Implementing biodiversity monitoring of rocky shores using photo-quadrats and Artificial Intelligence in support of data-driven decision-making of marine living resources

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Abstract

The Marine Biodiversity Observation Network Pole to Pole of the Americas (MBON Pole to Pole) conducted two workshops on 27-31 March 2023 and 22-26 January 2024 in the Argentinian Patagonia aiming to enhance capacity for long-term monitoring of rocky intertidal communities in Argentina and Chile by applying novel and easy-to-use methods for biodiversity observing. In these workshops, participants received training on the collection and processing of benthic photo-quadrat imagery and their analysis using open-source artificial intelligence applications. Workshop participants included park rangers, undergraduate and graduate students and scientists. These training activities covered theoretical concepts of rocky shore ecology and field exercises. The workshops promoted collaboration and knowledge exchange between users of biodiversity data and ecologists resulting in the development of a standardised biodiversity monitoring protocol for rocky intertidal communities available in the Ocean Best Practices System of the

Intergovernmental Oceanographic Commission of UNESCO. Participants learned to identify dominant species and functional groups (e.g. macro-algal taxa, molluscs, barnacles) commonly present in these habitats and their zonation patterns along elevation gradients, capture high-quality benthic photographs using quadrat frames and cameras provided by the MBON Pole to Pole and compute percentage cover estimates of observed taxonomic groups using open-source automated classifiers. Emerging recommendations underscored the importance of actively involving park rangers in survey efforts and facilitating communication with decision-makers managing Marine Protected Areas. These activities were endorsed by the UN Decade as contributions to the Marine Life 2030 programme towards increasing capacity in the implementation of coordinated, standardised and sustained biodiversity observing efforts in the Americas.

Keywords

rocky intertidal, ocean observation, Marine Protected Areas, capacity building, SDG14

Date and place

- 1st Workshop, 27-31 March 2023, Camarones, Chubut - Argentina - Website
- 2nd Workshop, 22-26 January 2024, Ushuaia, Tierra del Fuego - Argentina - Website

List of workshop contributors

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- MSc. Gonzalo Bravo (UNPSJB | IBIOMAR-CONICET)

Workshop supporters, moderators and facilitators:

- Dr. Juan Pablo Livore (IBIOMAR-CONICET)
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- Lic. Mariela Gauna (APN-Monte León)
- Biol. Ian Walker (APN-Makenke)

Workshops participants:

A total of 52 individuals participated in the workshops (Fig. 1), with 18 attending the first workshop in Camarones and 34 attending the second workshop in Ushuaia. The comprehensive list of all participants is available in the Suppl. material 1.

Introduction

Intertidal rocky habitats, comprising more than 50% of the world's shorelines (Davis and FitzGerald 2020) host a diverse array of marine life. They serve as sentinels of ecosystem-wide responses to environmental variability and, thus, enable early detection of climate change impacts (Mieszkowska et al. 2021, Hawkins et al. 2016, Mieszkowska et al. 2014, Hawkins et al. 2008, Barry et al. 1995, Sagarin et al. 1999) and are instrumental in forecasting and predicting future trends (Wethey et al. 2011, Poloczanska et al. 2008, Helmuth et al. 2006). Therefore, monitoring rocky intertidal habitats holds critical importance in our quest to understand how environmental change and human activities impact coastal biodiversity (Mieszkowska et al. 2021, Mieszkowska et al. 2019, Joseph and Cusson 2015, Thompson et al. 2002). This task is nonetheless riddled with challenges. Intertidal habitats are notoriously dynamic, constantly shifting with the tides and seasons and subject to influences of oceanographic features (Contreras-Porcia et al. 2017, Ritter 2009, Nielsen et al. 2003, Dahlhoff et al. 2002). At the community level, non-extractive biodiversity surveys, based on traditional and more novel quadrat observations, provide an effective, simple and low-cost methodology to assess the health of these habitats and can aid in detecting changes in biological assemblages at fine spatiotemporal scales (Livore et al. 2021, Menge et al. 2022, Monteiro et al. 2022, Pereira et al. 2022). Furthermore, along the Argentinian coast, there are already examples of how monitoring efforts have detected massive disappearance of a key species of bivalve in the rocky intertidal zone (Mendez et al. 2021). These methodologies present a promising pathway for continuously monitoring critical coastal areas that are essential for assessing, managing and conserving living resources on scales ranging from local to global domains.

To overcome these challenges, the Marine Biodiversity Observation Network Pole to Pole of the Americas (MBON Pole to Pole) has developed several standardised monitoring protocols for the collection of high-quality biodiversity observations that are comparable across surveyed locations and that follow widely accepted data schema standards. As a result, measurements gathered with MBON Pole to Pole protocols can be shared on open data repositories like the Ocean Biodiversity Information System (OBIS) and the Global Biodiversity Information Facility (GBIF) and used for global assessments. In workshops reported in this study, participants are trained in a novel methodology for biodiversity monitoring that applies photo-quadrat image collections with the ultimate goal of readily characterising rocky shore assemblages of dominant functional groups and detecting biodiversity changes through time. The protocol consists of three key pillars: capturing images with photo-quadrats, data analysis using artificial intelligence (AI) open-access automated classifiers and synthesising survey data with compelling data visualisation dashboards to inform decision-makers and the general public about changes in the health of coastal habitats in a timely manner. Photo-quadrats capture images within defined areas, providing a snapshot of species diversity and abundance with no impact on the community (Bravo et al. 2021, Livore et al. 2021, Montes et al. 2021). Meanwhile, AI algorithms provide tools to automate the processing and analysis of vast amounts of data, significantly reducing the time and effort required for monitoring (Bravo et al. 2021). These algorithms can be accessed through CoralNet, an open-source software tailored for collaborative analysis of photo-quadrats (Chen et al. 2021, Beijbom et al. 2015).

Enabling and promoting close collaboration with local stakeholders is crucial for the success and sustainability of monitoring efforts (Muller-Karger et al. 2021). Park rangers, conservationists and citizens possess invaluable knowledge and insights into local ecosystems. Engaging them in the monitoring process enhances spatial coverage and frequency of data collection efforts, while building community awareness and support for conservation initiatives. Such partnerships contribute to the establishment of long-term monitoring programmes that are deeply rooted in local contexts and are more likely to endure and produce meaningful results over time (Kaplanis 2023).

The MBON Pole to Pole programme initiated a series of workshops in the Argentinian Patagonia aimed at providing training on monitoring rocky intertidal areas and co-developing image-based survey protocols applying automated classifiers leveraging open-source artificial intelligence algorithms. These workshops covered practical aspects of sampling techniques and encouraged discussions on ways to improve these techniques and lowering the threshold for their implementation and adoption by different groups. The first workshop was hosted by the Instituto de Biología de Organismos Marinos (IBIOMAR-CONICET) in Camarones, Chubut, Argentina from 27 to 31 March 2023 where connections were forged with park rangers working in Coastal Reserves along the Atlantic coast of Argentina. During a second workshop, hosted by the Centro Austral de Investigaciones Científicas (CADIC-CONICET) from 22 to 26 January in Ushuaia, Tierra del Fuego, there was a concerted effort to engage additional park rangers and scientists from Argentina and Chile and integrate new sampling sites into the monitoring network (Fig. 2). This initiative broadened the geographic scope of monitoring activities and fostered stronger collaborations amongst various institutions and countries in the conservation of rocky intertidal zones. As a result, the network has successfully implemented 13 survey sites along 20º of latitude in Argentina and four stations in Chile

(Fig. 2). As of 9 April 2024, the effort has collected 10,488 photo-quadrats and 18 records of functional taxonomic groups following CATAMI categories (Althaus et al. 2015).

Workshop Objectives

General Objective:

The workshops sought to facilitate the implementation of a collaborative network of park rangers and scientists dedicated to long-term monitoring of rocky intertidal ecosystems in Argentina and Chile in support of the Nation's commitments towards Sustainable Development Goals (SDG), particularly in achieving Goal 14 "Life Below Water" of the United Nations' 2030 Agenda.

Specific Objectives:

- Provide theoretical and hands-on training to park rangers and scientists in techniques for capturing photo-quadrats and selecting suitable monitoring sites.
- Organise field demonstrations in rocky intertidal areas to reinforce understanding and skills.
- Introduce participants to Artificial Intelligence tools for photo-quadrats analysis, specifically the CoralNet software (Chen et al. 2021, Beijbom et al. 2015).
- Co-develop a standardised and easy-to-adopt field sampling protocol intended to serve as a comprehensive resource for future rocky shore biodiversity monitoring initiatives.
- Build capacity in coastal biodiversity literacy and conservation.
- Produce data synthesis products to provide information for management and decision-making.

Workshop Design and Implementation

During each day of the workshops, participants spent six to eight hours engaged in immersive, hands-on activities, combining theoretical knowledge with practical exercises. All participants enrolled to the workshop on UNESCO's Ocean Teacher Global Academy (OTGA) using their OceanExpert credentials, facilitating seamless registration and communication and permanent access to workshop materials and presentations. Upon completion of the OTGA feedback survey, attendees received a certificate and materials encompassing the theoretical content covered during the workshop, empowering them to continue their learning journey beyond the confines of the event. The sections were organised in the following order:

1. Foundational knowledge: The workshop commenced with expert-led presentations aimed at instilling fundamental concepts about rocky intertidal ecosystems. Subject matter experts delved into the intricate dynamics of these environments, covering topics ranging from species diversity to conservation imperatives.

2. Equipment familiarisation: Participants were introduced to the tools for sampling and monitoring rocky intertidal areas (Fig. 3), including cameras for photographic documentation, quadrat frames for standardised sampling and field data log sheets. This arrangement allowed participants to return to their respective work areas equipped with the necessary tools for conducting monitoring activities. The normalisation of the photographic equipment was particularly emphasised to ensure consistent quality in documentation across diverse locations.
3. Fieldwork practice: Fieldwork components of the workshop offered participants the opportunity to apply theoretical knowledge in real-world settings (Fig. 3). Through guided exercises, they identified intertidal zones (high-, mid- and low-tide levels), applied the sampling protocol and developed data collection skills under the guidance of the instructors.
4. Image analysis: Participants reviewed photographs captured during field activities to identify errors, perform data quality checks and develop an in-depth understanding of data collection methods and quality assurance practices.
5. Introduction to Artificial Intelligence: A segment dedicated to artificial intelligence provided insights into its role in biodiversity monitoring and the many ways AI is being utilised in biodiversity surveys. Participants gained a general understanding of AI tools in biodiversity data collection and analysis.
6. Software training: Practical sessions introduced participants to CoralNet, a software tool utilised for analysing photo-quadrats (Chen et al. 2021, Beijbom et al. 2015). Through interactive tutorials, attendees learned to navigate the software interface, upload photos, perform basic analyses and recognise conspicuous taxa in rocky intertidal photographs. The CoralNet classifier was trained with manual annotations using CATAMI categories as reference. In each photo-quadrat 100 annotations were made by workshop participants with the help of instructors and expert ecologists. After 20 photos were manually annotated, CoralNet automatically runs the classifier and computes percentage cover estimates of observed categories. To ensure adequate training for each category, more than 1000 annotations are required.
7. Protocol development: The workshop culminated in a collaborative effort to devise a participatory monitoring protocol, outlining best practices for data collection and analysis. Participants contributed their insights, nurturing a sense of ownership. This protocol was published in Ocean Best Practices System.

Key outcomes and workshop achievements

A primary objective was to develop skills of participants for capturing high-quality photographs and autonomously identifying the various levels or strata of the rocky intertidal zone for sampling. The data collected by participants after the conclusion of both workshops indicate that they successfully achieved this primary objective. The theoretical sessions of the workshops were characterised by dynamic discussions, indicating that participants were attentive to the provided content. However, we noted that discussions tended more towards technical elements and specific topics during the second workshop likely due to a higher percentage of biologists in attendance (~ 60% vs. 10% in the first workshop). This may have posed challenges for participants without a science background. Both workshops included demonstrations of CoralNet software and hands-on experience in analysing photos, computing percentage cover estimates for observed taxonomic categories and understanding of the value of using AI tools for automating data analysis. During the second workshop in Ushuaia, the CoralNet server experienced overload resulting in slower functionality and, thus, challenges in our ability to complete practical exercises. Participants of the second training were able to review results from sites sampled by attendees of the first workshop. This helped better illustrate workshop goals and the value of participating in the network. Moreover, Ariel Rodriguez, Mariela Gauna and Ian Walker from National Parks Administration who had participated in the first workshop as trainees were invited as instructors for the second workshop to share their experiences applying the protocol and lead field and laboratory exercises. Their experience as data collectors and active members of the network added great value to the second workshop as they communicated common challenges during the fieldwork and image uploading first hand. The availability of results for discussion prompted considerations on how to present data to relevant authorities and on mechanisms for building synergies between government agencies and jurisdictional authorities for coordination of survey efforts and alignment of priorities to ensure mandate fulfilment.

Recommendations and strategies identified

- Engagement of park rangers of Marine Protected Areas (AMPs in Spanish) is essential for the success of the biodiversity monitoring network. An important need that emerges from these activities is to provide a more participatory role to park rangers in the monitoring effort and to continue strengthening links with AMPs. Indeed, park rangers expressed a strong desire to participate in the network. This participatory approach can help build community awareness and support for conservation efforts and boost public trust in decision-making and management of living coastal resources.
- Training people for manual annotations of photo-quadrats is crucial for improving the accuracy of deep learning algorithms in identifying species. By providing a large dataset of accurately identified taxa, the algorithms can be trained to recognise patterns and improve their classification capabilities. Therefore, investing in the training of personnel for manual photo-quadrat analysis can significantly enhance the effectiveness of automated analysis and provide decision-makers with more reliable and accurate information on changes in intertidal ecosystems.
- Improving the workflow from obtaining photos to uploading them for analysis in CoralNet is vital. As the number of AMPs participating in the project increases, the volume of photos to be uploaded to CoralNet will also increase, leading to longer processing times. Therefore, it is critical to review the protocol for uploading photos to make the process as automated as possible. For instance,

implementing a Python code for batch-cropping quadrants in each photo could be useful to avoid errors from manual cropping. Furthermore, exploring the possibility of utilising the CoralNet API could streamline the uploading process and enhance efficiency.

- Creating HTML dashboards for real-time data visualisation is important for communicating survey results to data users. These dashboards enable instant display of data processed through CoralNet, providing stakeholders with timely updates on biodiversity changes and human impacts in intertidal areas (Fig. 4). Integrating these dashboards into organisational websites empowers decision-makers with better informed choices, supporting sustainable management and conservation efforts. Ensuring that monitoring results are presented in a user-friendly manner, accessible to a wider audience, including policy-makers and the general public, is essential for effective dissemination of information.

Conclusions and future steps

The workshops equipped participants with essential skills to autonomously carry out biodiversity surveys following a common, standardised protocol that enable comparisons between monitoring locations. As a result of these training workshops, park rangers have collected over 10,000 photo-quadrats spanning a range of over 3000 km, covering all the Argentinian coast. The methodology employed by workshop participants can, therefore, be readily implemented for the development of a standardised and sustained monitoring efforts focusing on rocky shore habitats of the Americas and other continents. Challenges that emerge from this initiative include data-sharing workflows and cloud-storage capacity for high data volumes produced at scale. This underscores the need for computer servers equipped with ample storage space and capable of executing Artificial Intelligence algorithms for automated classification. Additionally, conducting follow-up surveys amongst those already implementing surveys would be beneficial. Sustained biodiversity monitoring in coastal areas with high societal value, such as Marine Protected Areas, can be achieved with low-cost methods easily deployable by a range of stakeholders.

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Hosting institution

The first workshop was hosted by the Instituto de Biología de Organismos Marinos (IBIOMAR-CONICET) and the second workshop was hosted by Centro Austral de Investigaciones Científicas (CADIC-CONICET). Both workshops were carried out thanks to the following institutions: CONICET (IBIOMAR and CADIC), U Miami, NOAA, National Parks Administration (APN), Museo de la familia Perón, ProyectoSub Foundation and NASA.

Author contributions

Enrique Montes, Gregorio Bigatti and Gonzalo Bravo conceptualised the workshops; Gregorio Bigatti coordinated logistics in both workshops; Enrique Montes, Gregorio Bigatti, Gonzalo Bravo, Juan Pablo Livore, María (Pitu) Mendez, Fernando Lima, Rui Seabra and Rocío Nieto participated as instructors in the 1st workshop; Enrique Montes, Gregorio Bigatti, Gonzalo Bravo, Erasmo Macaya H., Nelson Valdivia, María Bagur, Ariel Rodriguez, Mariela Gauna and Ian Walker participated as instructors in the 2nd workshop; all authors contributed to the manuscript.

Conflicts of interest

The authors have declared that no competing interests exist.

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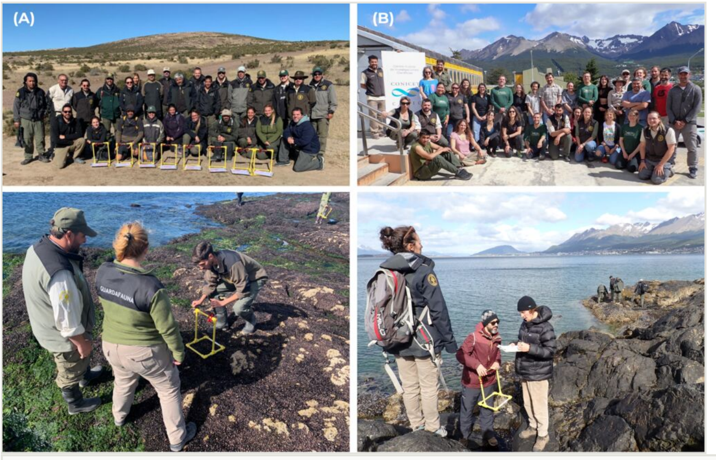

Figure 1.

Workshop participants and fieldwork photos. (A) in Camarones, Chubut, Argentina and (B) in Ushuaia, Tierra del Fuego, Argentina.

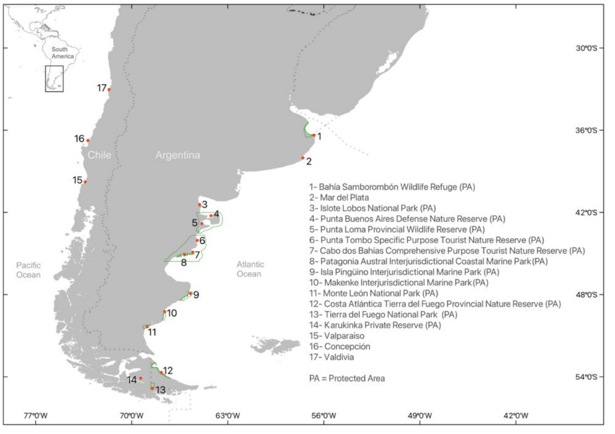

Figure 2.

Sites 1 through 11 were proposed for sampling during the first workshop and have already been sampled. Sites 12 through 17 were proposed as new monitoring sites during the second workshop. The dashed green lines represent the boundaries of the Protected Areas (PA) where the sampling sites were located (for Argentina only).

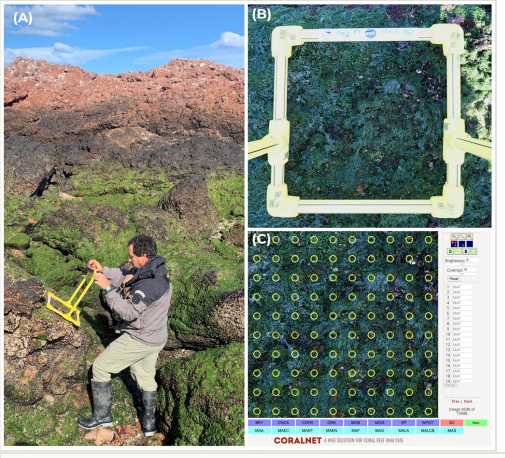

Figure 3.

(A) Park ranger using equipment provided by the MBON Pole to Pole to collect imagery in a rocky intertidal zone (Camarones, Chubut, Argentina). (B) View of the photo taken and (C) the same photograph analysed in CoralNet.

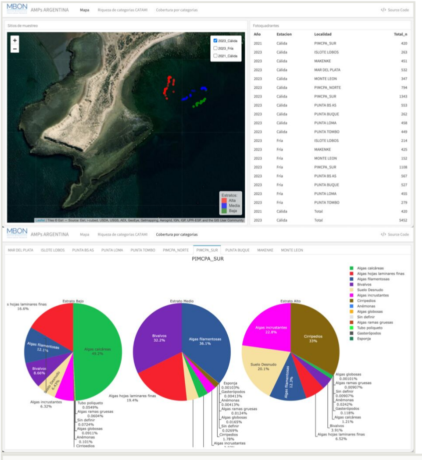

Figure 4.

Dashboard created using R Markdown for synthesis and visualisation of collected data, enabling users to consult the GPS position of each photo-quadrat on the map and percentage cover estimates of CATAMI groups in each sampled area. This interactive tool enables comprehensive analysis and interpretation of gathered information.

Supplementary material

Suppl. material 1: Workshop participants

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Data type: Excel file
Download file (14.98 kb)