporting with advanced annotation workflows. ● Sharing, collaboration and release of datasets are managed through user groups with granular permissions and data provenance and acknowledgements are tracked throughout the system. ● A comprehensive API makes it possible to build custom reporting tools and dashboards and to integrate automated annotation algorithms. The OGC-compliant data outputs facilitate integration with various third-party web-portals. ● Offers different annotation modes (whole-frame, points, polygons) and is designed to be media-type agnostic (images, videos, large-scale mosaics). ● The workflow includes QA/QC tools, including review flags and a dedicated QA/QC view for rapid, batch correction of labels. Supplementary annotations can be used to facilitate cross-validation between human annotators and between humans and algorithms. ● Supports multiple vocabularies, and has a semantic translation framework which enables standardisation in the labelling, allowing annotations to be cross-mapped and exported in a vocabulary of a user's choosing. This facilitates data reuse, syntheses between projects and large-scale training of machine learning algorithms. We present an up to date overview of SQ+ capabilities, example use cases and integrations.

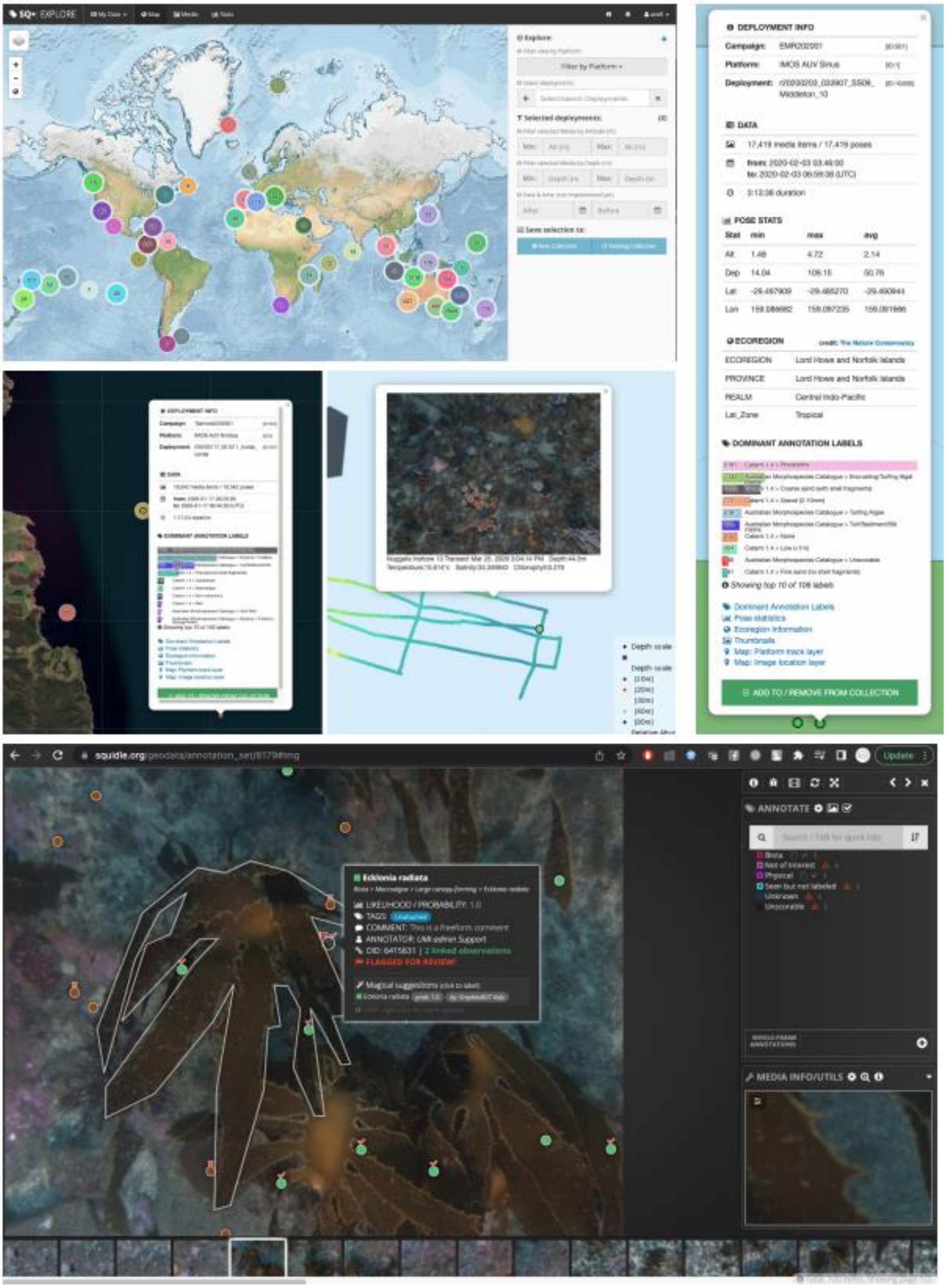

Figure 1: Showing map exploration interface with annotations summaries. Also annotation interface supporting polygons, bounding boxes, tags, comments, searchable annotation sche

SquidJam - a video annotation tool for the analysis of challenging video datasets: A case study on a midwater Environmental Impact Assessment in the Clarion-Clipperton Zone.

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SquidJam is an ecosystem of API-based tools that integrate with the marine image data management, discovery and annotation platform "Squidle+" (squidle.org) and the Squidle+ plugin, “SquidvidPRO”, a custom local video player. We present this workflow as a solution for dealing with data from Environmental Impact Assessments on Deep-Sea mining using imagery from a commercial ROV with sub-optimal lighting and challenging video analysis. SquidJam enables annotations to be done through playback of local video files that can be terabytes in size. The custom SquidvidPro player, compatible with most video formats and codecs, including full 4K or even 8K resolution Apple ProRes 4:2:2 codec video files, enables real time playback with frame-accurate shuttling and single frame forward and backward jogging. Frame captures at full resolution are sent to Squidle+, where environmental metadata is also displayed for easy data quality checking. During some transects, tens of similar organisms occurred simultaneously in video frames. Multiple tags can be applied to annotations, which can also be linked, and each annotation instance has an easily visible ID to facilitate quality control, enabling such transects to be successfully annotated. SquidJam annotations used the Aphia ID/WoRMS vocabulary with extensions. Localized image annotations can be output to produce training sets for machine-learning applications (eg. COCO format). Most image datasets provided as training sets for machine learning applications use optimally lit, in-focus images where organisms fill a large portion of the screen. In the real world, for most videos that need analysing this is rarely the case, and the current dataset should therefore prove invaluable for real world applications. In this presentation we introduce SquidJam functionality using a real world video dataset.

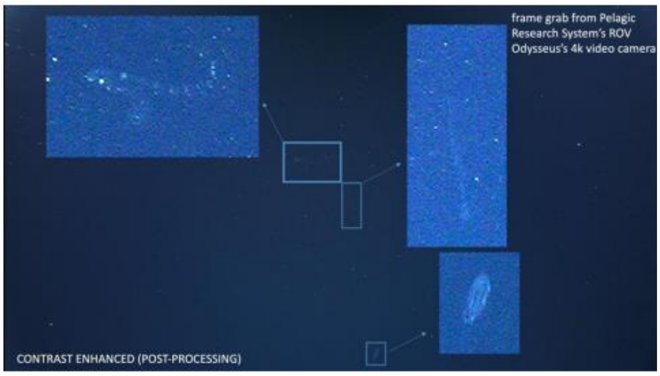

Figure 1: Sub-optimally lit ROV video example.

The benthic assemblage analysis in SE Baltic Sea reefs and Svalbard bays using Labelbox

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Underwater camera techniques are widely used in seabed habitat classification and mapping, marine environmental monitoring and impact assessment. However, underwater imagery analysis generally consists of a set of laborious and exceedingly time-consuming tasks, suggesting a strong need for automatization.
During the 2021 summer-autumn sampling season we filmed 289 video transects in offshore reefs and 66 in coastal reefs in Lithuanian marine area. Underwater video from Svalbard was collected during the 2018 - 2019 summer expeditions in 4 bays at 2-65 m depths. Data acquired was used for the extraction of video frames and the creation of 2D video mosaics. Visual features in frames and 2D mosaics were annotated using Labelbox tool. Annotated imagery was then used to train deep learning models for automatic detection and quantification of biotope features. For deep learning model we used 2-fold transect-stratified cross-validation, 50% of the imagery for training and 50% for testing. Also, we used annotated UWM to study the structure of the benthos in the upper sublittoral in two areas of western Spitsbergen, Isfjorden and Hornsund under various conditions: from ice melting and turbid river bays to glacier influence-free areas.
The results from underwater imagery analysis will be further used for the assessment of sea-floor integrity descriptor under MSFD, while the development of deep learning models for automated quantification of biotope defining visual features can lead to a more efficient and extensive video data analysis.

Optimizing underwater imagery protocol to monitor macroepibenthic communities colonizing artificial structures

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Underwater imagery is increasingly used as an effective and repeatable method to monitor benthic ecosystems. Nevertheless, extracting relevant ecologically information from a large amount of raw images remains a time-consuming and somehow laborious challenge. Thus, underwater imagery processing needs to strike a compromise between time-efficient image annotation and accuracy in quantifying benthic community composition. Designing and implementing robust image sampling and image annotation protocols is therefore critical to rationally address these trade-offs between ecological accuracy and processing time. The aim of this study was to develop and to optimise a reliable image scoring strategy based on the point count method using imagery data acquired on tide swept encrusting benthic communities. Using a stepwise approach, we define an underwater imagery processing protocol that is effective in terms of i) time allocated to overall image analysis (~45 minutes per picture and 6.75 hours for all replicates of a site), ii) reaching a satisfactory accuracy to estimate the occurrence of dominant benthic taxa (with a mean percentage cover ≥ 5%) and iii) adopting a sufficient taxonomic resolution (i.e. the so-called 'CATAMI' classification that is accessible to non-experts) to describe changes in community composition. We believe that our method is well adapted to investigate the composition of epibenthic communities on artificial reefs and can be useful in surveying colonisation of other human structures (wind turbine foundations, pipelines etc.) in coastal areas. Our strategy meets the increasing demand for inexpensive and time-effective tools for monitoring changes in benthic communities in a context of increasing coastal anthropogenic pressures.

Tator: A web-based platform for collaborative video annotation and automated analysis

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The number of platforms for visual observations of the ocean continue to accumulate, resulting in an avalanche of video and image data to process. Often these data are collected by one group or institution, but visual analysis requires collaboration between multiple expert teams located in disparate geographic locations. Effectively sharing massive volumes of video, including tools to create synchronize attendant metadata is a challenge. Since 2019 we have been developing Tator, a web-based tool for collaborative analysis and annotation of video and image data. Tator enables seamless analysis of media from expert teams across the world, with a single copy of the data and centralized collection of observations. Tator utilizes advanced transcoding and video playback features (e.g., multi-resolution streaming) to enable users with a range of internet connections to effectively access data. In addition to manual annotation and curation, increasingly machine learning (ML) algorithms are playing a role in visual analysis. Tator outputs curated data into common data formats for training ML algorithms (e.g., Pascal VOC), and allows viewing machine generated annotations in “layers” for algorithm validation and verification. Tator integrates algorithms and compute resources, facilitating analysis and QA/QC workflows directly within the platform, as well as experiences such as algorithm assisted annotation and tracking. The ability to connect to any model serving architecture, a fully featured REST API, and a complete python bindings library means that Tator can serve data science needs directly, without having to constantly snapshot and download new versions of data. CVision AI’s managed instance of Tator currently hosts over 40,000 hours of video, over 1 million images, and tens of millions of annotations, both human and algorithm generated. Tator is currently used by research, academic, for profit, and government agencies for video curation and analysis, in both underwater exploration and commercial fisheries management.

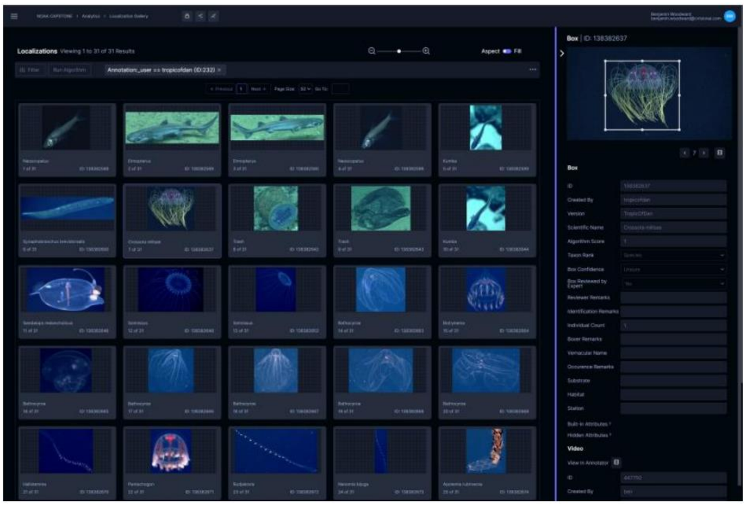

Figure 1: Tator Analytics view showing annotations from a single user across multiple media within a project. Rich filtering capabilities allow refininement based on user, sensor metadata, or even algorithm confidence

Automated image processing

Oral presentations

Exploring the potential of using multispectral imagery for mapping coastal living resources of intertidal rocky shores

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Monitoring intertidal assemblages traditionally involves targeting small areas of the rocky reef using quadrats, along transects or not, and collecting data on species biological traits. These methods are labour intensive and cover only a small area of the rocky reef due to time/tide constraints. In recent years, the application of Unmanned Aerial Vehicles (UAV) or Unoccupied Aircraft Systems, as low-cost yet efficient monitoring solution has increased in several contexts reducing the disparity in scale between traditional remote sensing methods and on-ground monitoring techniques in various ecosystems. New sensors, such as multispectral cameras, that can be integrated with UAV, have been developed providing new tools for research implementation. This work presents the workflow for the assemblage of supervised classification maps in the intertidal zone of Vila Chã rocky shore (Portugal) along four sequential sampling UAV flight campaigns during 2020. The same workflow will be will be applied to multispectral data from Viana do Castelo rocky shore collected during 2022 in the scope of the project BlueForesting. Multispectral data were acquired with a UAV equipped with a MicaSense RedEdge camera. At Vila Chã, supervised classification maps were obtained with the QGIS Supervised Classification Plugin using seven training per class areas, and three independent training areas were used for validation procedures. A decrease in seaweed cover was observed from July to December 2020, in line with the predicted seasonal patterns, despite some misclassification of underwater seaweeds. Fluctuations in the cover of the other classes were the reflection of sediment movements caused by hydrodynamics, affecting particularly sand, and recruitment patterns for the main sessile invertebrates. There is potential for using multispectral imagery to map intertidal areas, such as the sheltered upper rocky shore at Viana do Castelo, although improvements must be made for mapping underwater elements of shallow rock pools.

On the importance of training dataset preparation for fishes detection and classification in underwater images

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Deep learning is becoming more and more popular in marine ecology to process underwater images and videos. Implementations of several architectures are now easily applied to any field, with just the need of having a labeled dataset of the objects of interest. In the case of marine fish, most of the available underwater fish images datasets are from tropical areas. There is a lack of labeled data from temperate areas such as the Mediterranean, making it necessary to create species (and background)-specific datasets.

Here we present an experiment with different underwater background images from the Mediterranean Sea. More than 1500 images have been annotated, labeling all fishes with their species names, (20 species). FASTER RCNN has been chosen to train different scenarios with the aim to understand the basics for a good (if any) generalization, how do the small fishes affect the precision, how many images are needed and if they should be randomly selected or not, questions that have not been completely solved in the literature yet.

The first results indicate that it is possible to work with fewer images if they are carefully selected. The generalization of the training for using an unseen dataset improves with the use of different backgrounds in the training dataset. The color preprocessing of images plays a principal role in the annotation process but also in the training results. Finally, avoiding images with small fishes in the training set is translated in better precision and recall results.

Cloud-enabled benthic underwater video annotation

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MBARI fields high-resolution video equipment to record hundreds of deployments of our remotely operated vehicles (ROVs) and other platforms (e.g., miniROV, AUV, still camera) each year. Since 1988, more than 27,005 hours of underwater video have been archived, annotated, and maintained as a centralized institutional resource using MBARI's Video Annotation and Reference System (VARS). MBARI's digital video library contains detailed footage of the biological, chemical, geological, and physical aspects of Monterey Bay and other areas.Extraction of information from the video is a mission-critical capability at MBARI. Our mission is to share our technology to help the entire oceanographic research community collect more information about the ocean.Our new development is an AI-powered augmentation to our existing manual annotation process. Using a cloud ecosystem, we apply state-of-the-art machine learning techniques to the problem of extracting scientific knowledge from the video. Video captured at sea in high-definition and 4k formats is prepared onshore for analysis and then transferred to the cloud in low or high-resolution format, triggering a scalable batch prediction workflow. A web dashboard presents the results, and a custom video player is used to edit the results in VARS.This system runs AI algorithms to detect objects of interest in video, tracks objects (to enable enumeration), and classifies them to the most precise scientific level possible against a standard taxonomy. Abundant training data, including 1308 unique taxa/concepts, 198634 bounding boxes, and 96602 total images expertly curated by our specialist video annotators, are used to train and validate the system. Multiple detection models, classification models, and tracking systems run in the cloud to meet the varying levels of annotation needs.We present results applying this system to benthic videos, and report costs, ease of use, and community access to our products.

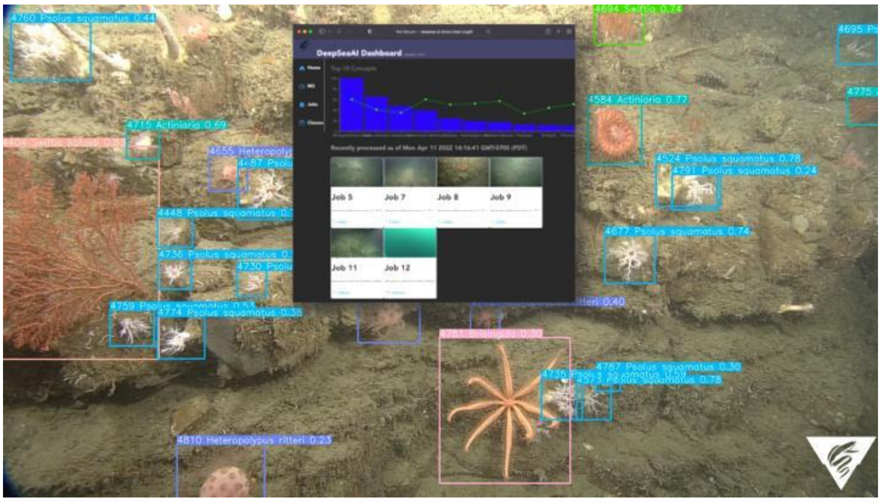

Figure 1: Top-level view of the web dashboard and example detections from our YOLOv5 detection and DeepSort tracking pipeline

Find the good imaging technique for automatic identification of meiofauna - Part of the Blue Revolution project.

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Meiofauna includes all benthic (sediment-dwelling) metazoans in size range from 20µm to 1mm that live in sediments. Due to their high abundance, diversity, wide distribution, relatively fast generation times and rapid metabolic rates, infaunal benthic organisms are one of the best marine bioindicators available for assessing ecosystem health and global environmental changes. However, today only a small fraction of this diversity has been described, and knowledge of their biology and ecology is fragmentary. The BLUE REVOLUTION project will develop imaging protocols coupled with Deep Learning-based classification tools to generate quantitative and functional data of benthic communities at rates never seen before. However, several factors related to meiofanua communities imply that imaging meiofauna is not a simple task. The benthic compartment is a complexe matrice with high proportion of sediment and organic particles. This implicates the need to separate meiofauna of interest before imaging, thus limiting *in situ* observations. Also, the relative large size range implies the use of complementary imaging technics. And finally, the resolution needed for taxonomic identification have to be in accordance with the size of morphologic details necessary for taxonomic identification. With all these requirements, the choice of imaging method is a game of trade-offs that must be decided in relation to the fundamental scientific question. This is a key step consider further developments of automatic identification of meiofauna by machine learning.

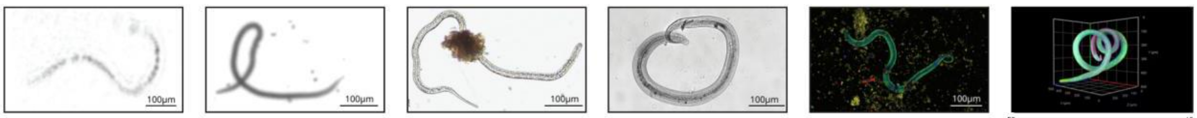

Figure 1: Nematodes imaged with 6 different imaging system from low (left) to high (right) resolution.

Simple and accessible machine learning for automatic classification of broad-benthic habitats

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Identification of benthic habitats from imagery is fundamental to marine spatial planning. Automation through Machine Learning, particularly transfer learning, has proved to be a powerful way to overcome time and resource limitations. Here, pre-trained and general convolutional neural networks (CNNs) are used with an additional domain-specific tuning step. However, these techniques are complex. They are often left inaccessible to a non- specialist, as they require large investments in time (for comprehension by the user and for training) and computational resources.

We demonstrate that we can use transfer learning, for classifying benthic habitats, in a much simpler framework. Specifically, we take an 'off-the-shelf' CNN (VGG16) and use it to extract features from benthic images (without further training). The default outputs of VGG16 are then fed in to a Support Vector Machine (SVM), a classical and simpler method than deep nets. We explore the discriminative power of our VGG16+SVM classifier on three benthic datasets (574-8354 images) from Norwegian waters; each using a unique imaging platform. Benthic habitats are broadly classified as soft substrates (sands, muds), hard substrates (gravels, cobbles and boulders) and reef (*Desmophyllum pertusum*). Each dataset was split into 80\% training and 20\% testing and SVM hyperparameters tuned using 5-fold cross validation of the training set, taking between 1.5-123 minutes.

This approach performed well, with test accuracy ranging from 0.83-0.95 (average= 0.88 (±0.07)), increasing with dataset size. Average recall and precision results were also good across datasets, with 0.82 (±0.1) and 0.86 (±0.11) respectively. This framework is simple, fast and consistent. It's usage is particularly suited for offshore use; offering near real-time decision making, development of sampling protocols, triaging data collection and providing quick, albeit crude, insights into habitat presence. It can also support automation by grouping images into similar categories, for annotation or model selection, and be used to screen old- datasets.

Conserving deep-sea coral reefs: applying deep learning to remote sensed image data

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The conservation of deep sea Vulnerable Marine Ecosystems (VMEs) has become an important issue for global marine management. Effective management of these environments requires that we understand where VMEs occur and how they are impacted by fishing operations such as bottom trawling. Image-based remote sensing surveys have conventionally been used to map and monitor VMEs, but are limited by their prohibitive expense and significant human annotation effort. With the ongoing improvement of underwater remote sensing technologies, coupled with key data acquisition partnerships with commercial fishers, we are anticipating an order of magnitude increase in the volume of data that will soon become available. However, the full value of these data can only be realized if image processing and annotation can keep up with the increasing rate of data acquisition. We have approached this problem by implementing a deep learning system to classify reef- building stony corals amongst other seabed substrata and fauna. Using a previously annotated dataset, we trained a convolutional neural network on approximately 75,000 classified images comprising 6 benthic substrate classes, including 'coral matrix'. We investigated a range of model performance improvements including dataset cleaning, transfer learning, and hyperparameter optimisation, that together resulted in the final trained model achieving validation accuracy and F1 scores of 98.11% and 0.96 respectively. Our analysis showed that the trained deep learning system was able to accurately differentiate benthic substrate types, in some cases more consistently than human annotators, and can be used to inform marine management processes. These results demonstrate a prospective solution to automatically process large volumes of industry-collected image data and improve the protection and management of deep-sea coral reef VME.

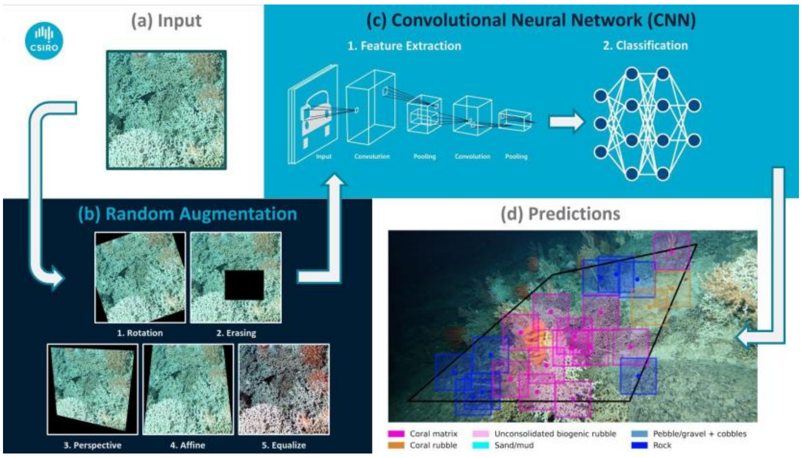

Figure 1: Deep coral classification data pipeline

FathomNet: An open-source image database for training underwater artificial intelligence

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Ocean-going platforms are integrating high-resolution, multi-camera feeds for observation and navigation, producing a deluge of visual data. The volume and rate of this data collection can rapidly outpace researchers' abilities to process and analyse them. Recent advances in machine learning enable fast, sophisticated analysis of visual data, but have had limited success in the ocean due to lack of dataset standardisation, sparse annotation tools, and insufficient formatting and aggregation of existing, expertly curated imagery for use by data scientists. To address this need, we are building FathomNet, a public platform that makes use of existing (and future), expertly curated data. Initial efforts have leveraged MBARI's Video Annotation and Reference System and annotated deep sea video database, which has more than 6M annotations, 1M framegrabs, and 4k terms in the knowledgebase, with additional contributions by National Geographic Society (NGS) and NOAA's Office of Ocean Exploration and Research. FathomNet has over 100k localizations of 1k midwater and benthic classes, and the database and portal (www.fathomnet.org) was released in late 2021. We will demonstrate how machine learning models trained on FathomNet data can be applied across other institutional video data, (e.g., NGS' Deep Sea Camera System, MBARI's I2MAP-AUV, and NOAA's ROV *Deep Discoverer*), and enable automated acquisition and tracking of midwater animals by underwater vehicles. As FathomNet continues to develop and incorporate more image data from other oceanographic community members, we hope that this effort will ultimately enable scientists, explorers, policymakers, storytellers, and the public to understand and care for our ocean.

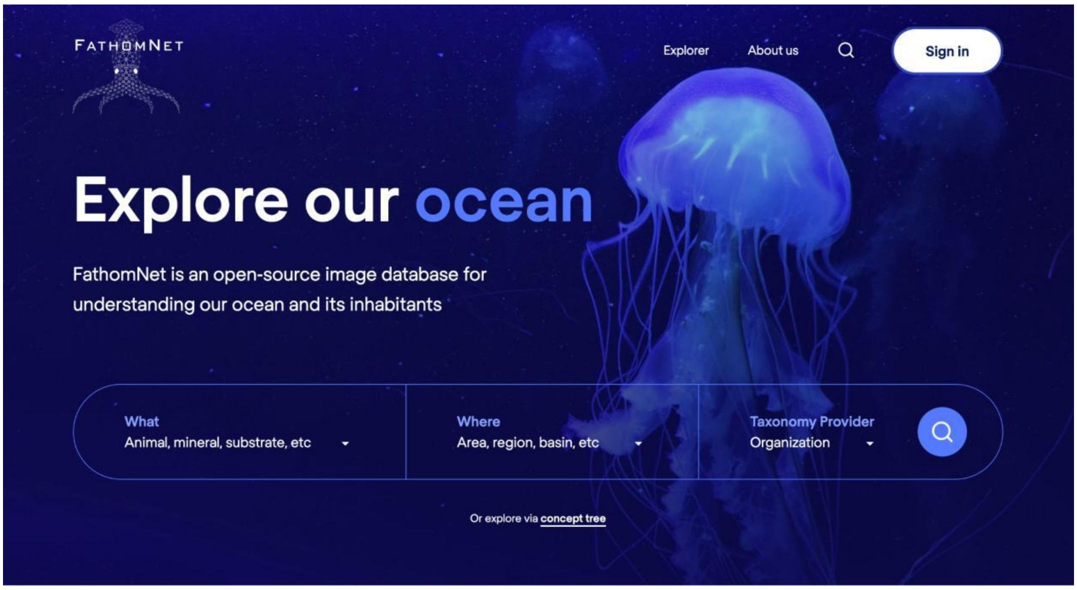

Figure 1: FathomNet home page at www.fathomnet.org.

Plankton image classification using convolutional neural networks and image features

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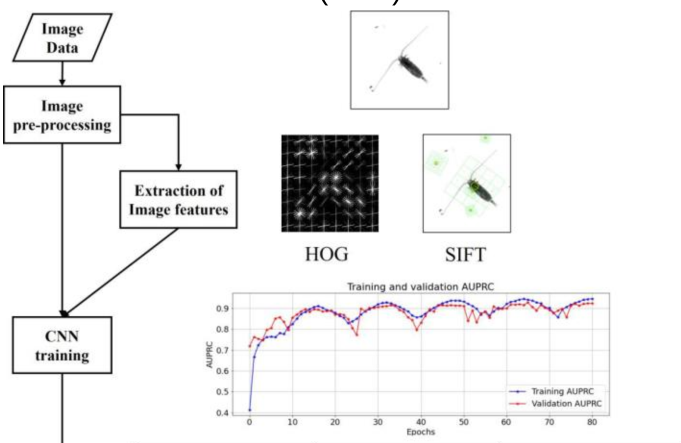
To understand the effects of environmental changes to marine ecosystems, the study of plankton distribution through an automated classification system for images of plankton emerges as a key tool for marine ecologists. Deep learning methods, such as Convolutional Neural Network (CNN) models, have been widely used for classification of particle images as plankton and other organisms, but they require an adequate dataset. However, real-world plankton data contains various sources of heterogeneity such as extremely severe class imbalance distribution, class ambiguity and noisy labels. To address these pitfalls, here we explore specific approaches for CNNs models training an automated plankton image classification system (Fig. 1). We use a large-scale real-world plankton dataset of 65,706 images covering 29 taxonomic classes acquired by a ZooSCAN imaging device. This dataset is extremely imbalanced with 2 abundant classes which have more than 20,000 images, whereas 4 rare classes with 100 images. We show that using a simple method such as assigning class weights inversely proportional to the class frequency gives better performance than modifying the loss function such as Focal Loss. We further demonstrate that classification accuracy of the CNN model was slightly improved by incorporating with texture and local image features such as Gabor filter, local binary pattern (LBP), Histograms of oriented gradients (HOG) and scale-invariant feature transform (SIFT).



Average Precision			Average Recall			Average F1-score		
Abundant classes	Intermediate classes	Rare classes	Abundant classes	Intermediate classes	Rare classes	Abundant classes	Intermediate classes	Rare classes
72.43	54.95	55.95	90.19	80.23	44.87	80.23	81.59	47.46

Figure 1: Experimental design for training Convolutional Neural Networks (CNNs) for classification of a large- scale real-world plankton image data.

Identification and measurement of tropical tuna species in purse seiner catches using computer vision and deep learning

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Fishery monitoring programs are essential for effective management of marine resources, as they provide scientists and managers with the necessary data for both the preparation of scientific advice and fisheries control and surveillance. The monitoring is generally done by human observers, both in port and onboard, with a high cost involved. Consequently, some Regional Fisheries Management Organizations (RFMO) are opting for electronic monitoring (EM) as an alternative or complement to human observers in certain fisheries. This is the case of the tropical tuna purse seine fishery operating in the Indian and Atlantic oceans, which started an EM program on a voluntary basis in 2017. However, even when the monitoring is conducted though EM, the image analysis is a tedious task manually performed by experts. In this paper, we propose a cost-effective methodology for the automatic processing of the images already being collected by cameras onboard tropical tuna purse seiners. Firstly, the images are preprocessed to homogenize them across all vessels and facilitate subsequent steps. Secondly, the fish are individually segmented using a deep neural network (Mask R-CNN). Then, all segments are passed through other deep neural network (ResNet50V2) to classify them by species and estimate their size distribution. For the classification of fish, we achieved an accuracy for all species of over 70%, i.e., about 3 out of 4 individuals are correctly classified to their corresponding species. The size distribution estimates are aligned with official port measurements but calculated using a larger number of individuals. Finally, we also propose improvements to the current image capture systems which can facilitate the work of the proposed automation methodology.

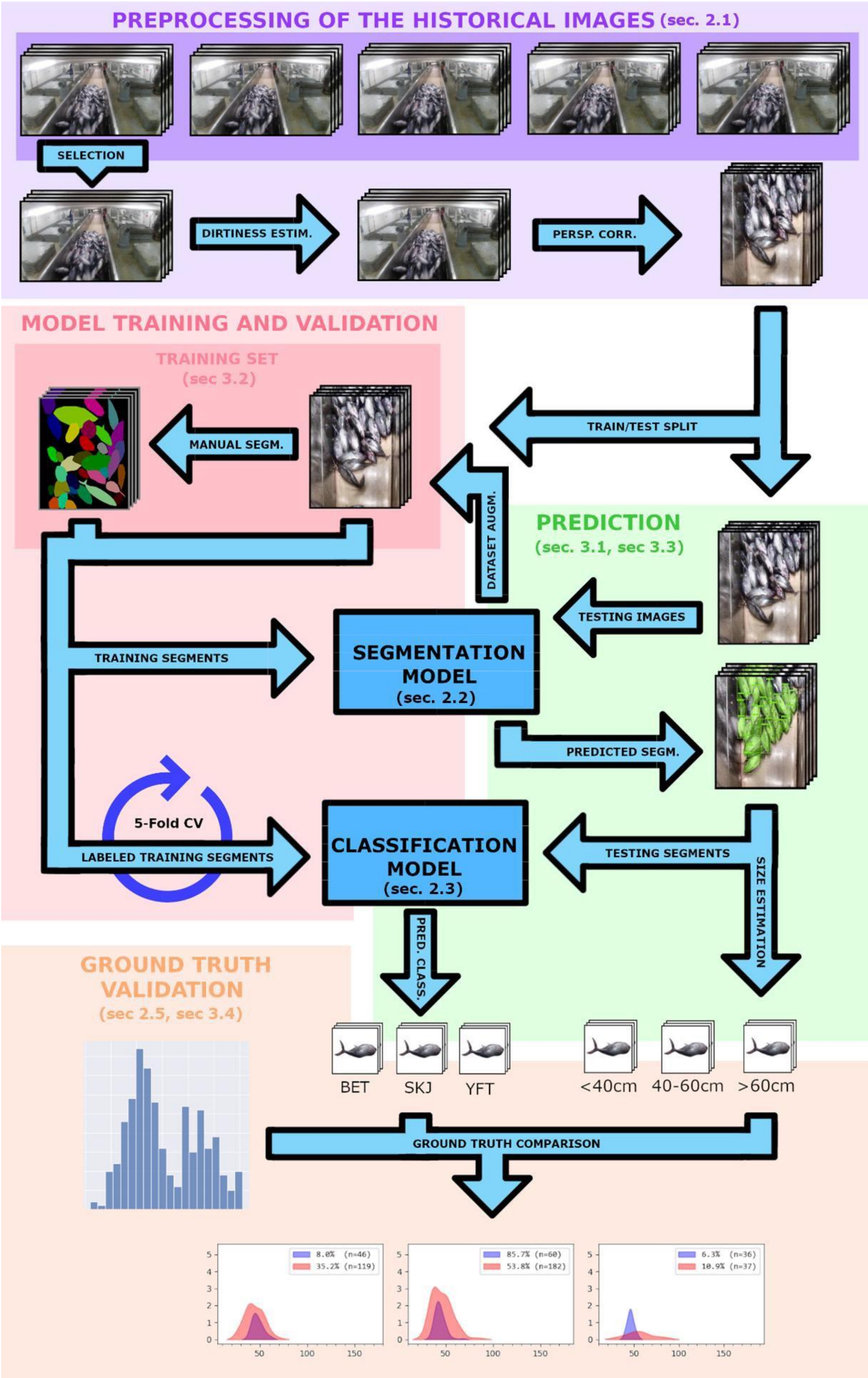

Figure 1: Diagram of our methodology. There are four main modules: Preprocessing of historical images (purple), model training and validation (red), prediction making (green) and ground truth validation (orange). The original image database (dark purple) and the training set (dark red) are also highlighted. Source: Lekunberri et al., 2022

Posters

Extending Depth-of-Field of Underwater Dark-field Camera via Deep Learning for in situ Imaging of Marine Plankton

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In order to have enough magnification and resolution for resolving small planktonic organisms, existing underwater cameras generally have shallow depth-of-field (DOF). This is prone to generate defocus blur in the in situ captured images, leading subsequent image recognition difficult and low water sampling efficiency due to small water volume in correspondence with a single image captured. Imaging Plankton Probe (IPP) is a new dark-field camera developed by our group, which features spatially compressed lighting to match the thickness of the imaging DOF for reducing the probability of defocus blur. However, the problems of low observation throughput and defocus blur caused by the DOF-illumination mis-match still exist. It is still difficult for IPP to totally avoid defocus blur in its images correspond to plankton with a broad size range and random positions as illustrated in Figure 1. To overcome this issue, we developed a novel DOF extension method based on deep neural network for IPP for in situ plankton imaging. We firstly constructed a defocus-focus plankton image pair dataset with known defocus distance label. Then, it was used to train a self-guided deep learning network named IsPlanktonEF. Extensive experiments were performed and the results proved that the method could restore defocus blur of plankton into much clearer images, and the 3 mm DOF of a 0.5x IPP camera could be extended by ~7x. We also demonstrated the refocused images could improve the classification accuracy of a ResNet18 classifier trained on clear image set, and IsPlanktonEF has good generalizability for different plankton taxa images and acquired by different imagers. In this workshop, we will report this new technology and it is expected to enhance the observation capability of IPP and other dark-field underwater cameras for future in situ plankton imaging and observation.

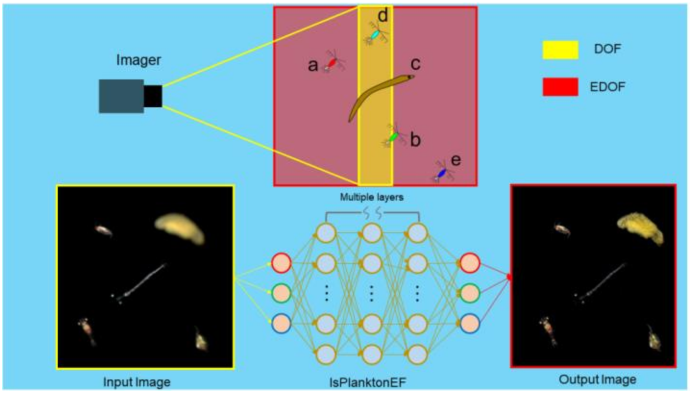

Figure 1. Schematic diagram of the deep neural network based DOF extension method IsPlanktonEF. a-e corresponds to planktonic organisms with different sizes and positions relative to the camera.

Application of image analysis tools as an improvement of staining methods for microplastics identification in zooplankton samples

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Microplastics (MPs) identification in aquatic samples is a growing field of research. Fluorescence microscopy in combination with Nile Red staining offers an effective and nonexpensive technique applicable for various types of environmental samples, including zooplankton samples. However, Nile Red stains MP particles and organic material alike, leading to misidentification of MPs. Therefore, an effective preceding digestion of organic matter is required. Practice shows that digestion with a strong base is able to remove most of the organic matter, but works insufficiently for zooplankton samples containing many chitinous remains. Meanwhile, zooplankton samples are a major focus for MP identification and analysis since these samples provide a holistic view on potential encounter, uptake and trophic transfer by marine organisms. Image processing tools can fix the issue of insufficient digestion and co-staining of organic matter at the end of the data processing chain. Trainable Weka Segmentation is a plugin of Fiji software that uses machine learning algorithms to produce a segmentation of images based on pixel classification. By using the differences in pixel contrast, intensity, and texture and depending on the area selected for separation, the model divides the image into 2 or more segments. After application it is possible to remove areas of organic material from the sample and hence to avoid the issue of MPs overestimation even in the case of ineffective digestion treatment for zooplankton samples

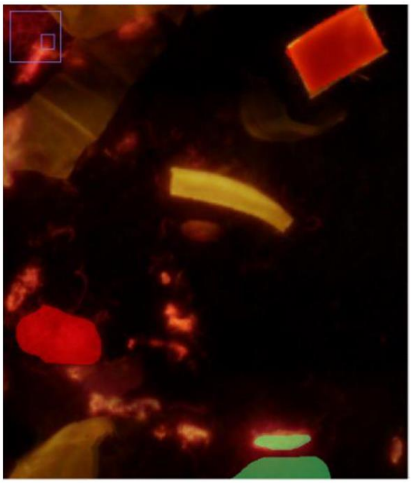

Figure 1: Image of organic matter and MP particles after Nile Red staining. Manually chosen region of interest for segmentation classification in red for plastic partciles and green for organic matter

Automated classification of fauna in seabed photographs: the impact of training dataset size, with considerations for the class imbalance

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Machine learning is rapidly developing as a tool for gathering data from imagery and may be useful in identifying (classifying) visible specimens in large photo datasets. Application of an automated classification workflow requires manually identified specimens to be supplied for training and validating the model, with typical partitioning of manually-identified specimens into training and validation datasets at ratios of 75:25 or 80:20. However, this approach would be difficult to scale up to the classification of huge datasets desired. A second problem is the 'class imbalance', where natural community structure means that fewer specimens of rare morphotypes are available for model training. We investigated the impact of variation of the training dataset size on the performance of a convolutional neural network classifier on benthic invertebrates in a very large set of seabed photographs. We tested the impact of increasing training dataset size on specimen classification in a single validation dataset. Recall, precision, F1-score indicated that classification improved with increasing training dataset size. In terms of ecological metrics, the number of morphotypes recorded increased, while diversity decreased with increasing training dataset size. Variation and bias in diversity metrics decreased with increasing training dataset size. Multivariate dispersion in apparent community composition was reduced, and bias from expert-derived data declined with increasing training dataset size. Thus, the selection of an appropriate training dataset size is key to ensuring robust automated classifications of benthic invertebrates in seabed photographs, in terms of ecological results, with confidence that similar results will be obtained in a larger production dataset. In addition, our results suggest that automated classification of less common morphotypes may be feasible, providing that the overall training dataset size is sufficiently large. Thus, tactics for reducing class imbalance in the training dataset may produce improvements in the resulting ecological metrics.

Detecting harmful algae and toxic blooms

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Phytoplankton are mostly free living photosynthetic algae that occur in both freshwater and seawater. Natural phytoplankton communities are morphologically diverse, have high temporal variability in species composition and abundance, and can span up to 4 orders of magnitude in size (0.2um - 2mm). In the presence of concentrated nutrient sources, phytoplankton can grow exponentially and form Harmful Algae Blooms (HABs), with some species producing toxic compounds that are dangerous to animals and humans. Processing phytoplankton samples is labour-intensive due to the presence of organic and inorganic detrital particles, and the requirement of a high level of taxonomic expertise to achieve accurate species identification. This work aims to develop automated methods to identify HAB species from water samples containing mixed phytoplankton communities. We investigated machine learning techniques based on deep neural networks to detect and classify a diverse range of Australian phytoplankton. This involved establishing an expertly curated Australian phytoplankton image database, and the implementation of human-in-the-loop machine learning techniques to minimise the required dataset annotation effort. We show that custom deep learning models can accurately detect and differentiate harmful and non-harmfull phytoplankton species. Further developing these models will significantly improve the speed of HAB species identification and deliver vital environmental information to government and industry stakeholders. These capabilities will impact aquatic environmental management, key decision-making processes in Australian fisheries, aquaculture and tourism, and mitigate risks in the Australian seafood industry.

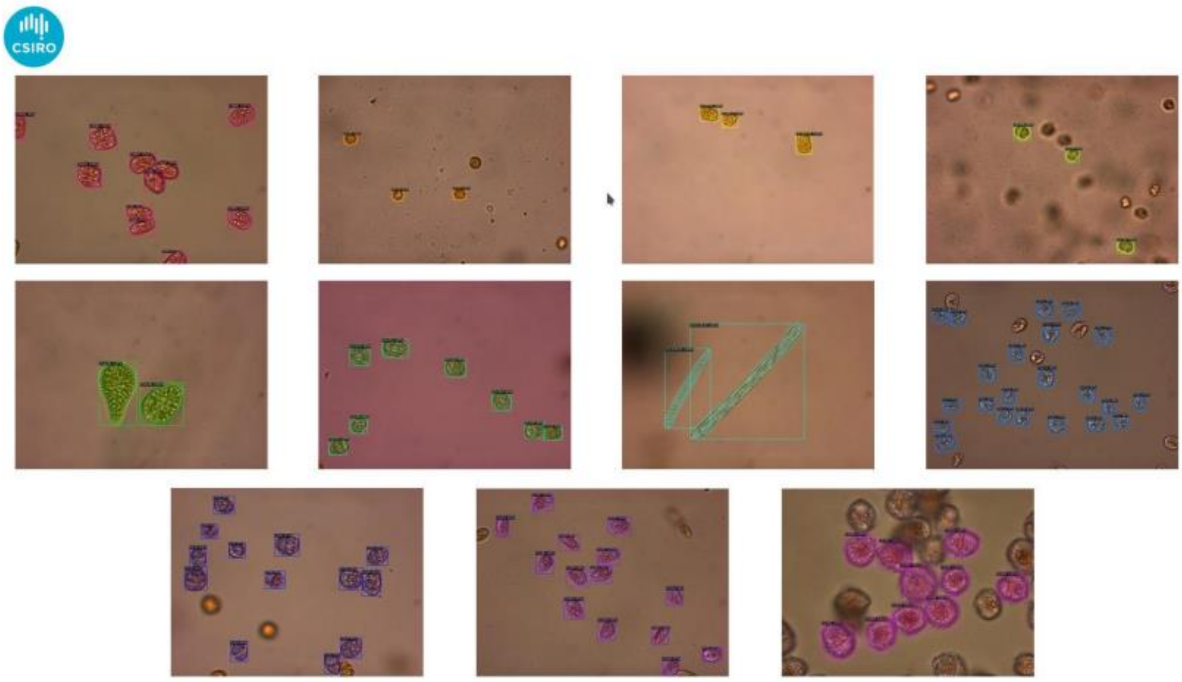

Figure 1: Mask R-CNN instance detections of Australian phytoplankton

Automation of deep-sea organisms and debris detection using deep learning with a large number of videos/photos at JAMSTEC

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The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) archives a large number of deep-sea videos and photos obtained from surveys conducted by manned and unmanned research submersibles, e.g. "SHINKAI6500" and "HYPER-DOLPHIN". These videos and photos are published to the internet site "JAMSTEC E-library of Deep-sea Images: J-EDI (https://www.godac.jamstec.go.jp/jedi/e/)" with manually annotated information of deep-sea objects such as organisms and marine debris.
J-EDI provides approximately 40 thousand hours of videos and over 1.7 million photos obtained from more than 5.7 thousand deep-sea surveys (as of July 2021). Since the number of videos and photos is expected to continue increasing, it has become a challenge to automate and improve efficiency of the annotation process.
In order to tackle the challenge, we developed an object detection process using "Convolutional Neural Network: CNN". A large-scale dataset for training, validating, and testing CNN was created from deep-sea videos and photos archived at the JAMSTEC sites. The dataset is composed of image, label of each object category and its area information in the image. More than 40 thousand images of organisms and 50 thousand images of debris were included in the dataset, and multiple types of CNNs have been trained and tested on the dataset.
In addition, trained CNNs have been tested on the video processing for automated extraction of scenes in which notable organisms and debris are captured.
In this presentation, we report on the latest trial results of deep-sea organisms and debris detection, current issues, and future prospects.

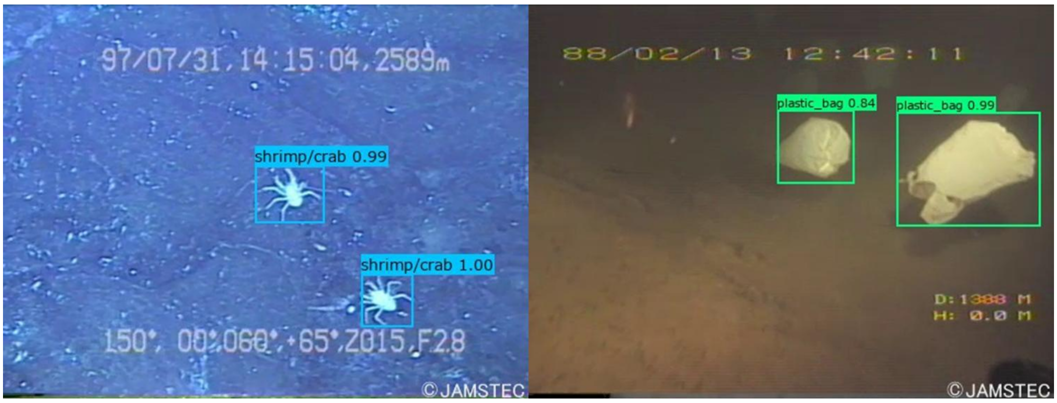

Figure 1: Sampled detection results of deep-sea organisms and debris

Working with imperfect machines: managing error while using ML in the field

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Our vast and dynamic ocean is largely undersampled and its inhabitants poorly understood. Imaging systems, supported by machine learning-based automated analysis, promise to help us establish a more consistent presence in this difficult to access habitat. But on-going challenges with ML-systems keep the dream of an ocean teeming with robots capable of autonomously reporting observations or tracking rare individual organisms just out of reach. Indeed, the very signals we wish to measure – rapidly fluctuating, spatially and temporally heterogeneous biological distributions – confound supervised machine learning systems that are encoded with a static view of the world. Bridging the gap between these imperfect systems and deployable instrumentation requires supervised autonomy: keeping a human-in-the-loop to ensure the machine is doing the right thing. Here we describe two supervised autonomy experiments that push the limits of allowing in situ platforms to make decisions based on imagery. In the first, we couple a multi-object detector and a 3D stereo tracker on a Remotely Operated Vehicle to find and track midwater organisms while a human observer confirms the chosen target. In the second, we demonstrate transmitting selected Regions of Interest, chosen by a real time binary detector, from an Autonomous Underwater Vehicle at depth via an acoustic modem. Together, these experiments represent steps toward allowing a computer to trigger a behaviour change based on visual data to track a salient feature. Both fundamentally rely on a human operator to confirm the machine's choice. Enabling this type of constructive interaction between potentially inaccurate machines and human supervisors is critical to ensure that our in situ systems operate in an efficient and unbiased manner.

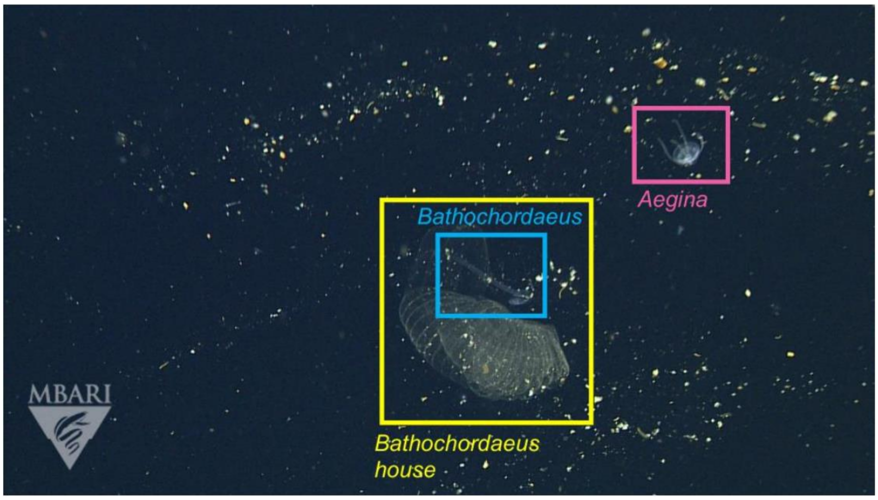

Figure 1: Midwater visual data is processed in real time for autonomous decision making.

Marine Bubble Stream Characterization Using Wide-Baseline Stereo Photogrammetry

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In this contribution we outline our characterization method for marine bubble streams (speed and size distribution) rising through a dedicated high-speed stereo camera system that can record terabytes of bubble imagery when deployed at a seep site for later automated analysis. The visual data can be obtained ROV-based for short sequences at different locations, or in autonomous "lander" mode, where the instrument can run for several days on battery power (few minutes in each hour) at a single spot, in order to capture bubble flow variations due to e.g. tide dependent pressure changes or reservoir depletion. The analysis first subtracts a static background, then finds contours and matches them across the two views using epipolar geometry. Afterwards, ellipsoids are fitted in space, and each bubble is tracked while it rises through the camera's field of view. Bubbles are counted once they pass a virtual reference surface. In controlled experiments with glass marbles we obtain an achievable accuracy of about 1% of the radius.

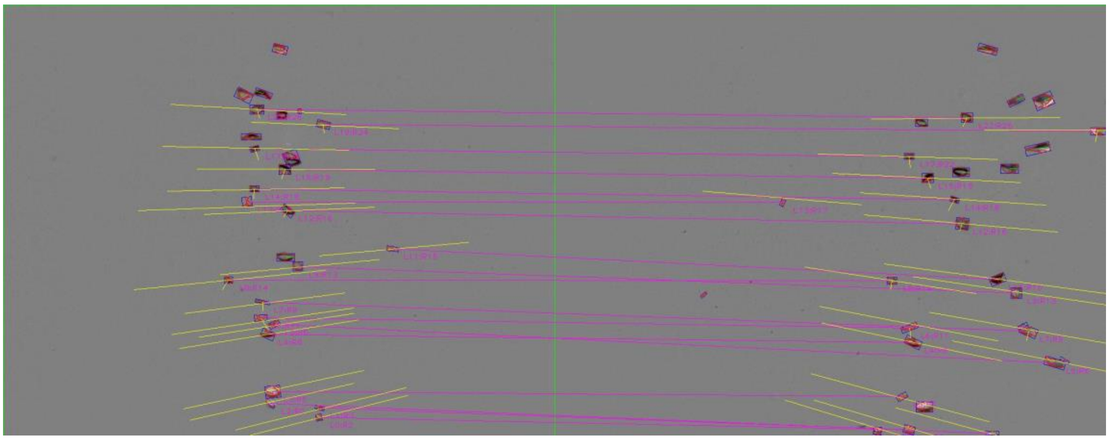

Figure 1: Bubble matches between left and right camera after background removal

EcoTransLearn: an R-package using Transfer Learning for ecological studies. A plankton case study in the English Channel

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Recently, Deep Learning (DL) has been increasingly used in many fields, such as image recognition, due to its ability to solve problems where traditional machine learning algorithms fail. However, building an appropriate DL model from scratch in the context of ecological studies, such as monitoring marine ecosystem, is a difficult task due to the dynamic nature and morphological variability of living organisms, as well as the high cost in terms of time, human resources, and skills required to label a large number of training images. To overcome this problem, Transfer Learning (TL) can be used to improve a classifier by transferring information learnt from many domains thanks to a very large training set composed of various images, to another domain with a smaller amount of training data. For this purpose, while few easy-to-use software are available for non-expert users, the 'EcoTransLearn' R-package is being developed to allow greater automation in classification of images acquired with various devices, thanks to different TL methods pre-trained on the generic ImageNet dataset. As a proof-of-concept, this R-package was used to analyse plankton image datasets acquired with a FlowCam system during scientific cruises (CAMANOC, IBTS) and within monitoring networks (SRN-REPHY). The experimental results can then be used to assess the operational capability of monitoring the diversity of micro- phytoplankton samples in near-real time during cruises, as well as detecting, tracking, and counting the most common taxa found in the English Channel in the context of monitoring networks. Due to its simplicity and speed of analysis, this tool could be an integral part of a more general decision support system, by being coupled with other machine learning tools using integrated environmental data (from automated buoys, satellite, modelling).

Biodiversity underestimation in our bLUe planEt: artificial intelligence (AI) REVOLUTION in benthic taxonomy (BLUEREVOLUTION project)

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The Earth's Ocean is the largest three-dimensional living space on our Planet. It is crucial to life as we know it, yet we know less about the entire seafloor than we do of the surface of the moon. Infaunal benthic communities comprise some of the most diverse groups of organisms on Earth, and only a very small amount of this diversity has been described by science. Despite our partial exploration of this vast domain, all marine habitats, including the deepest trenches, experience direct or indirect human impacts. Thus, the scientific community faces the need for fast and accurate monitoring studies and building baseline datasets to measure future changes and biodiversity losses. The introduction of DNA taxonomy and metabarcoding initiated the development of fast fingerprinting methods to address this growing need. However, molecular identities (OTUs) are in themselves not valuable if not linked to species obtained through thorough taxonomic identification and for which we have biological and ecological information. Inspired by the pioneering project "Tara Oceans" merging expertise in taxonomy, ecology, molecular biology and bioinformatics to conduct a large-scale inventory of plankton diversity, the BLUEREVOLUTION project aims at developing in- and ex-situ methods using automatic imaging techniques (holographic microscopy and 3D-fluorescence imaging) linked with taxonomic classification tools (AI) for high throughput analysis of benthic diversity. This will ultimately allow for quantitative, genetic and functional data of benthic communities being generated at speeds unseen before and will produce a standardized method for building open-access reference databases together with fast and reliable tools for impact assessments and biodiversity surveys. The project will also contribute to the training of the next generation of benthic integrated taxonomists and ecologists with skills in species identification and the ability to employ cutting-edge techniques to revolutionize the way we discover and monitor our Ocean's seafloor.

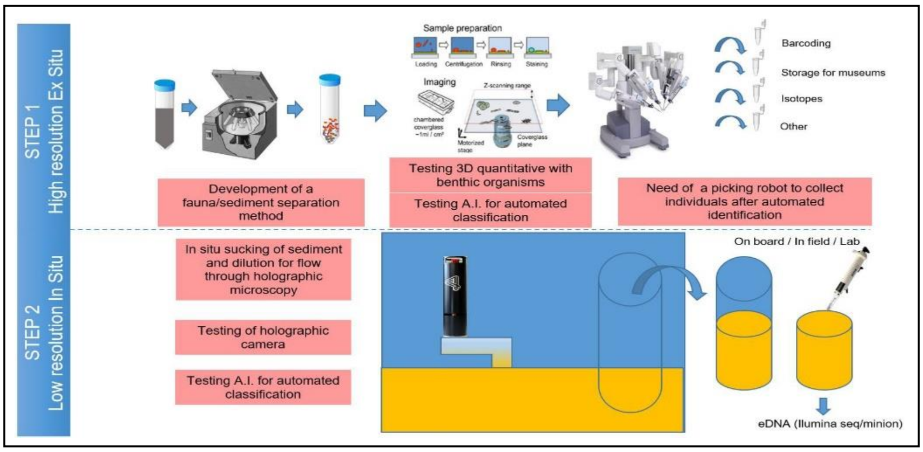

Figure 1: Workflow BLUEREVOLUTION

Quality control, standardization, and sharing of imagery data

Oral presentations

A method for scaling seafloor images when laser lights are not present

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The most common method for scaling seafloor images is the mounting of two or more lasers on the camera platform so that their lights are visible within the image at a known distance apart. Unfortunately, whether it is due to laser malfunction, or turbid water conditions, the laser lights are not always visible on the image during analysis. This issue may result in the loss of the usability of individual images or of whole transects or dives, and depending on the goals of the study, have a significant effect on the research. Here we present a method to scale downward-facing seafloor imagery and video with no detectable laser lights using the relationship between the mean red colour intensity of the image and known image areas. We will discuss multiple pipelines for implementing this method (e.g., imageJ, R, Python) and how results compare across different habitats (i.e., muddy bottom vs. rocky substrate). We will demonstrate some applications of this method, and also compare the results of using this method with historical methods of estimating image area prior to the addition of lasers to a towed camera system.

The Antarctic Seafloor Annotated Imagery Database (AS - AID)

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Craig Johnson, University of Tasmania (Australia)
and many international collaborators

Marine images are a comparatively cost-effective tool to collect data on seafloor organisms, biodiversity and habitat morphology. However, annotating these images to extract detailed biological information is time-consuming and expensive, and publicly available datasets of expert annotated seafloor images are rare. Here, we present the fully reproducible Antarctic Seafloor Annotated Imagery Database (AS-AID), a result of a multinational collaboration to collate and annotate regional seafloor imagery datasets from 19 major Antarctic research cruises between 1985 and 2019. We have collated more than 100,000 georeferenced downward facing seafloor images, of which a subset of ~3,500 has been annotated. Annotations are based on CATAMI (Collaborative and Automated Tools for Analysis of Marine Imagery), have been expert reviewed and, because the location of each annotation in each image is available, annotations can be easily viewed, reviewed and customised to suit individual research priorities.
This dataset can be used to investigate species distributions, community patterns and can be used to train neural networks for automatically detecting and annotating marine fauna.

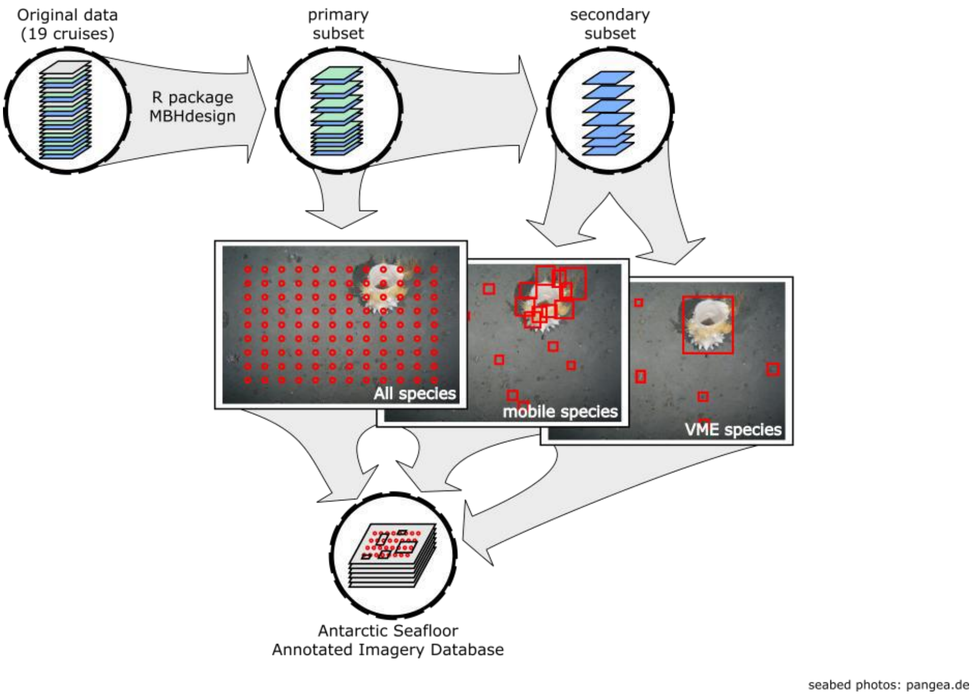

Figure 1: Workflow to create AS-AID. The database contains images with point-scores for all species and substrates, of which a subset was further exhaustively searched for mobile species and species that form part of vulnerable marine ecosystems (VMEs). All annotations and images are in the process of being made publicly available and accessible.

How to evaluate the outputs of automated classifiers – why computer vision metrics are not enough

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Automated classification is gaining popularity as a tool for identifying organisms in seabed photographs for ecological studies, but the evaluation of classifier outputs is not simple. Validation of classifiers often includes comparison against human-generated identifications in the same seabed photographs. Computer vision traditionally uses metrics, such as accuracy/recall, precision and the F1-score, for evaluating classifier performance. While these metrics provide valuable information for tuning a model and understanding its strengths/weaknesses, they do not address the classifier's performance on generating the ecological data of interest – a problem that crosses disciplines. We use automated classification and human-generated identification data from published studies, and simulated community and classification performance data to examine the relationship between computer vision metrics and ecological parameters (e.g., abundance, diversity, community composition). We show how the natural state of ecological communities (class imbalance) impacts both types of metrics, and how this can be considered when evaluating classifier outputs. Finally, we consider the implications for the required size of the human-generated dataset to adequately evaluate a classifier.

From 2D to 3D annotations: a process to accurately georeference image annotation data with ray-tracing

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Thanks to the popularization of 3D scanning technologies, 3D models of the sea floor are becoming increasingly accessible, and could help in improving ecosystem cartography. Study of hard to reach ecosystems such as deep sea hydrothermal vents could thus be greatly facilitated. But if 2D annotation of ROV images is now common practice, geo-locating these annotations in 3D models or digital elevations models (DEM) is still difficult and/or imprecise, and can reduce usability of such annotations. Here we propose a workflow from 2D annotations of sea floor images to 3D mapping and analysis using a 3D model.
3D models of the surveyed area are first created using ROV images and photogrammetry (Matisse3D software). A subset of non-overlapping images is then annotated for faunal and geological features using the Biigle software. Precision and reproducibility of these annotations is established using the RecoMia principles. These annotations are reprojected on the 3D model through ray tracing using camera position rotations and positions, and python Blender library. 3D annotations can then be converted to vector layers for use in GIS software, and corrected for remaining overlaps. Several metrics such as slope, roughness and benthic position index (BPI) can ultimately be derived from the 3D model, and overlaid on annotations. Distance from vents raster can also be computed.
This process was successfully implemented to study active hydrothermal vents and their periphery in the Lau and Futuna back-arc basins, surveyed during the CHUBACARC cruise (2019). High accuracy was achieved, as the offset between annotation position on the image and on the 3D model is small (7 ± 2 mm). Considering the high amount of annotations to be produced in the future using participative science projects and deep learning, this process could be very useful to investigate these fragile ecosystems.

PSSdb: A pelagic size structure database from multiple in situ imaging devices

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Allometric relationships rule many cellular to ecosystem processes (e.g. metabolic reactions, carbon and nutrient uptake, particle sinking, trophic transfer). Therefore, the size structure of planktonic communities has a profound imprint on marine biogeochemical cycles and ecosystem services, including commercial fishery stocks. As such, global observations of size distribution are needed to monitor and predict the general functioning and health of pelagic ecosystems under current and future anthropogenic pressures.

So far, size-structure datasets have had limited spatial coverage and focused on specific size ranges, ignoring the broad scale of marine organisms. These methodological limitations have been reduced for a range of non-intrusive imaging devices, which produce large community composition datasets along with complementary size measurements across orders of magnitude, spanning small phytoplankton to macrozooplankton, at high spatial resolution.

In this presentation, we focus on the development of PSSdb, a global pelagic size structure database derived from multiple in situ imaging devices. We will present the workflow implemented to standardize, harmonize, and integrate simultaneous observations on plankton abundance and size from images obtained with the Imaging FlowCytobot, the Underwater Vision Profiler, the ZooScan and the In Situ Ichtyoplankton Imaging System. The resulting combined datasets will be used to describe global patterns of this holistic pelagic size distribution, determine the ecological mechanisms by which changes in oceanographic conditions can affect ecosystem services, and be compared with biogeochemical models.

iMagine: Imaging data and services for aquatic science

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iMagine is an EU-funded project providing a portfolio of image datasets, high-performance image analysis tools empowered with Artificial Intelligence (AI), and Best Practice documents for scientific image analysis ‘free at point of use’. These services and materials enable better and more efficient processing and analysis of imaging data in marine and freshwater research, accelerating our scientific insights about processes and measures relevant to healthy oceans, seas, and coastal and inland waters.

By building on the Compute platform of the European Open Science Cloud (EOSC) the project delivers a generic framework for AI model development, training, and deployment, which can be adopted by researchers for refining their AI-based applications for water pollution mitigation, biodiversity and ecosystem studies, climate change analysis and beach monitoring, but also for developing and optimising other AI-based applications in this field.

The iMagine compute layer consists of providers from the pan-European EGI federation infrastructure, collectively offering over 132,000 GPU hours, 6,000,000 CPU hours and 1500 TB-month for image hosting and processing.

The iMagine AI framework offers neural networks, parallel post-processing of very large data, and analysis of massive online data streams in distributed environments. 12 RIs will share over 9 million images and 8 AI-powered applications through the framework. Having representatives of so many RIs and IT institutes, developing a portfolio of eye-catching image processing services together will also give rise to Best Practices. The synergies between aquatic use cases will lead to common solutions in data management, quality control, performance, integration, provenance, and FAIRness, contributing to harmonisation across RIs and providing input for the iMagine Best Practice guidelines. The project results will be integrated into and will bring important contributions from RIs and e-infrastructures to EOSC and AI4EU.

Making marine image data FAIR with iFDOs

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Underwater images are used to explore and monitor ocean habitats, generating huge datasets with unusual data characteristics that preclude traditional data management strategies. Due to the lack of universally adopted data standards, image data collected from the marine environment are increasing in heterogeneity, preventing objective comparison. The extraction of actionable information thus remains challenging, particularly for researchers not directly involved with the image data collection. Standardized formats and procedures are needed to enable sustainable image analysis and processing tools, as are solutions for image publication in long-term repositories to ascertain reuse of data. The FAIR principles (Findable, Accessible, Interoperable, Reusable) provide a framework for such data management goals. We propose the use of image FAIR Digital Objects (iFDOs) and present an infrastructure environment to create and exploit such FAIR digital objects. We show how these iFDOs can be created, validated, managed, and stored, and which data associated with imagery should be curated. The goal is to reduce image management overheads while simultaneously creating visibility for image acquisition and publication efforts.

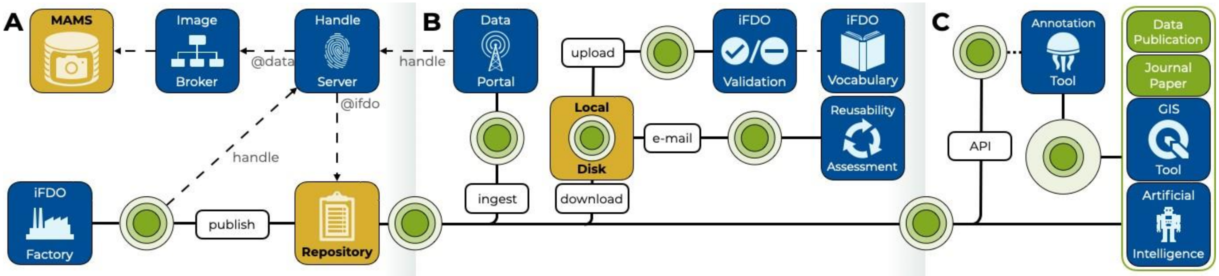

Figure 1: Creation and progression of an iFDO (green circles) and its derived versions. Part A (left) shows how an iFDO uses persistent identifiers to reference itself within the FAIR infrastructure. Part B (middle) shows how iFDO files can be discovered, shared, advertised, and validated. Part C (right) shows how implementing iFDO- compliant APIs to marine science tools facilitates reuse of image data for arbitrary purposes.

Ocean Spy: a platform dedicated to image annotation by citizen for the study of marine ecosystems

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In marine research the use of digital imaging and video has become a major tool for understanding, assessment and communication of the biodiversity and habitats in both shallow and deep environments. Indeed, marine visual imaging allows ecosystems studies to be conducted both spatially and temporally at unprecedented scales and resolutions. However information extraction from the huge volume of imagery data generated by those approaches is still extremely time-consuming although promising methods based on machine-learning (ML) approaches are developed. Inspired by the success of the previous citizen science project Deep Sea Spy, Ocean Spy is a collaborative initiative that has the high-level objective to enable the efficient and effective analysis of these large existing and growing datasets thanks to the development and application of new computer-based analytic methods using citizen-built datasets. From the Ocean Spy platform internet users will have access to diversified images of different marine ecosystems and will be able to participate in their annotation through attractive interfaces and adapted functionalities. The project is therefore based on collaboration between scientists and citizens: the engagement of citizens serving science for the improvement of understanding of these environments, the scientists providing knowledge and raising awareness among the general public. The Ocean Spy project is led by a multidisciplinary and complementary consortium (science, communication, IT). Engineers and researchers will be able to administrate in a flexible manner the platform and images sets depending on the imaging analysis approach to be addressed. Scientific data processing (analysis, curation, interpretation and building of training datasets for ML algorithms development) will be performed by Ifremer scientists, possibly in collaboration with external colleagues, computer vision and artificial intelligence experts. Ocean Spy will thus respond to the special challenges in marine imaging and also be a valuable tool to build the bridge between science and society globally.

Figure 1: Ocean Spy main interface

Introducing a Standardised Marine Taxon Reference Image Database (SMarTaR-ID) to help promote standardisation in deep-sea image annotation

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SMarTaR-ID consortia https://smartar-id.app/development

The use of image-based data in marine ecology is now routine. However, there are challenges in the identification of marine animals from imagery, and the taxonomic level it is possible to achieve in the field. To support field identification of marine animals many different organisations have developed their own in-house reference image libraries. Some have published their libraries as websites, apps, or papers. These reference libraries have proved a valuable source of information in supporting interpretation of image-based data. However, there are currently no standards around the identification of taxa from imagery. We introduce the SMarTaR-ID initiative, the key aim of which is to provide a reference standard to which image-based data can be annotated, ultimately making it easier to combine image- based datasets for analysis by ensuring some commonality in how animal morphotypes are named. In support of existing efforts we have aligned as far as possible with the CATAMI classification in our morphological filter. In addition, SMarTaR-ID aims to provide the tools to support training of researchers in the field-based identification of marine animals. Taxonomists within the SMarTaR-ID family have developed field keys to some taxa and we hope to develop more over time under the Challenger 150 UN Ocean Decade programme's imagery technical working group. We begun the development of field-based multi-access keys to marine animals in the form of filters on the database. This is a first step and we recognise there is much more to be done. We hope this tool can help support the aims of the UN Decade of Ocean Science for Sustainable Development.

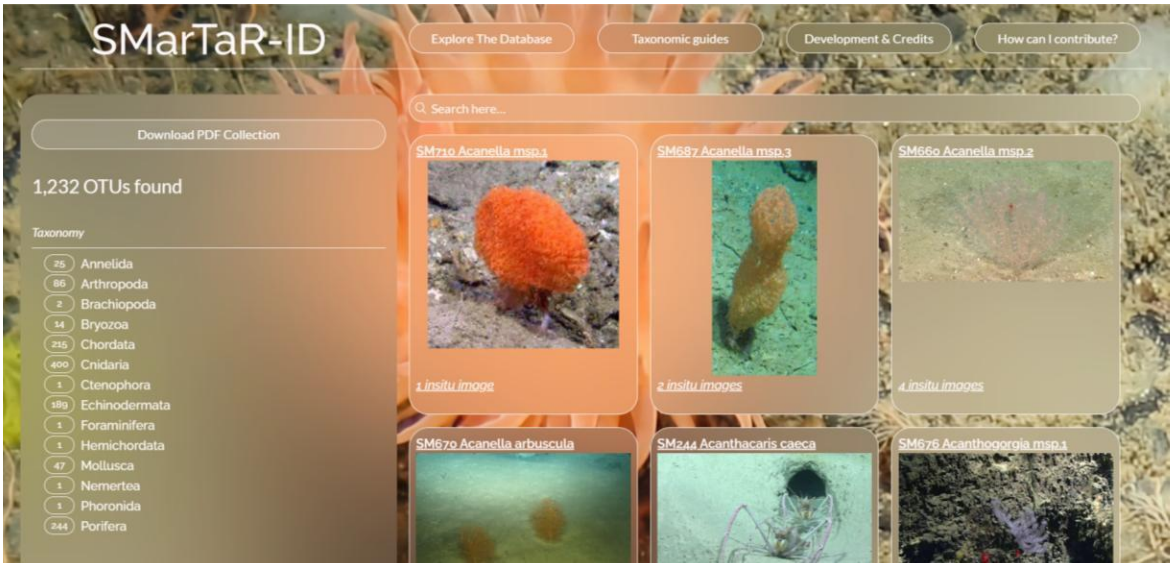

Figure 1: Screen shot of the SMarTaR-ID web tool

Why and how plankton imaging could become operational at basin scales

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Plankton is the major driver of oceanic biogeochemistry and plays several essential roles in the ocean (e.g. oxygen production, carbon storage, food web dynamics). Plastic particles also are nowadays observed in plankton samples and plastic pollution creates a major threat for marine life. To monitor plankton dynamics at a spatial and temporal scale that permits management of fisheries and aquaculture is therefore a global challenge for policy and society and should be a major goal for the UN Decade of Ocean Science for Sustainable Development. Plankton covers a size range from nanometers to meters and only optic tools allow to bridge this enormous span.An enormous toolkit of digital plankton cameras ranging from in situ microscopes to large high definition cameras has been developed and deployed in recent years. First autonomous deployments are underway and real time analysis will enable the direct conversion of data into knowledge and policy advice. In this presentation, we will discuss why plankton imaging needs to, and how it could enter an operational stage where information on plankton, particle and plastics distribution from research vessels, gliders, floats, moorings and Citizen Scientists could be obtained, integrated and analyzed almost in real time.

A framework for Coupling underwater acoustic and image surveys

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Mapping of the seafloor and its character requires the collection and analysis, at different scales, of a number of diverse data sets including bathymetry, acoustic backscatter, seafloor images , oceanographic information, environmental conditions, narrative descriptions, etc. Therefore, there is a need for a specialized and multidisciplinary approach to the problem of seafloor characterization. This work focuses on the development and application of novel tools for the concurrent analysis of co-located bathymetric digital elevation models, acoustic backscatter data, and accurately co-registered seafloor imagery fulfilling the need of a unified platform for the collection and concurrent analysis of diverse datasets. The tool-kit allows seafloor digital terrain models, backscatter mosaics and seafloor images to be interactively explored. It also allows the concurrent extraction of the backscatter from any given region (including the angular response curves for the backscatter) as well as any associated imagery for the region. It also provides tools for rapid annotation of this imagery as well as the construction of micro-topographic digital terrain models from the imagery if stereo pairs exist. The overall objective is to provide an efficient means of understanding the relationships between morphology, backscatter and the observed biota and thus understanding the relationship between the physical and ecological elements of the seascape.
The ability to concurrently analyze:

- biota (image annotations)
- visual information with fine scale roughness (microtopography from stereo images)
- acoustic backscatter and its angular dependence
- bathymetry and its derivatives including morphological features (generic and specific geomorphometry)
- seafloor energy (oceanographic models)

provide new ways for the interpretation of remotely sensed information derived from MBES and for the development of spatial distribution models. Furthermore, such an approach will support the incorporation of ground-truth databases used for the development of formal mathematical models that link acoustic backscatter observations to intrinsic properties of the seafloor.

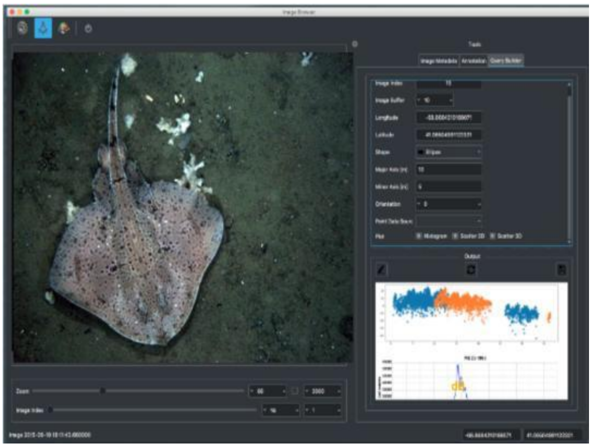

Figure 1: Ground Truth browser and annotation tool-kit

Impacts of multi-user annotations on Machine Learning segmentation in seafloor images

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Machine Learning (ML) has the potential to greatly reduce human effort by automating the annotation of seafloor images used in research and monitoring studies. However, supervised ML techniques risk propagating the errors and biases inherent in human generated training data. If ignored, such errors can impact the ecological metrics derived from seafloor image annotation and reduce their power to detect real biological change in the ecosystems under study. We investigated the impact of human biases on ML image segmentation using seafloor photographs of cold-water coral from the Darwin Mounds Marine Protected Area (bathyl North-East Atlantic), with 11 training datasets of the same 96 images that were annotated for cold-water coral by 11 different users. Preliminary results showed that using individual user's annotations to train Mask-RCNN (Region-Based Convolutional Neural Networks) lead to high variability in ML performance with some coral cover estimates predicted to be more than four times greater than others. To reduce annotator variability in training data and improve coral cover predictions, we will explore the impacts of combining multiple users' annotation sets to use as training data. Data combination techniques include: using average segments, selecting segments with the greatest number of vertices, and using non-binary heatmaps of segments, and we will evaluate ML coral predictions trained with each technique. Predictions from this supervised ML technique will be further combined in future work with predictions of coral habitat type using a self- and semi- supervised image classification ML technique (Geo-CLR, Yamada et al. 2022) to explore how complimentary ML techniques can be used to semi-automate a more comprehensive evaluation of seafloor ecosystems from images.

Yamada, T., Prugel-Bennett, A., Pizarro, O., Williams, S., Thornton, B., 2022. GeoCLR: Georeference Contrastive Learning for Efficient Seafloor Image Interpretation. Field Robotics.

Posters

How to Improve Your Underwater Photos & Video: A Guide for Oceanographers, Marine Biologists & Researchers

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As an oceanographic scientist, researcher, or professional, it can be challenging to get vessel time for your project. Often one of the goals of a subsea project is to collect footage and images. You only get a short amount of time to collect the survey data, so being prepared is important. Join Chad Collett, Founder & CEO of SubC Imaging as he reviews some of the fundamentals of underwater photography, with the goal of helping you be more prepared to make that next big discovery and collect high-quality survey data. Designed for beginners and pros alike, this webinar will help you understand topics such as lighting, depth of field, ISO, aperture, shutter speed, backscatter, and digital noise so that you can capture better footage and images for your scientific research.

Improving coral monitoring by reducing variability and bias in cover estimates from seafloor images

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Organism seafloor cover is an established metric for assessing the health of many vulnerable marine ecosystems and other features of conservation interest. When deriving cover estimates from seafloor imagery, a common monitoring approach, human annotators introduce variation and bias in the extracted ecological data used to estimate the true distribution of biota. We investigated the variation and bias of multiple human annotators in estimating cold-water coral cover from seafloor images using two annotation methods; grid- based and segmentation. Size selectivity bias in segmentation, where the minimum size of targets that can be segmented varies between annotators, was addressed using two modelling techniques that imputed colony area where annotators identified coral presence but failed to segment the colony. Eleven annotators estimated live coral cover using both annotation methods from the same 96 seafloor images of the Darwin Mounds Marine Protected Area (bathyl NE Atlantic), a well-known location with low coral cover. We found that the coefficient of variation between annotators was 8% greater in the grid-based method compared to segmentation, and that annotator grid-based estimates tended to systematically overestimate coral cover. Low segmentation-based cover estimates and high variation between annotators were the results of substantial variation in the minimum size of coral colonies segmented by the annotators. Using the modelling techniques to impute small coral sizes in segmentation reduced the coefficient of variation by 10% and reduced method bias by up to 27%. Our results suggest that for sparse, low seabed cover targets, image segmentation produces results with lower inter-annotator variability and bias than grid-based annotation. Uncertainty in cover estimates is further reduced by addressing annotator size selectivity bias when annotating small organisms through the use of data-driven modelling techniques.

The Big Picture Group – Encouraging collaboration to improve methods in marine imagery

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As methods and standards in marine imagery improve, it is essential that these developments do not happen in isolation. To encourage collaborative working between UK organisations, the Big Picture Group (BPG) was set up in 2019. The BPG is a collection of imagery users from a variety of backgrounds, including academia, industry, and government. The purpose of the BPG is to collaborate on marine imagery projects, and in 2019 the group members were invited to attend a workshop which led to the creation of the Benthic Imagery Action Plan. This action plan is a strategic framework to carry out necessary improvements to a wide range of imagery analysis standards in the UK. Since the creation of the Benthic Imagery Action Plan the BPG has been working towards completing the tasks it contains. This talk will discuss the development of the action plan, provide an update on how the BPG has addressed actions in the action plan, and explain how the group can be engaged with from both inside and outside the UK.

Koster Seafloor Observatory - a citizen science and machine learning system to analyse subsea movies

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The increasing access to autonomously-operated technologies offer vast opportunities to sample large volumes of biological data. However, these technologies also impose novel demands on ecologists to apply efficient tools for data management and processing, which are publicly available and easy to use. Such tools are starting to be developed by the scientific community and here we present a system that combines a number of essential analytical functions for analysing large volumes of subsea image data for marine ecological research. This paper presents the latest version of Koster Seafloor Observatory (KSO), an open- source system combining functionalities to i) manage and archive subsea movies and images, ii) involve citizen scientists to accurately classify footage or images, and iii) train and test machine learning algorithms for detection of biological objects. These functions are made available through a series of Jupyter notebooks allowing users to upload image/movie data, explore, format and manage classifications, as well as train and test object detection models. Here we present the current state of the available functions, plans for further development and integration with research infrastructures as well as a number of scientific use cases. Examples include application of the system for mapping mussel beds in the Baltic Sea, studying the impact of trawling on soft bottom fauna in the eastern part of the North Sea, and for long-term monitoring of key ecological species in Sweden’s marine national park - the Kosterhavet.

Figure 1: Object detection model for sea pens developed by Koster Seafloor Observatory (KSO). The model is able to classify *Pennatula phosphorea* and *Virgularia mirabilis*.

Image analysis and benthic ecology: first proceedings to analyze in-situ long-term image series

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Long time series of underwater images have become a tool widely used within the benthic ecology research community. The development of new acquisition systems with bigger storing capacities lead researches to deploy them for longer periods resulting in big amounts of data. Here we will focus on the first step when analyzing big amount of underwater images, which is to assess the amount of valid data. The question here addressed is how many of the in-situ acquired data can be really used for a benthic ecology purpose. To answer this question, we use a method based on the dissimilarity of the Gray-Level Co-occurrence Matrix (GLCM) to automatically classify images into usable or not usable. The proposed method has been used with four different sets of still time-lapsed images acquired for long periods going from 73 to 371 days in a row, and representing 42831 images. Results show accuracy values between 82% and 91% depending on the dataset and the elimination of up to 22% of the images. The main advantage of proceeding with this elimination would be to ease and accelerate automation of subsequent analyses.

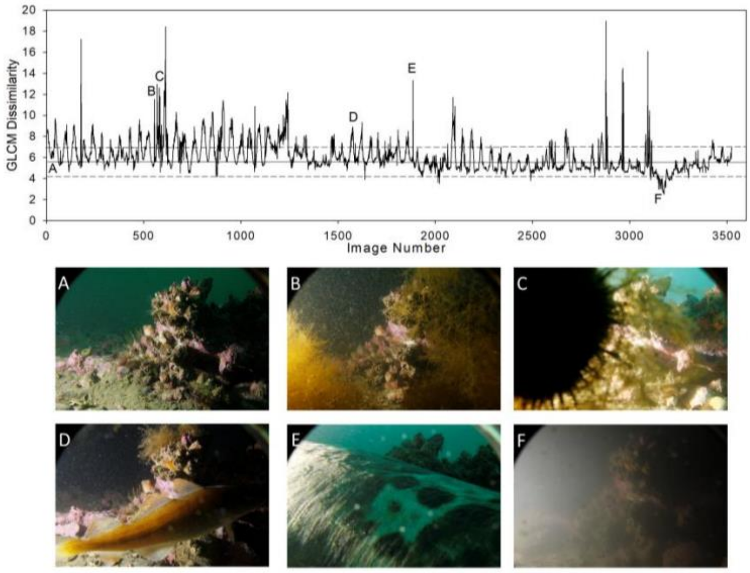

Figure 1.GLCM dissimilarity of 3500 images belonging to one of the datasets. A) image of the desired view field to analyze, B),C),D),E),F) images of different obstructions detected by their dissimilarity values

Scientific advancements in biology and geology using underwater imagery data

Oral presentations

Morphological diversity increases with oligotrophy along a zooplankton time series

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Biological diversity encompasses all the variations of life, from genes to ecosystems, and is typically described from a taxonomic, genetic, phylogenetic, or functional point of view. Here we describe the changes in morphological diversity of zooplankton along a coastal time series. Morphology is characteristic of taxa but also has functional consequences; size, for example, is often considered as a dominant functional trait.

Using high-throughput imaging of weekly plankton samples, collected from 2009 to 2019 in the Mediterranean Sea, we automatically measured 40 morphological traits on > 600,000 individuals. A reduced morphological space was defined through Principal Component Analysis and individuals were regrouped in 200 ”morphs” through clustering. In this morphological space, timeseries of indices of morphological richness, divergence, and evenness were computed using the same metrics as the ones usually defined for functional diversity.

Size, circularity, and opacity were the characteristics of the organisms that varied the most along the series. The morphs were homogeneous in appearance and recognisable, but of- ten comprised more than one taxon. All morphological diversity indices were lower in the spring. Over the eleven years, morphological divergence increased significantly while overall plankton concentrations decreased; since 2001, surface waters became significantly warmer and more oligotrophic. Overall, this fits the theory that oligotrophy leads to niche specialisation which, here, translates into morphological divergence.

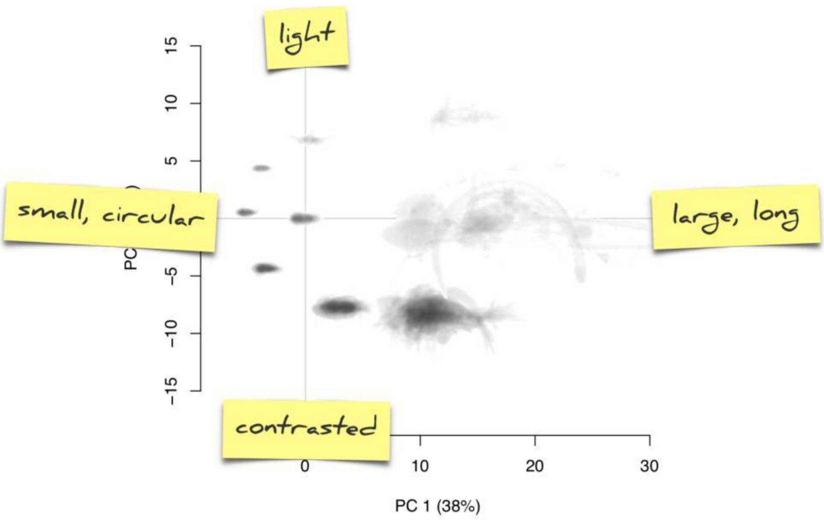

Figure 1: Morphological space of the marine zooplankton of the Point-B time series.

Deciphering the impact of mesozooplankton diversity on the ecosystem functioning in the Sargasso Sea, using molecular and imaging data

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Mesozooplankton play an important role in pelagic ecosystems. Linking primary producers and higher trophic levels, they are also involved in the biological carbon pump through the production of particles sinking into the deep ocean. This carbon flux is amplified by the diel vertical migrations (DVM) of some mesozooplankton taxa. Recent methods, like quantitative imaging, produce an enormous quantity of data at the individual scale. Then, data can be used in a trait-based approach focusing on individual morphological characteristics of the organisms in order to better understand the link between ecosystem structure and functioning. In this study, we investigated various facets of mesozooplankton diversity in a time series of the Sargasso Sea, the Bermuda Atlantic Time-series Study (BATS). We used Zooscan imaging and metabarcoding data (18S V1V2 region), to relate changes in mesozooplankton community and environmental and/or ecosystem's functioning changes. A morphological space was created from 18 morphological descriptors of 69,950 individual images to identify the main morphological traits that vary in the mesozooplankton community. A co-occurrences network was built from 225 Amplicon Sequence Variants (ASVs) and 6 groups of taxa (or "modules") were identified. Our results showed that environment variations structured the taxonomic composition of mesozooplankton, but did not affect the overall morphology of the community. These were linked to changes in ecosystem's functioning and/or in the community's morphology. DVM importance was confirmed, with darker opacity for migratory organisms that was linked to higher carbon export, and with the existence of a module with taxa preferentially sampled during the night.

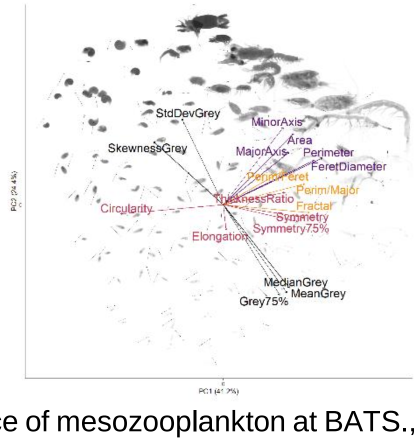

Figure 1: Morphological space of mesozooplankton at BATS., constructed on a PCA on 69,950 individual ZooScan images and 18 morphological descriptors. The first two significant axes of the PCA performed on morphological descriptors are represented. Morphological descriptors

are coloured according to their category. Morphotypes are represented according to their coordinates in the morphological space.

Automatic and non-invasive initial stock assessment of the sea cucumber Cucumaria frondosa in the EEZ of St- Pierre-et-Miquelon

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While some marine resources have been exploited for centuries and offer solid data for stock assessment, others are being harvested for less than a decade. This is the case of the sea cucumber *Cucumaria frondosa* in the EEZ of Saint-Pierre-et-Miquelon. The species triggers a remarkable interest for fishermen due to its sky-high commercial value (up to 400€/kg dry weight) increasing the pressure on the stock. Classical approaches for harvesting stocks consist in using fishing techniques such as bottom trawling or dredging and catching the species. These methods are intrusive and impact the ecosystems. In order to manage this stock and define a sustainable TAC, we evaluated the species biomass through two scientific cruises in 2021 and 2022 using a non-invasive, repeatable and time-effective assessment of *C. frondosa* abundance. We collected high-quality images on the first cruise that enabled training a deep learning model (CFRNN architecture) reaching high performances on both juvenile and adult life stages. We further evaluated the variability in the manual (i.e. human expert) estimated counts and compared it with the model-based estimates; both matched quasi-systematically. The benefits of the proposed approach are to enable a direct counting of the animals without assumptions on efficiency and selectivity of the gear. The use of the ratio estimator and non-parametric bootstrap provided estimates of biomasses of adults of 157 kt [107-210 (CI 95%)] in the EEZ. Our method therefore provides a state-of-the-art, fully automatic assessment for an exploited species, demonstrating that dredging or bottom trawling can now be bypassed by non-invasive methods for biomass evaluation of epibenthic species.

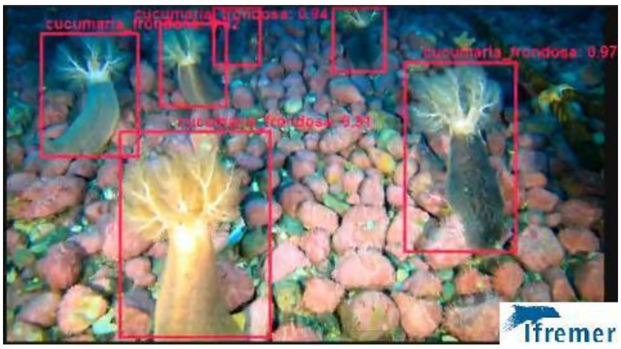

Figure 1: Example of automatic detection of adult C. frondose in the EEZ of St-Pierre-et-

Miquelon.

A revised derivation of aggregate sinking velocity and its implications for particle flux measurements using underwater camera systems

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Marine snow sinking velocity is an important determinant of the efficiency of the biological carbon pump, but there are large deviations between measured and predicted size-specific sinking velocities. To better understand the sinking behaviour of marine aggregates, we analysed the flow field around 95 *in situ* collected samples using Particle Image Velocimetry. In addition to measuring basic parameters, we used empirical relationships to independently derive the drag coefficient from the fluid boundary layer.

Our results indicated that the fluid boundary layer thickness, drag coefficient, and general flow field did not noticeably differ from those of impermeable spheres with similar Reynolds numbers, suggesting that *in situ* formed aggregates behave according to Stokes' law. In line with previous comparisons of size-to-sinking relationships for marine aggregates, we observed that Stokes' law underestimates the sinking velocities of small aggregates and overestimates those of larger aggregates. This is likely due to their fractal nature, with porosity increasing with increasing size, following a power function. This results in a decrease in excess density with increasing diameter, and lower sinking velocities than predicted by Stokes' law.

As expected from the Reynolds number regime, the Stokes' drag was not sufficient to accurately predict sinking velocity, but the White relationship, as well as our best fit, yielded a significant improvement. By applying the drag and porosity relationships derived in this study, the controlling variables of sinking velocity can be reduced to diameter, solid hydrated density, gravitational acceleration, water viscosity, and density. Most of these are easily measured with underwater cameras and CTDs, but obtaining the solid hydrated density requires physical sampling of marine snow. Because this is not always possible, a better

characterization of particle types and their mass densities from different oceanic regions is necessary to refine sinking velocity assumptions for particle flux measurements using underwater camera systems.

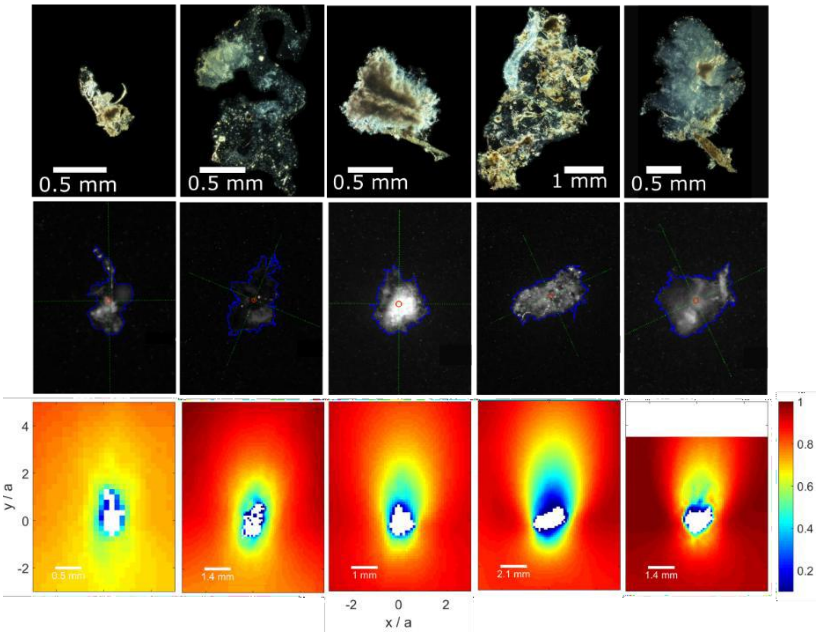

Figure 1: *In situ* collected samples including marine snow, faecal pellets and mucous aggregates (top row), with aggregate masking applied to images extracted from the PIV recording (middle row), and the resulting flow fields (bottom row)

An image-based multi-scale approach to map the distribution of deep-sea coral and sponge communities

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Understanding the spatial distribution of marine organisms in relation to topography and environmental conditions is key for ecosystem-based management and conservation. In particular, there is an acute need to map the distribution of vulnerable marine ecosystem indicators such as deep-sea coral and sponge (DSCS) communities. However, due to technological limitations, there is often a scale mismatch between seabed mapping and biological sampling. Using multiple subsea platforms and imaging methods, we mapped the spatial distribution of DSCSs on Sur Ridge (800-1250 m depth; off Central California) at several scales: 1) benthic communities were characterized at the scale of the entire ridge using over 100 video transects conducted with a remotely operated vehicle (ROV) between 2014 and 2021 (Figure 1A). Megafaunal communities were mapped in the context of a 1-m scale bathymetric map of the 20 km long and 4 km wide ridge from autonomous underwater vehicle (AUV) surveys, and related to environmental conditions (*i.e.* currents). 2) the distribution of faunal communities was also characterized at a ~5 mm scale from photomosaics built using low altitude ROV surveys covering roughly 100 x 100 m areas (Figure 1C, D). Terrain variables extracted from 1-cm and 5-cm scale topography obtained simultaneously from lidar and multibeam sonar systems, respectively, mounted on the ROV were then related to species distributions (Figure 1B). Because acoustic (sonar) sensing sees through soft animals that optical (lidar) systems map, differencing the two bathymetry models reveals the location and size of many animals, providing a new tool to quantify benthic habitats and estimate densities of foundation species such as coral and sponges. By clarifying the role of topography and environmental conditions on DSCS communities at multiple spatial scales and resolutions, this study will help refine existing species distribution models, contributing to the protection and management of these vulnerable ecosystems.

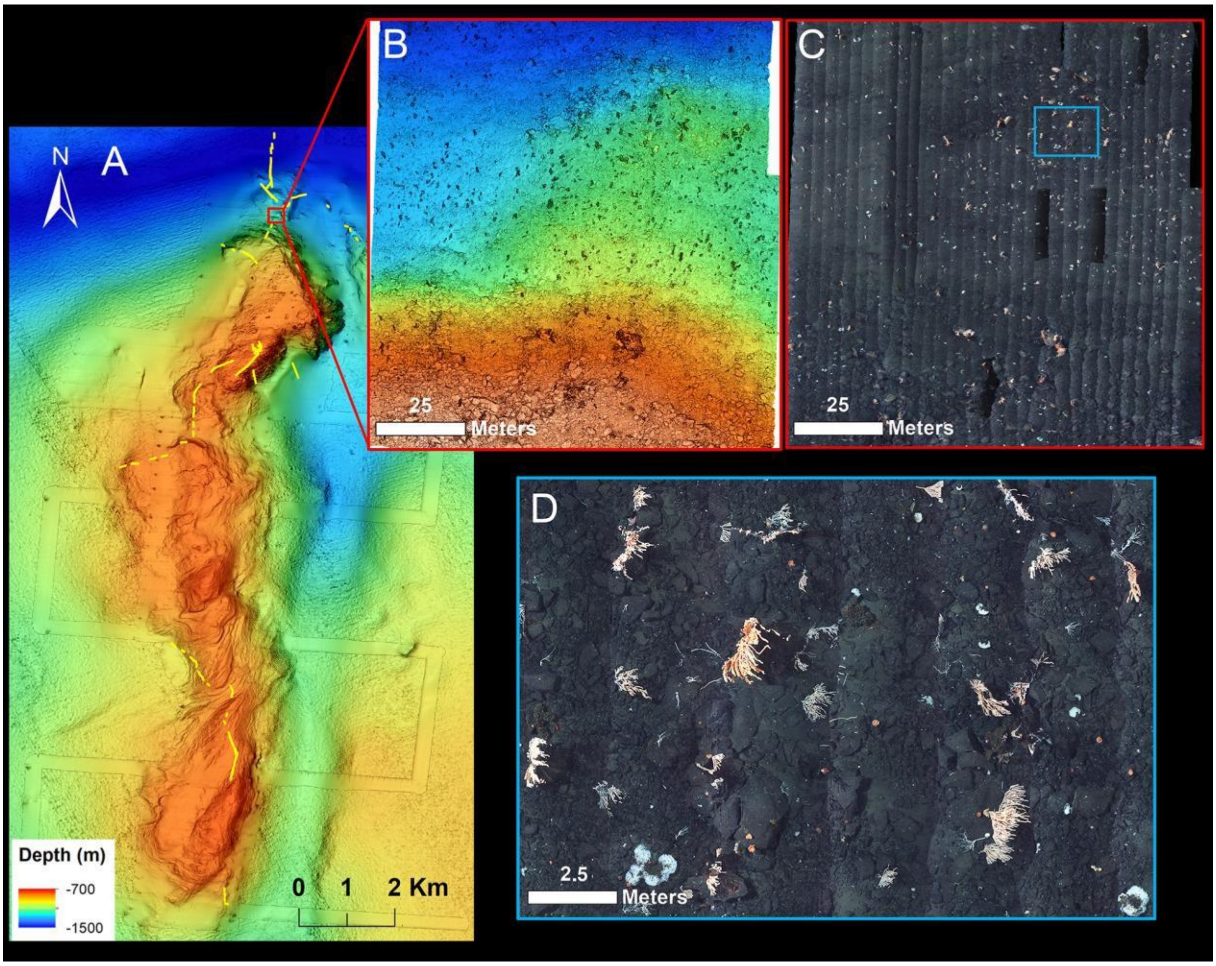

Figure 1: Multi-scale mapping of topographical features and biological communities on Sur Ridge. (A) 1-m scale topography of Sur Ridge from 400 kHz multibeam sonar mounted on AUVs. Yellow lines represent video transect tracks from the ROV. (B) 1-cm scale lidar topography and (C, D) 5-mm resolution photomosaic obtained with low- altitude ROV surveys. Blue box in C shows extent of D

A morpho-functional approach to palliate poor taxonomic resolution of cnidarians and poriferans from deep-sea images: case studies from poorly sampled areas.

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Cnidaria and Porifera are key phyla of marine ecosystem functioning, for example by providing shelter, nursery, and food source or by offering additional ecological niches to associated species; thus promoting diversity. They are also slow-growing and long-lived taxa, making them poorly resilient to human disturbances. For these reasons, they are used as indicator taxa of Vulnerable Marine Ecosystems. However, assessing the spatial and diversity patterns of these habitat-forming taxa is difficult in the deep-sea, as this relies on seafloor images, usually associated with low taxonomic resolution.
Indeed, identification from images of cnidarians and sponges beyond class/order ranks is particularly challenging. These taxa exhibit complex taxonomy and high morphological plasticity within species or convergence among taxa, even at high taxonomic rank. Their identification requires the observation of microscopic diagnostic characters (e.g. sclerites for corals, spicules for sponges) that are not visible on images.
To overcome this issue, a standardized classification based on sponges functional morphologies was recently proposed (Schönberg, 2021).
Here, we applied (1) an image-based classification relying on a multiple macro-morphological traits approach, adapted from Schönberg classification scheme for Porifera, and we created one for Cnidaria based on the same principle. Then we built (2) a framework for defining statistically morphological groups based on these traits that are related to morphological functions rather than taxonomical entities. These morpho-functional groups were then used as entities (response variable) in ecological analyses, instead of taxa.
To illustrate this methodology, we will take examples from poorly sampled regions where taxonomic identification issue is particularly critical. Mozambique Channel and New Caledonia seamounts as well as island slopes data were analysed to characterise: (a) sponges and cnidarians diversity and distribution patterns at various spatial scales, (b) their responses to environmental constraints/gradients, (c) their structuring roles on associated megafaunal communities.

Classification of cold-water coral (CWC) reefs in high resolution: using 3D photogrammetry and machine learning for CWC habitat classification of the Piddington Mound, southwest of Ireland

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

This research combines 3D photogrammetric techniques and machine learning methods to yield automatic high spatial resolution analyses of CWC reefs and seabed features. The aim is to develop a multiclass classification scheme for 3D data using optimised algorithms by analysing the parameters for pre-processing, classification, and feature selection.

To this end, a multiclass semi-supervised ML workflow was developed to further understand the applications, effects and results of different algorithms, hyperparameterisation and dataset sizes. Eighteen variations of six ML algorithms were trained and evaluated using a 3D reconstructions of Northeastern segment of the Piddington Mound (Porcupine Seabight, NE Atlantic). Each algorithm was trained in two datasets of different sample sizes in order to evaluate the accuracy variation in relation to the number of samples. Run times were measured to evaluate the trade-off between processing and accuracy.

Preliminary results shows that certain algorithms proved to be more suited for the specific classification task proposed, namely: Gradient Booted trees (GBT), Random Forests (RF), K-Nearest Neighbours (KNN), and Multilayer Perceptron (MLP) with F1 accuracies of >90% and ability to discern between the four classes, especially those with usually similar characteristics e.g coral rubble and dead coral. The accuracy variation among them was 3.4% which suggests that they can be used interchangeably depending on the classification task. Future research will involve the application of the proposed classification workflow on different CWC reef locations and further optimization of input variables.

Application of automated object detection for quantitative deep-sea benthic ecology

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Deep-sea ecology researchers are faced with the difficult challenge of exploring and understanding an immense and hard to reach ecosystem and more data is needed to fill up the gaps in our knowledge. Sampling technologies have greatly improved in recent years. Thanks to digital High Definition imaging, remotely controlled and autonomous vehicles can sample larger and larger areas of the seabed, providing hundreds of thousands or even millions of images. Technological development on automated image annotation is needed to take advantage of this large amount of data and translate it to ecological knowledge.
Image annotation is a slow and tedious task, but can be automated with Artificial-Intelligence applied to image analysis or Computer Vision (CV). In the last 5 years, the growing accessibility of algorithms, capable of quickly detecting animals in images and identifying them with high accuracy, has put it within reach of ecologists, without extensive engineering and programmer training.
Here we investigated how well these algorithms can perform in practical applications in benthic ecology. We trained YOLO (V4 & V5) Convolutional Neural Networks (CNNs) to detect specific benthic species (including sea-pens, bamboo corals and xenophyophores) in images, taken by both ROV and AUVs, in order to measure and map their abundance and distribution.
The results of these experiments show that CV can be a viable alternative to manual annotation. The CNNs could annotate tens of thousands of images in a matter of hours and give abundance results sometimes more than 95% similar to what manual annotation would give. Additionally, recall and precision were above 0.8 or even 0.9 with only hundreds of training images. Performances were not homogenous however, and many factors can influence whether or not CV is a suitable replacement for manual annotation. Thus, more research is needed on its implementation in benthic ecology.

Fish nests, crawling sponges and deep diving whales: Spatial assessment of new deep sea ecosystems / seafloor interactions with photo and acoustic cameras

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Natural light does not penetrate to the deep sea ocean depths, and therefore considerable amounts of power must be delivered to artificial light sources to illuminate regions of interest. Despite ongoing improvements in light design, platforms investigating these deep and remote locations generally focus on a few square meters of seafloor at a given time. Acoustic based systems, such as side scan sonars and acoustic cameras, are not inhibited by lack of illumination in their imaging of the seafloor, and can survey broader areas. Side scan systems are commonly used in marine mapping, but acoustic cameras are commonly only used by commercial Remote Operated Vehicle (ROV) systems to image underwater features, such as oil rig legs, in turbid waters or at distances of many meters, and have had little application scientifically to date. Here we present recent scientific research highlights which have been made with a towed platform, the Ocean Floor Observation and Bathymetry System (OFOBS), which integrates video and still image cameras with side scan and acoustic camera systems to give both a broad spatial analysis of seafloor regions, as well as detailed close up images of remote and novel targets of interest. By combining these various data types, and by subsequent processing of image and video data to derive ‘Structure from Motion’ (SfM) 3D mosaics, researchers from the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, together with collaborators, have been able to present broad analyses of new and remote ecosystems, such as the recently discovered icefish breeding colony of Antarctica, moving sponge fields of the high Arctic and the activities of the deep diving whales of the mid Pacific than would have been possible using only one of these data types, or without subsequent SfM analysis.

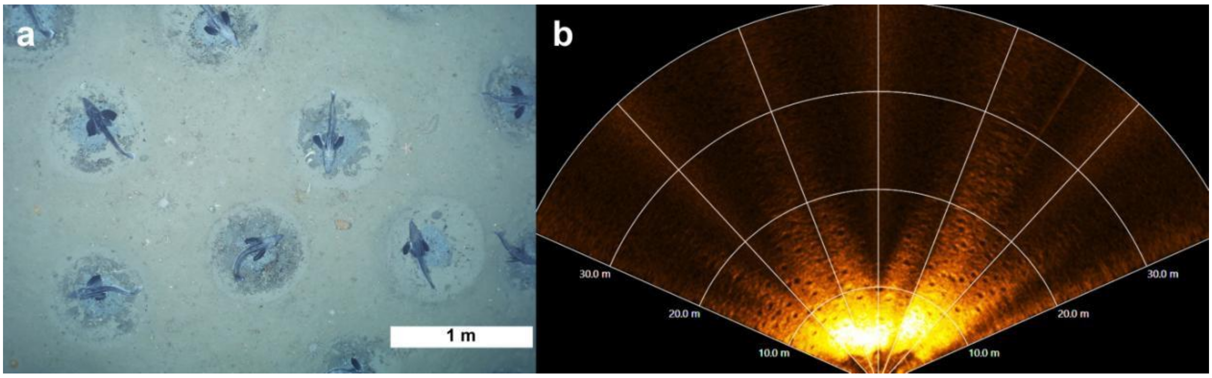

Figure 1: a) The icefish nest arrays of the Weddell Sea, Antarctica, as imaged from the OFOBS towed camera sled in 2021 during the PS124 expedition.b) The same fish nests, as imaged with a forward facing acoustic camera mounted on the OFOBS. Every individual fishnest is visibel in the acoustic image, to a distance of 40 m.

High resolution characterization of plankton and particles with multi-scale imaging in the North Atlantic

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High levels of spatial and temporal variability in plankton and organic matter-rich marine snow aggregates make it challenging to assess their role in ocean food webs and carbon cycling. We are working to meet this challenge by combining multiple high throughput imaging approaches. Here we highlight case studies in the North Atlantic combining imaging- in-flow cytometry (Imaging FlowCytobot, IFCB) to quantify nano- to microplankton and in situ shadowgraph imaging (Deep-focus Plankton Imager, DPI) to quantify meso- to macroplankton, including gelatinous organisms. Our shipboard IFCB observations comprise automated sampling of underway surface waters and discrete samples at selected depths, while the DPI observations are made on a vertically profiling towed vehicle. By combining these imaging approaches with automated image classification via convolutional neural networks, we quantify spatio-temporal patterns with taxonomic resolution across trophic levels. Our results emphasize high gradient changes in community structure associated with frontal dynamics at the Northeast U.S. Shelf Long-Term Ecological Research (NES-LTER) site and mesoscale eddy dynamics in the subpolar eastern North Atlantic during the Export Processes in the Ocean from Remote Sensing (EXPORTS) campaign in spring 2021.

Marine imaging mapping and characterisation of vulnerable habitats in Norwegian fjords

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In the deep waters of Norwegian fjords some coral and sponge species form habitats that play a key role in the functional ecology of the benthic environment. These foundation species provide structural complexity in areas usually flat and featureless, allowing the creation of feeding and nursery grounds for an important diversity of organisms. Due to their functional significance, sensitivity and slow recovery, such habitats are considered vulnerable. However, deep coastal waters are poorly mapped and there is only sparse information about their distribution and characteristics, which complicates decision-making process. In Norwegian fjords, these habitats are often subject to conflicting interests between conservation efforts and human activities such as fishery or aquaculture and a thorough understanding of their distribution, diversity and environmental requirements is needed to manage them. To overcome these knowledge gaps, we conducted deep-water ROV and towed videos surveys of the seabed associated with environmental characterisation in 5 different fjords located in Nordland County (Norway). Coastal imaging mapping techniques and annotation methods used by the Norwegian Institute of Marine Research will be presented. During these surveys, we observed different vulnerable habitats such as bamboo coral (*Isidella lofotensis*) gardens, *Desmophyllum pertusum* coral reefs and hard bottom sponge gardens (*Phakellia* spp., *Godia* spp.). Specifically, through the analysis of 52 video transects we were able to estimate i) the density range of the different habitat-building species and ii) the diversity and composition of species associated with each habitat. Also, further work will aim to link these biological data to physical conditions to obtain a better understanding of environmental drivers and their local distribution, in improving the prediction of their regional distribution. Such information is essential for a more informed management of anthropogenic activity in Norwegian fjords and the conservation of these extremely long lived, functionally important and iconic habitats.

Subcellular monitoring of viral infections in marine diatoms by automated confocal microscopy

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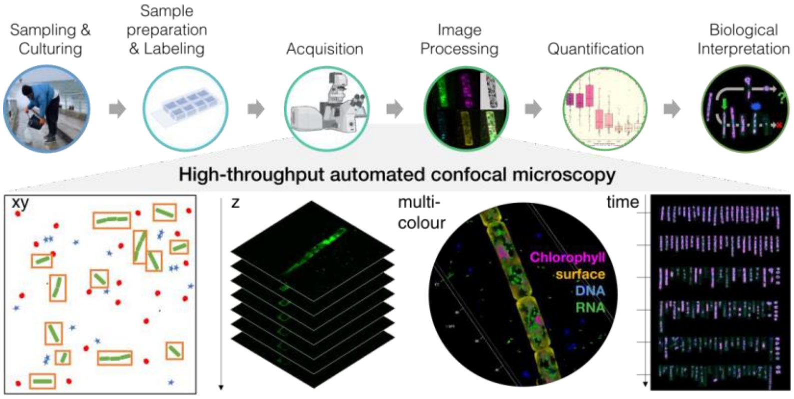
Deciphering biotic interactions in marine microbes often requires observations on the subcellular scale. However, imaging at high resolution usually comes at the price of low throughput of observable cell numbers. One way to overcome this blind spot in marine ecology is to automate repetitive steps of microscopic image acquisition and image analysis.Here, we present our recent work on the impact of viral infections on the abundant marine diatom *Guinardia delicatula*. These globally distributed and ecologically successful organisms form large annual blooms, which are regulated in part by RNA viral infections[1]. Detecting such viruses remains however difficult due to their small size (25-35 nm) and low genome content (9 kb). While they are too small to be <u>resolved</u> by light microscopy, we have recently succeeded to develop an imaging assay to <u>detect</u> cytosolic viral accumulations in infected cells with confocal microscopy. We integrated automated 3D microscopy[2] and quantitative image processing with classical physiological measurements to gain insights on both, subcellular and population level.This approach has yielded new detail of the dramatic morphological impact of marine viral infections on their hosts and on how diatoms escape such viral infection. Quantitative morphometry of the deformation of essential cellular structures allows for a direct measurement of the degraded biomass. In the future, this work will help us to better understand the extent to which viruses and other parasite infect natural diatom populations and their cascading effect on the marine food-web and global biogeochemical cycling[3].

1. Arsenieff et al. "First viruses infecting the marine diatom *Guinardia delicatula*." *Frontiers in Microbiology* 9 (2019), 2.Colin et al. "Quantitative 3D-imaging for cell biology and ecology of environmental microbial eukaryotes." *eLife* 6 (2017), 3. Rohwer & Thurber. "Viruses manipulate the marine environment." *Nature* (2009)



To study subcellular processes inside many individual cells, automated microscopy methods are indispensable. In a two-step acquisition procedure, 3D multicolour confocal z-stacks of hundreds of marine diatoms at pre-selected coordinates are acquired. This approach and resulting data allow for subsequent quantitative image analysis of the degradation of subcellular organelles during a viral infection.

In situ Particle Measurements Deemphasize the Role of Size in Governing Particle Sinking Velocity

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In recent years, the use of in situ optical methods has emerged as an important tool in the study of marine particles, and their role in sequestering carbon in the deep sea via the ocean's biological carbon pump. These novel approaches can provide information on particle abundances, size, and type, and may be deployed autonomously, providing far greater spatiotemporal coverage and resolution than traditional ship-based methods. In addition, particle image analysis can also be used to estimate sinking particle fluxes, when combined with information on carbon content and sinking velocity. Particle sinking velocities are influenced by a number of factors, such as particle size, type, shape, and ballast content. Whilst particle size has received the most interest and is widely held to be a strong predictor of sinking velocity, a recent work using an in situ optical method has questioned the strength of this relationship. Here we carried out an extensive literature review (62 datasets) into the size-sinking velocity relationship, and find the relationship is much weaker for studies examining particles in situ (median R^2 = 0.03) compared with ex situ studies (median R^2 = 0.35). This may be because particles examined in the laboratory have more uniform properties than those studied in situ, and represent only a subset of particles from the natural environment. Our findings suggest a simple relationship between size and sinking velocity may be insufficient when calculating sinking particulate fluxes in the ocean, with immediate implication for the use of particle image datasets in determining particulate fluxes. When deriving estimates of particulate fluxes from particle size spectra, considering individual size-scaling relationships for different particle types will enable more accurate calculations of particulate fluxes.

Characterizing Pathways of the Biological Carbon Pump in two Fjords with Contrasting Pelagic Food Web Structures

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With rising atmospheric carbon dioxide levels, understanding the pathways of the biological carbon pump (BCP) marine ecosystems becomes more important than ever.
Here, we compare the BCP of two adjacent Norwegian fjords (Masfjord and Lurefjord) with similar topography but different pelagic ecosystems. In the Masfjord, two mesopelagic fish species are present, while in the Lurefjord high abundances of the helmet jellyfish *Periphylla periphylla* are documented. We used in situ imaging techniques (Underwater Vision Profiler UVP5HD, and the Pelagic In Situ Observation System PELAGIOS) combined with scanned samples collected with a Multinet Midi and Maxi, to estimate both the sinking flux as well as the biomass and metabolic rates of pelagic organisms. Comparing these imaging techniques allows to understand the differing pathways of the BCP in the two fjords and to identify possible instrument-specific sampling biases
Results indicate major differences between the fjord ecosystems that can be seen across all the different instruments used. High appendicularian abundances were found in the Masfjord by mainly the data collected with the UVP5, which was validated by PELAGIOS video data. Contrasting to that, large copepods such as *Calanus glacialis* were more abundant in the Lurefjord with only few appendicularians found. Copepods could mainly be detected using the MultiNets and UVP5 as they were too small to identify exactly using the PELAGIOS. Whole *P. periphylla* organisms could however only be observed in the PELAGIOS video footage as they were usually too large to be captured by the UVP5. Based upon size to biomass estimates and allometric metabolic rate functions, we here present a tentative budget of carbon fluxes through the epi- and mesopelagic mediated by the different key players.

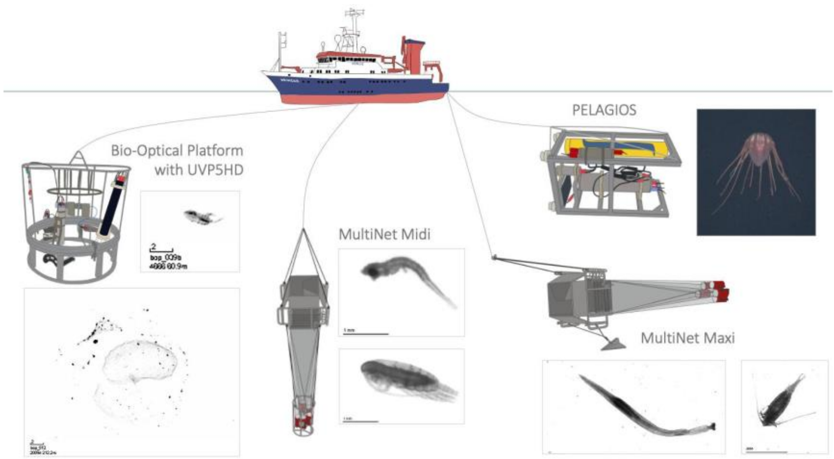

Figure 1: Instruments used for collecting samples and image data with example images of organisms present.

Posters

Interannual variation in benthic megafauna community composition in the Arctic Ocean

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Benthic megafauna in the Arctic Ocean plays a pivotal role in the functioning of deep-sea ecosystems and influences the global carbon cycle. The structure of benthic communities in the Arctic Ocean is primarily determined by food availability and therefore by phytodetrital flux from surface layers. Hence, highly productive marginal sea-ice zones provide high food supply for benthic communities. With the advance in climate change, marginal sea-ice zones are shifting and organisms are faced with changing phytodetrital fluxes. This study was designed to increase the understanding of benthic megafauna community dynamics in the Arctic Ocean and infer predictions about the future. Therefore, the benthic megafauna was quantified at three stations, with contrasting extent of sea-ice coverage, located in the north (N3), centre (HG-IV) and in the south (S3) of the HAUSGARTEN observatory in the Fram Strait. Image data from different years between 2016 and 2021 were annotated and analysed in context with sea-ice coverage measurements. The benthic megafauna communities showed a shift in dominant functional traits, from sessile suspension feeders, to mobile deposit feeders at all stations. The dominance of mobile deposit feeders was attributed to one species, the sea cucumber, Elpidia heckeri. Additionally, a positive relation between benthic megafaunal density and the extent of sea-ice coverage at N3 and HG-IV was indicated. Variations in phytodetrital quality and quantity are most likely the reasons for these strong density increases of the opportunistic sea cucumber. For the future, similarly strong variations in deposit feeding holothurian densities are expected, given their ability to quickly respond to changing phytodetrital fluxes. The results also indicate that benthic megafauna community composition as a whole is likely to exhibit strong variations in density and diversity. This research shows how valuable image data from time-series studies are in order to detect long-term trends in the future Arctic Ocean

Is there hope for accurate carbon flux estimates based on UVP images?

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The ocean's capacity to take up and store carbon via the Biological Carbon Pump (BCP) is a key uncertainty in our understanding of the global C cycle and its response to anthropogenic perturbations. The gravitational component of the BCP is the largest one, with sinking particles as the vehicles of the C to deep waters in the Particulate Organic Carbon (POC) form. The use of underwater cameras to study the particle properties has impacted the field of oceanography within the last decades, with Underwater Vision Profiler (UVP) type cameras one of the most widely used optical system. UVPs allow for the remote collection of large data sets on particle abundances and their size distributions and enable much higher space and temporal resolutions than traditional methods. The goal is, therefore, the global use of UVPs to develop a budget of C flux with Argo floats. Nevertheless, the quantitative translation of these immense datasets into biogeochemical properties remains a challenge and a systematic method to reliably calibrate particle images against C fluxes has not been established. Here, we confront the Guidi et al. (2008)1 approach using coincident sediment trap and thorium-234 C flux, and aggregate size distribution observations from the two EXPORTS field campaigns: i) the North Pacific campaign (Ocean Station Papa, 50°N, 145°W) in later summer 2018, and ii) the North Atlantic campaign (Porcupine Abyssal Plain Site, 49°N, 16.5°W) in May 2021. We find the optimally tuned model explains slightly less than 50% of the variance with the matchups over the entire EXPORTS data set made with the measured sinking POC fluxes. We suggest next steps to reliably assess C export by using UVP images. 1Guidi et al. (2008) 'Relationship between particle size distribution and flux in the mesopelagic zone', Deep

Small-scale zooplankton distribution during a mesocosm study in the Peruvian Upwelling system, observed with the PIScO imaging system

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We present the first plankton dataset collected with the newly developed plankton imaging with scanning optics (PIScO) “extended depth-of-field” zooplankton imaging system. The system combines high optical resolution (~12 µm/pixel) with a very large sample volume (2 liters per image), thereby drastically improving the identification and analysis of plankton species in the size range between 200 µm and 10 mm. The images were recorded *in situ* during a mesocosm experiment in the Peruvian Upwelling System off the coast of Callao, Peru, to examine the effects of changing upwelling and light conditions in a future ocean.
The image characteristics allow for the application of state-of-the-art object-detection models (e.g. YOLOv5) and results were compared to those of a similar imaging method.
The presented data demonstrate a new level of detail for the quantitative examination of plankton, in that not only a wider size range of plankton is detected, but also at a higher optical resolution. This greatly facilitates the classification and analysis of each recorded object. Furthermore, the *in-situ* imaging approach can resolve small-scale spatial features on the order of few cm.
In the context of the mesocosm study our data indicates a clear relationship between the copepod size and their abundance. This was additionally modified by light conditions, and a strong temporal variability of vertical biomass distribution over the course of an upwelling-induced bloom period.

High-throughput video and acoustic imaging from seafloor cabled observatories for benthic ecosystem monitoring in coastal and deep-sea settings

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Ocean Networks Canada (ONC) operates large seafloor cabled observatories in the Arctic, Atlantic and Pacific, with some of its long-term observations surpassing 16 years. We present snapshot results from long-term video time-series observations and *in-situ* experiments studying the benthic boundary layer in two coastal and one continental margin setting of Canada's Atlantic and Pacific Oceans. Using video imagery spanning for 7 years (2013-2020) we studied the deep-sea pink urchin *Strongylocentrotus fragilis* with respect to the expanding oxygen minimum zone in Barkley Canyon (420 m), NE Pacific. In a second case study, we analyzed 6 months of hourly videos from the newly installed Holyrood observatory in Conception Bay, Newfoundland, Atlantic, to investigate benthic-pelagic coupling following the onset of the 2021 spring bloom. From a series of short-term experiments, we combined video and acoustic imagery (dual-frequency identification sonars) and passive acoustics data to better understand poorly understood fish vocalizations, overall temporal changes in benthic abundance and diversity, and behavioural responses to artificial lighting. In a first experiment, in turbid waters of the Fraser River Delta (150 m), Strait of Georgia, the acoustic camera proved to be the most efficient device for measuring faunal densities, while the video was more efficient in detecting a moderately diverse assemblage of fish and invertebrates. Light avoidance behaviour was detected in a large number of species while light attraction was verified for the spotted ratfish *Hydrolagus colliei*. In the second and third experiments, deployed at 640 m depth adjacent to Barkley Canyon, sequential bait-introduction was employed for the study of benthic successional patterns of deep-sea scavenger communities under limiting dissolved oxygen conditions. Lastly, we present an example of machine learning using a deep learning neural network applied to the automatic detection of commercially harvested sablefish, *Anoplopoma fimbria*. With an 92% average precision detection algorithm, we applied results to more than 650 hours of video imagery, and discuss its applications for stock-related assessment metrics and monitoring.

Underwater optical imagery as tool for the study of benthic succession on settlement panels in an Arctic fjord

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One of the earliest applications of underwater photography was specifically for scientific purposes. Long-term underwater experiments can gather and archive baseline data of considerable ecological value. However, these data require robust and repeatable processing protocols and well-designed downstream analyses. Technology for automating such protocols and analyses is rapidly developing and constantly evolving; and although establishing a well-suited workflow often requires trial–error feedback, automation can be a more efficient approach in the long run. We investigate suitable workflows to process and analyse underwater settlement panel photographs registered between 2010–2021 in Isfjorden (78°N). This includes the analysis of archival (underwater) imagery for evaluating the recruitment and succession of benthic assemblages using HIPS panels (high impact polystyrene, artificial substrata) as hard-bottom surrogates. Automation is explored through input to output, although some activities require supervision (semi-automatic). At the input level, automation can be achieved with the 'scripting instead of actions' approach in Photoshop (PS), by using custom scripts to open, rename, and order the files, according to the users' needs. Using PS, 304 (77.6%) out of 393 photopanels were successfully photomerged (Fig.1). Further processing is expected to include automated image enhancement (adjustment of levels, curves, HSB), image segmentation, and the implementation of machine learning (ML) into our imagery workflow. Using a supervised ML-framing, we aim to utilise a multi-class, multi-label classification model to distinguish among two or more discrete classes (e.g., morphospecies, growth forms) and assess spatial contest (interference) competition (win, loss, stand-off). We aim to build, analyse, and share a long-term image-data series; develop and share the models, algorithms and code considering the FAIR principles (Findable, Accessible, Interoperable, and Reusable) at all stages.

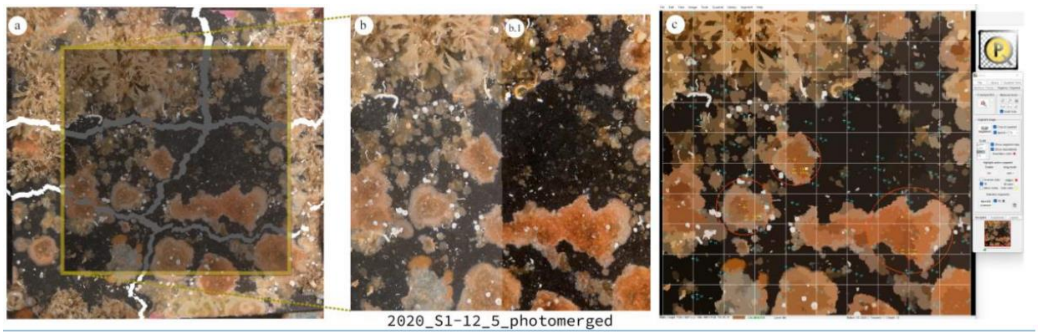

Figure 1: Image processing of an underwater photopanel. a) Photomerging of six (overlapping) subpanels and demarcation (yellow frame) of b) the area of interest (100x100mm); b.1) image enhancement (tone control adjustment of curves and levels), label below (year_station-depth_panel code). c) Image segmentation and calibration, with grids and randomised points for identification, quantification, and further measurements. Software: Adobe Photoshop CC 2021 (a,b,c); photoQuad v.1.4 (d).

A new approach for mapping marine benthic habitats using Full Motion Video and underwater photogrammetry within the Marine Strategy Framework Directive (MSFD)

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The EU Marine Strategy Framework Directive (MSFD) aims to achieve and /or maintain the good environmental status (GES) of the European seas, adopting management measures based on ecological indicators, methodological standards, and monitoring programs. A specific monitoring program, carried out by Italy within Descriptor 1 - Biodiversity (D1), aims to characterize and monitor the environmental status of three benthic habitat typologies: i) Posidonia oceanica; ii) Coralligenous and Cold-water corals (CWCs); and iii) Rhodoliths beds. A multi-resolution and multi-scale approach based on machine learning algorithms is tested to improve and speed up the mapping and video analysis. The Full Motion Video (FMV) technique by underwater photogrammetry, DEM (Digital Elevation Model), backscatter and bathymetry from high-resolution Multibeam (MBES), and ROV (Remotely Operated Vehicle) -imaging were integrated. The data were collected in 2020-2021 in three Italian pilot sites: Cirella and Elba Islands in the Tyrrhenian Sea and Linosa Island in the Strait of Sicily. The surveys were carried out by a multibeam EM 2040 MBES, a towed vehicle equipped with cameras, and a ROV (Perseo). The acquired data were georeferenced using NATO's Stanag 4609 protocol; FMV videos were converted in Trasport Stream (.TS) file format; and the entire dataset was analysed using ArcGIS Full Motion Video. All the frames were processed using the Structure from Motion (SfM) algorithm to generate very high-resolution 3D and orthomosaics models. Bathymetry backscatter was classified by means of eCognition software, according to the Object Image Analysis (OBIA) approach. The results confirm that multi-data integration procedure (FMV, SfM, and OBIA) significantly improves quality and strongly reduces the time-consuming of habitat mapping. Machine Learning application in the ecological study of marine habitat can play an important role in improving the knowledge on species and habitat distribution and condition, allowing its adoption for the MSFD monitoring activities in Italy.

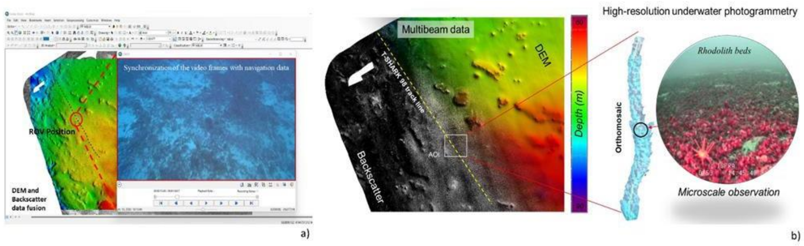

Figure 1: a) ArcGIS Full Motion Video tools, b) Example of multiscale approach for Rhodolith beds.

Under the lens of a ROV. Deep-sea associations studied through marine images.

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Deep-sea corals and sponges are known to form associations with other invertebrates, which often use them as a substrate, shelter or as a source of food. Although marine imaging has already proved to be a turning point in deep-sea ecological research, associations are still mainly studied through the analysis of collected specimens.
In 2016, 2017 and 2018, ROV Holland I – deployed from RV Celtic Explorer - was used to acquire samples, images and video data in several deep-sea cruises undertaken on the Irish continental slope, including Whittard Canyon, and the Porcupine Bank.
For all the corals and sponges collected in CE16006, CE17008 and CE18012, we analysed both in-situ images and photos taken on deck, looking for the presence of associations. We thus created a dataset yielding information about the hosts (ID, size and morphological characteristics), and their associates (ID, number and size).
We used imagery data to investigate the role that characteristics such as morphology, texture and size of a host play in the presence, number and size of associated invertebrates. Moreover, we detected a difference between the associates observed on in-situ and on-deck pictures. This means that some information may be lost when analysing collected samples without referring to in-situ images and videos.
Our work proves the importance that marine images have in the study of deep-sea ecology. The implementation of marine imagery as an ecological tool to study deep-sea ecosystems will allow a better exploitation of huge amounts of data that have already been collected, thus having important implications for deep-sea research and conservation management.

Figure 1: *Paragorgia* sp. with associated zoanthids and ophiuro

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