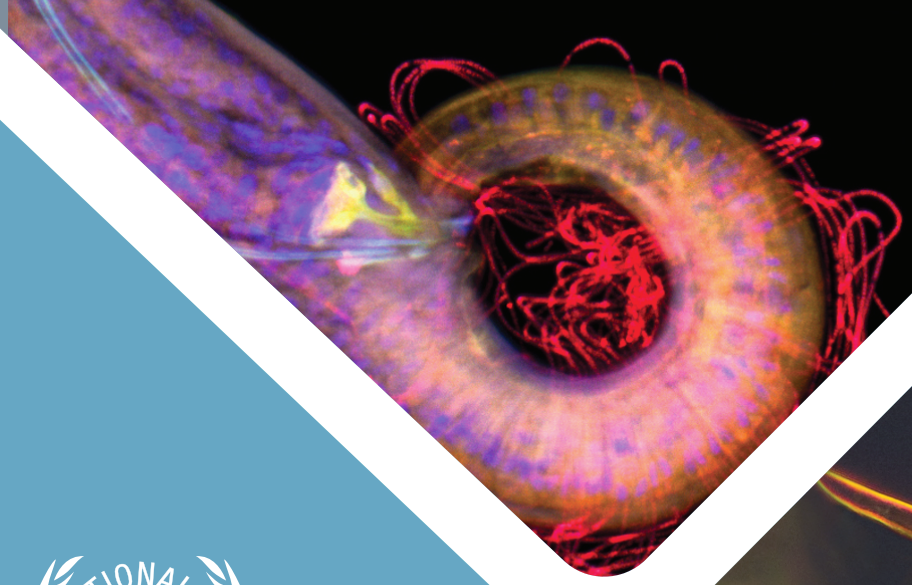

REPORT OF THE WORKSHOP ON ENHANCING IMAGE-BASED BIODIVERSITY ASSESSMENTS TO ADVANCE DEEP-SEA TAXONOMY

REPORT OF THE WORKSHOP ON ENHANCING IMAGE-BASED BIODIVERSITY ASSESSMENTS TO ADVANCE DEEP-SEA TAXONOMY

12-14 October 2021, Online

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CONTENTS

ABBREVIATIONS

AI	artificial intelligence
CATAMI	Collaborative and Annotation Tools for Analysis of Marine Imagery
CCZ	Clarion-Clipperton Zone
EU	European Union
FAIR	Findable, Accessible, Interoperable and Reusable
GBIF	Global Biodiversity Information Facility
Ifremer	Institut français de recherche pour l'exploitation de la mer
IOC-UNECO	Intergovernmental Oceanographic Commission of UNESCO
IOM	Interoceanmetal Joint Organization
ISA	International Seabed Authority
ISO	International Organization for Standardization
MABIK	National Marine Biodiversity Institute of Korea
MOMAF	Ministry of Oceans and Fisheries of the Republic of Korea
NOC	National Oceanography Centre
OBIS	Ocean Biodiversity Information System
OTU	operational taxonomic unit
REMP	regional environmental management plan
ROV	remotely operated vehicle
SSKI	Sustainable Seabed Knowledge Initiative
UNCLOS	United Nations Convention on the Law of the Sea
UNESCO	United Nations Educational, Scientific and Cultural Organization
URL	uniform resource locator
WoRDSS	World Register of Deep-Sea Species
WoRMS	World Register of Marine Species

INTRODUCTION

1. In accordance with the United Nations Convention on the Law of the Sea (UNCLOS) and the 1994 Agreement relating to the implementation of Part XI of the Convention, the International Seabed Authority (ISA), on behalf of the States Parties to UNCLOS, is mandated to administer the mineral resources in the Area and to control and organize current exploration activities and future mining activities in the Area for the benefit of [hu]mankind as a whole. ISA is also mandated to take necessary measures with respect to activities in the Area to ensure effective protection for the marine environment from harmful effects and to adopt appropriate rules, regulations and procedures for, inter alia, the prevention, reduction and control of pollution and other hazards to the marine environment, the protection and conservation of the natural resources of the Area and the prevention of damage to the flora and fauna of the marine environment.[1]

2. ISA is required to promote and encourage the conduct of marine scientific research in the Area, and coordinate and disseminate the results of such research and analysis when available.[2] The importance of this mission was highlighted by the Strategic Plan of ISA for the period 2019-2023, adopted by the Assembly at its twenty-fourth session in 2018.[3] The Members of ISA have established their vision in Strategic direction 4 (Promote and encourage marine scientific research in the Area) implemented according to the High-Level Action Plan for 2019-2023 adopted by the Assembly at its twenty-fifth session in 2019.[4]

3. In 2017, the United Nations General Assembly proclaimed the United Nations Decade of Ocean Science for Sustainable Development 2021-2030. In December 2020, the ISA Assembly adopted the Action Plan for Marine Scientific Research in support of the United Nations Decade of Ocean Science for Sustainable Development[5] to formalize and organize its contribution to the implementation of the United Nations Decade, building on the strategic directions, high-level actions and associated outputs set out in the above-mentioned Strategic Plan and the High-Level Action Plan.

4. The following priorities highlight the importance of expanding the deep-sea knowledge base and standardizing taxonomic information among the six strategic research priorities identified in the Action Plan: i) advancing scientific knowledge and understanding of deep-sea ecosystems, including biodiversity and ecosystems functions in the Area and ii) standardizing and innovating methodologies for deep-sea biodiversity assessment, including taxonomic identification and description, in the Area.

5. In collaboration with the Ministry of Oceans and Fisheries of the Republic of Korea (MOMAF) and the National Marine Biodiversity Institute of Korea (MABIK) and in pursuance of the strategies and priorities identified above, ISA organized an online workshop entitled "Deep-sea taxonomic standardization: strategic approaches for collaboration" between 15-16 September 2020. This workshop successfully identified key needs, priorities and collaborative approaches to increasing deep-sea taxonomic knowledge, further developing and consolidating them into a roadmap to promote effective integration of deep-sea taxonomic information into ISA's efforts to protect the marine environment.

6. Building on the results of the above-mentioned workshop on deep-sea taxonomic standardization, ISA organized an online workshop in collaboration with MOMAF and MABIK entitled "Enhancing image-based biodiversity assessments to advance deep-sea taxonomy" between 12-14 October 2021. Responding to

[1] UNCLOS, Article 145.
[2] UNCLOS, Article 143.
[3] ISBA/24/A/10, Annex, para. 29.
[4] ISBA/25/A/15.
[5] ISBA/26/A/17.

the needs and priorities identified, this workshop aimed to identify technical means and key elements for a standardized model necessary to facilitate effective sharing and use of image data in the context of ISA, with a view to enhancing deep-sea species identification and quantification, as well as increasing capacity and literacy in deep-sea taxonomy.

7. This workshop was conducted in two separate sessions: a technical session for invited experts from 12-13 October 2021 and an open session for registered participants on 14 October 2021. The technical session focused on: i) archiving and utilizing images for the development of species identification methods and facilitation of machine learning for automatic image recognitions on which future Artificial Intelligence (AI)-powered tools can rely, ii) standardizing image annotation methodologies and tools, iii) improving methods for image acquisitions and analyses and iv) innovating image data products and outreach activities using deep-sea taxonomy image platform. The open session focused on: i) providing updates on the results of the technical session, ii) presenting the short-, medium- and long-term priority actions identified by the previous taxonomic standardization workshop in 2020 for the effective integration of deep-sea taxonomic knowledge into ISA's work on the protection of the marine environment and iii) exploring potential ways and means to enhance collaboration among Members and stakeholders of ISA, including the scientific community, Contractors and decision-makers, for effective generation, use and sharing of deep-sea taxonomic information.

8. Drawing on the results of this workshop, the ISA Secretariat can start developing a practical model of sharing images, as well as optimizing and standardizing the application of images for biodiversity assessments, in support of the work of ISA. Likewise, the workshop provided an opportunity to ISA Members, Contractors and other relevant stakeholders to explore collaborative approaches on innovating image-based deep-sea species identifications, increasing the awareness of associated methodologies and promoting capacity-building efforts in the field of deep-sea taxonomy.

9. Part I of the workshop (technical session) was attended by 46 invited experts. A total of 128 participants attended Part II of the workshop (open session) in their individual expert capacities through online registration. The full list of workshop participants is provided in Annex I to this report.

PART I: TECHNICAL SESSION

A. Opening of the technical session

10. The Secretary-General of ISA, Mr. Michael W. Lodge, a representative of the MOMAF, Mr. Sang Keun Song, and a representative of MABIK, Mr. Sun-Do Hwang, opened the workshop at 06:00 (GMT-5) on Tuesday, 12 October 2021.

11. Mr. Michael W. Lodge, Secretary-General of ISA, welcomed the participants. He expressed his appreciation to MOMAF and MABIK for sponsoring the organization of the workshop and collaborating on the design of the workshop programme. He thanked Ms. Kerry Howell (Chair), speakers and panelists for their scientific and technical contributions to the workshop. He then highlighted the relevance of the mandates of ISA under UNCLOS, particularly on the protection of the marine environment from potential harmful effects that may arise from activities in the Area. He also emphasized the unique role of ISA to promote and encourage marine scientific research in the Area and underlined the importance of advancing deep-sea taxonomy in generating biodiversity data, necessary to establish an effective regulatory framework for activities in the Area. The ISA Action Plan in support of the United Nations Decade of Ocean Science for Sustainable Development was introduced as one of the key frameworks within which ISA's efforts towards promoting marine scientific research are developed, including standardization and innovation of methodologies for deep-sea biodiversity assessment as one of the six strategic research priorities. Lastly, Mr. Lodge highlighted previous activities of ISA in the field of deep-sea taxonomy, including a series of taxonomic standardization workshops organized since 2013. He particularly underlined the most recent workshop of September 2020 that identified key needs, priorities and collaborative approaches to advance deep-sea taxonomy. These are consolidated in the form of a roadmap to guide future activities of ISA to facilitate the effective integration of deep-sea taxonomic information for the protection of the marine environment.

12. Mr. Sang Keun Song, Deputy Minister, Marine Policy Office, MOMAF, Republic of Korea thanked Mr. Lodge, the Secretary-General of ISA and Mr. Sun-Do Hwang, the President of MABIK for co-organizing this workshop. He also thanked Ms. Kerry Howell for chairing the workshop and all presenters and participants for their support and contributions. Mr. Song highlighted that the ISA workshop on deep-sea taxonomic standardization held in September 2020 successfully established an important basis to enhance the collective efforts to advance deep-sea taxonomy, which led to the organization of the present workshop focusing on image-based biodiversity assessment. He emphasized the importance of increasing the utility of image data for effective deep-sea biodiversity assessments, as well as the need to further promote sharing of the best available scientific information among experts and the public for their adequate understanding and active engagement in the work of ISA. Lastly, he noted the ongoing collaboration between the Government of the Republic of Korea and other governments to promote ocean data and knowledge sharing, as well as its willingness to further collaborate with Members and stakeholders of ISA on advancing deep-sea taxonomic research.

13. Mr. Sun-Do Hwang, the President of MABIK, thanked Mr. Lodge, the Secretary-General of ISA and Mr. Sang Keun Song, Deputy Minister of MOMAF, for their continuous support and collaboration in advancing deep-sea taxonomy within the context of ISA. He then thanked Ms. Kerry Howell for chairing the workshop and all presenters and participants for their support and contributions to the organization of the workshop. He highlighted the successful outcomes of the ISA workshop on deep-sea taxonomic standardization held in September 2020, including the organization of this workshop. He also emphasized the importance of

enhancing image-based biodiversity assessments and MABIK's collaboration with MOMAF on digitalizing ocean data and information, particularly in the field of taxonomy. He underlined MABIK's expertise in using marine information systems and its experience in implementing various outreach activities for public engagement. Lastly, he affirmed MABIK's willingness to continue collaborating with ISA and other stakeholders in accelerating the collective efforts toward advancing deep-sea taxonomy.

B. Technical session: background, scope and expected outputs

14. Part I of the workshop was organized in plenary sessions introduced by selected panelists. The workshop Chair, Kerry Howell, University of Plymouth, UK, moderated the workshop deliberation.

15. Under this item, participants had before them following documents: (i) ISA Action Plan in support of the United Nations Decade of Ocean Science for Sustainable Development and (ii) report of the Workshop on Deep Sea Taxonomic Standardization: Strategic Approaches for Collaboration (15-16 September 2020).

16. Luciana Genio, ISA Secretariat, presented on workshop background, scope and expected outputs (*see* Annex II).

17. Participants exchanged insights and views, highlighting:

a) This workshop addresses one of the six strategic research priorities identified in ISA Action Plan in support of the UN Decade of Ocean Science for Sustainable Development, focusing on standardization and innovation of methodologies for deep-sea biodiversity assessment, including taxonomic identifications and description in the Area.

b) ISA has undertaken various activities to address standardization of methods and analysis for biodiversity assessments, including technical studies, a series of workshops and the biodiversity synthesis for the Clarion-Clipperton Zone (CCZ) region. Notably, the virtual workshop on taxonomic standardization in September 2020 discussed strategic collaborative approaches to advance deep-sea taxonomic knowledge and highlighted the importance of taxonomic identifications based on image data and the need to establish reference image libraries.

c) Building on the results of these activities, this workshop aims to identify technical means and key elements for a standardized model necessary to facilitate effective sharing and use of image data within the context of ISA. It is expected that the workshop will support ISA Members, Contractors and other relevant stakeholders in exploring opportunities to collaborate on innovating methods and tools for image-based deep-sea species identifications, effectively sharing images and image-based assessments, and promoting capacity-building efforts in the field of deep-sea taxonomy.

C. Image data flow: archiving, cataloguing, processing and sharing image data and information

18. Kerry Howell, University of Plymouth, UK presented on the image data workflow for biodiversity assessments highlighting challenges faced by those generating and using these data (*see* Annex II).

19. Participants exchanged insights and views, highlighting:

a) The workflow of image-based data, as illustrated in Annex III, comprises the following steps: (i) collection of images/videos and associated data, (ii) storage of raw images/videos and data, and onward use for non-scientific purposes (e.g., education and outreach), (iii) quality control and cleaning of images/videos and data (iv) analysis of image-based data to extract biodiversity information and (v) storage of annotated and biological data.

b) Different gear types produce different qualities of images/videos, which affects the ability to discriminate animals in the imagery. This leads to challenges in comparing biodiversity data across surveys. The lack of systemic archiving of raw data files makes image-based data rarely adhere to the Findable, Accessible, Interoperable and Reusable (FAIR) principles. In addition, data is not machine readable currently due to the lack of common formats and standards for naming and archiving imagery and metadata files. Common standards and tools to support image analyses are also lacking. Quality control procedures are not standardized in image-based data analysis. Effective storage of processed data needs to be considered to support the development of deep-learning, AI-based tools to accelerate the annotation process.

c) There is a need for standardization during the various steps of image data workflow for biodiversity assessments, including acquisition of benthic, pelagic and specimen images, metadata reporting templates, reference image catalogues, image annotations and quality control processes.

d) It is important to perform quality control and assurance to ensure consistency among image-based surveys, enable scientifically robust compilation, synthesis and analysis of image data for effective environmental management, including the development and implementation of regional environmental management plans (REMPs). Possible modalities for quality control of image data were discussed, including periodic regional workshops to gather relevant experts, in close linkage with the REMP processes for relevant mineral provinces.

e) There are challenges of a globally declining taxonomic skill base associated with the difficulty of identifying animals in image data and limited access to taxonomic expertise. There is a need for targeted training for both para- and traditional taxonomists and enhanced collaboration among them.

D. Image acquisition: needs and requirements for biological image surveys and laboratory studies

20. The following experts shared ideas and insights on different approaches to image acquisition in a panel discussion (*see* Annex II):

a) Daniel Jones, National Oceanography Centre (NOC), UK, on image surveys of benthic communities

b) Dhugal Lindsay, Japan Agency for Marine-Earth Science and Technology, Japan, on image surveys of pelagic communities

c) Daniela Zeppilli, Institut français de recherche pour l'exploitation de la mer (Ifremer), France, on microscopic observations, including three-dimensional imagery

21. Participants exchanged insights and views, highlighting:

a) Video data is important for assessing pelagic communities because it allows capturing behavioral features critical for species identification; still images are generally sufficient for benthic communities. The quality required for pelagic video data varies according to gear type with very high quality for towed camera (8K resolution) and lower resolution for remotely operated vehicles (ROVs) (4K resolution or even high definition). It was suggested that video or imagery acquisition for benthic surveys should be at 1-3 m above the seafloor, although specific requirements will vary depending on the particular purpose of data collection.

b) Specific guidance is required for *ex-situ* images of physical specimens taken in offshore laboratories. This should draw from existing initiatives, such as the ongoing efforts across networks of natural history museums to standardize digitization, archiving and exchange of physical specimens, including specimen images.[6] Photographs and three-dimensional scans of physical specimens would also be effective to validate taxonomic identifications by expert taxonomists, avoiding the potential loss of valuable physical specimens, including small infauna specimens and morphotypes.

c) Documentation of best practices for image acquisition was suggested for compilation into the IOC-UNESCO Ocean Best Practices System,[7] building on existing guidelines and manuals for image-based survey and specimen imagery. Some examples of existing guidelines were provided including, *inter alia*:
   - International Organization for Standardization (ISO) recommendations for the gathering of image-based data at seafloor where epifauna and benthopelagic fauna with a minimum dimension of 1 cm are used as a proxy for the status of the biological community: ISO 23731:2021.
   - New technical committee for standardization in the field of biodiversity (under development): ISO TC 331.
   - Field manuals developed by the Marine Biodiversity Hub for Australian waters.[8]
   - ISA draft guidelines for the establishment of baseline environmental data;[9] section on megafauna imagery provides specific guidance on image acquisition.

[6] Distributed System of Scientific Collections in Europe and Integrated Digitized Biocollections (iDigBio) in the USA.
[7] IOC-UNESCO Ocean Best Practices System.
[8] Marine Biodiversity Hub, Field manuals for marine sampling to monitor Australian waters.
[9] ISBA/27/C/11.

E. Infrastructure needs for imagery data archiving and exchange

22. The following experts shared ideas and insights on infrastructure needs for imagery data archiving and exchange (*see* Annex II):

a) Sheldon Carter, ISA Secretariat, on ISA DeepData database

b) Pieter Provoost, IOC-UNESCO, on the Ocean Biodiversity Information System (OBIS) database

c) Kakani Katija, Monterey Bay Aquarium Research Institute, USA, on the FathomNet database

23. Participants exchanged insights and views, highlighting:

a) Several possible ways for storage and sharing of large amounts of image and video data were identified, including: (i) cloud-based storage and the use of persistent uniform resource locators (URLs) and digital object identifiers, (ii) storage of high resolution data on external hard drives with a subset of lower resolution (compressed) data stored online, (iii) use of tags in video data to extract relevant sections and (iv) storage and sharing of annotated data via platforms like FathomNet. It was noted that ISA DeepData database can potentially increase its storage capacity (hardware) with the ability to create interoperable links with other databases.

b) Development and implementation of data use policies is needed to protect valuable taxonomic information as required/desired.

c) Detailed and standardized metadata is critical for effective archiving, sharing and use of imagery data. It was noted that ISA DeepData reporting templates were recently updated in alignment with accepted international standards such as the Darwin Core for biological information; these templates are living documents and will continue to be updated as needed to incorporate new standards. Examples of existing metadata templates and developing standards were provided, including:

- World Ocean Database[10]
- Audubon Core (akin to Darwin core for specimens)[11]
- Ecological Metadata Language[12]
- Image FAIR Digital Objects[13]
- Dublin Core[14]
- NASA PDS4[15]
- Integrated Marine Observing System[16]
- ISO 23731, 23732, 23734. Further guidelines for image metadata reporting may be submitted to the new developing ISO standard for biodiversity (ISO TC 331)

d) It was also noted that *ex-situ* specimen imagery needs to be linked with *in-situ* imagery.

[10] World Ocean Database, National Centers for Environmental Information.
[11] Audubon Core - Audubon Core. Note: It is possible to provide input to Audubon core terms.
[12] Ecological Metadata Language. Note: data set level metadata.
[13] Overview: FAIR marine images. Note: a set of metadata fields grouped by core, capture and content information.
[14] DCMI: Home.
[15] PDS: What Is PDS4?.
[16] IMOS AUV Images Viewer.

e) File naming conventions are needed to support machine readability of image data. As prescribed in ISO 23731 standard, filenames for archived images should include a unique identifier for the cruise/survey/platform, the date and time of the first frame in the format YYYYMMDD-HHMMSS and a camera identifier, separated by hyphens (e.g., PLATFORM-YYYYMMDD-HHMMSS-CAMERA1-01.mov).[17]

F. Image annotations: standard reference catalogue

24. The following experts shared ideas and insights on different software for image annotations and classification (*see* Annex II):

a) Timm Schoening, GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany, on BIIGLE and other annotation tools

b) Candice Untiedt, Commonwealth Scientific and Industrial Research Organization, Australia, on Collaborative and Annotation Tools for Analysis of Marine Imagery (CATAMI) classification scheme

c) Kirsty McQuaid, Plymouth University, UK and the South African National Biodiversity Institute, South Africa, on *SMarTaR-ID* framework.

25. Participants exchanged insights and views, highlighting:

a) Aligning efforts among software developers to ensure standard formats of data inputs and outputs is crucial to enhance inter-operability among image annotation tools. For instance, there is ongoing work for standardizing video annotations on Squidle into Darwin Core format, while VARS software allows users to choose the export format. Another example of online video annotation tool (Tator)[18] was pointed for consideration as a common export format accepted by the wider community. The development of a "translation tool" was suggested to facilitate linking annotation fields by different users/systems. Some research institutions (e.g., Ifremer) initiated it on an *ad hoc* basis, but a standardized approach would be needed for wider accessibility of the data. OBIS was suggested as a platform to export image annotation data, although Darwin Core is limited to contain annotation information. Other controlled vocabularies (e.g., CATAMI, *SmarTaR-ID*, EUNIS) could be extended to OBIS, aligned with annotation tools.

b) It was noted that standard image reference catalogues are needed for species identifications, considering inter-operability across taxonomic and morphological classifications. For example, Squidle has a translation scheme linking the World Register of Marine Species (WoRMs) catalogue of taxonomic names with the CATAMI classification scheme and it also allows creation of new labels. The use of multiple classification schemes in one annotation (e.g., multiple labelling trees available in BIIGLE) was also suggested as a possible way to standardize identifications across image annotators. Currently some annotation tools allow adding multiple names in the *Comments* field, as in Squidle.

[17] An example developed during the Marine Imaging Workshop organized by Ocean Networks in Canada, Victoria, in 2019.
[18] Tator.

c) Regarding the use of open nomenclature, guidelines for handling temporary names (which may be non-scientific) are provided by OBIS, but those names must be linked to a scientific name to the lowest possible taxonomic rank, because WoRMS (the taxonomic backbone of OBIS) only accepts formally published names; further details for the standardization of open taxonomic nomenclature for image-based identifications are available in a recent peer-reviewed publication.[19] The development of a search function in OBIS for temporary names was suggested.

d) Mechanisms to assign uncertainty in image-based species identifications should be considered, such as assigning fuzzy labels (e.g., 50 per cent chance morphospecies 1, 50 per cent chance morphospecies 2). The need to establish a set of standardized modifiers to accompany the chosen classification system was indicated. Intercalibration workshops for comparing image-based species identifications among different annotators were also considered important for standardizing vocabularies and crosswalks between annotation tools and classification schemes.

e) The need to standardize color correction and initial processing of imagery data prior to image analysis was emphasized. Similarly, consideration should be given to standardize the use of scale bars or lasers for size measurements and biomass estimates; scaling of oblique videos/images can be solved by use of stereo cameras.

f) The importance of quality control and assurance of image-based identification was highlighted, although access to qualified expert taxonomists is limited. Modalities for training image annotators with expert taxonomists were suggested, such as allocating specific funds for these training activities under research grants, as well as within the ISA Contractors' Training Programme. Dedicated training courses and training materials (video tutorials, identification guidelines) were also suggested to enhance image annotation capacity. Course fees and paid access to training resources (Skillshare platform)[20] were suggested to financially support taxonomic expertise. Mechanisms to support members of developing States were also discussed (reduced fees). Increasing the number of qualified taxonomists and annotators would also contribute to developing a quality assurance process based on accreditation of imagery identifications. This would ensure the quality of data that is used for decision making processes, as well as for further development of automated tools using AI. However, the certification of identification skills would require accredited training to be developed, e.g., through the Ocean Teacher Global Academy.

G. Image data products: keys, guides and outreach materials

26. The following experts shared ideas and insights on various image data products (*see* Annex II):

a) Kamila Mianowicz, Interoceanmetal Joint Organization (IOM), Poland, on Atlas of Megafauna

b) Adrian Glover, Natural History Museum, UK, on DeepSea ID and CCZ species list

[19] Horton T, Marsh L, Bett BJ, Gates AR, Jones DOB, Benoist NMA, Pfeifer S, Simon-Lledó E, Durden JM, Vandepitte L and Appeltans W (2021) Recommendations for the Standardisation of Open Taxonomic Nomenclature for Image-Based Identifications. Front. Mar. Sci. 8:620702. doi: 10.3389/fmars.2021.620702.
[20] Skillshare platform.

c) Youngdawng Moh and Jinwook Back, MABIK, Republic of Korea, on image platform for public outreach

27. Participants exchanged insights and views, highlighting:

a) Specific tags or labels should be used to store selected images with identified value for media products, public engagement and deep-sea literacy projects. Several examples of imagery use and existing resources for public education and outreach were provided, including deep-sea image guides,[21] three-dimensional models[22] and virtual reality reconstructions of deep-sea specimens and habitats.

b) A citizen science platform for image annotations has also been developed for hydrothermal vent systems and is expected to be expanded to other deep-sea ecosystems.[23] The Deep Ocean Education Project was also listed among existing initiatives for deep-sea literacy.[24]

H. Summary and conclusion

28. The workshop Chair provided a summary of the workshop results, including ways and means for effective and standardized generation, use and sharing of image data and information to support image-based biodiversity assessments and advance deep-sea taxonomy. Some key points are summarized below:

a) Image-based surveying and monitoring is a very powerful noninvasive methodology for investigating the deep-sea environment. Deep-sea imagery has become an essential tool, providing a different perspective on deep-sea ecosystems from those obtained from traditional sampling methods such as trawling and coring. However, deep-sea image-based biodiversity assessments still face many challenges at every step in the process of the image data workflow: image data acquisition, storage, processing, analysis, archiving and reporting.

b) Survey designs considering specific scientific goals are of utmost importance during the image acquisition phase. The compilation of existing guidelines and manuals for image acquisition into the IOC-UNESCO Ocean Best Practice System was suggested to facilitate the standardization of deep seafloor and water column image-based surveys. Existing initiatives for museum specimen digitalization were also noted to provide guidance for imaging physical specimens, including at-sea and in-land laboratories.

c) Regarding infrastructure needs for imagery data archiving and exchange, possible next steps include the implementation of metadata reporting standards to ensure data subscribes under the FAIR principles and the development of ISA DeepData database for storage of raw data as well as annotated metadata for wider use, including machine-learning data sets and AI developments. The recently launched FathomNet provides an example of possible ways to store and share annotated data.

[21] MBARI's Deep-Sea Guide.
[22] MBARI (@mbari) – Sketchfab.
[23] Ifremer, Deep Sea Spy.
[24] Deep Ocean Education Project.

d) Aligning efforts among software developers to standardize data inputs/outputs formats is crucial for interoperability of data produced by the different annotation tools. Another important step is the intercalibration of image-based identifications. This can be achieved by hosting regional workshops related to different mineral provinces, in close linkage with the REMP process, to standardize image references catalogues (and annotations), including morphological and taxonomic classification schemes. The need to develop a pool of taxonomic expertise and platform for knowledge exchange was highlighted, as well as the development of training materials and the identification of trainers among taxonomic experts. An accredited quality assurance/quality control process for annotated data was also considered of key importance to ensure data quality.

e) Deep-sea imagery and videos are a valuable resource, not only for generating biodiversity data but also as an educational tool and for public outreach. The development of specific tags to identify and store imagery and video for non-scientific purposes (media products, education, etc.) was suggested. Data use policies and protection of ownership were considered important in the development of various products and initiatives for wider dissemination of deep-sea images and videos. Several examples of ongoing activities were shared, including three-dimensional models and games.

29. The workshop participants expressed appreciation to the Chair for her able steering of the workshop deliberations and excellent summary, to the ISA Secretariat and MABIK for organizing the workshop and to the Government of the Republic of Korea for financially sponsoring the workshop, and called for continuous support for this important initiative.

I. Closure of the technical session

30. Part I was closed at 10:00 (GMT-5) on Wednesday, 13 October 2021.

PART II: OPEN SESSION

A. Opening of the open session

31. The Secretary-General of ISA, Mr. Michael W. Lodge, a representative of MOMAF, Mr. Sang Keun Song, and a representative of MABIK, Mr. Sun-Do Hwang, opened the workshop at 06:00 (GMT-5) on Thursday, 14 October 2021. Their opening messages are summarized in section I.A

B. Open session: background, scope and expected outputs

32. Part II of the workshop was organized in plenary sessions introduced by selected speakers and panelists. The workshop Chair, Kerry Howell, University of Plymouth, UK, moderated the workshop deliberation.

33. Under this item, participants had before them the following documents: (i) ISA Action Plan in support of the United Nations Decade of Ocean Science for Sustainable Development and (ii) the report of the Workshop on Deep Sea Taxonomic Standardization: Strategic Approaches for Collaboration (15-16 September 2020).

34. Luciana Genio, ISA Secretariat, presented on workshop background, scope and expected outputs (*see* Annex II).

C. Enhancing image-based biodiversity assessments to advance deep-sea taxonomy

35. The Chair briefed the workshop participants on the key results of Part I as summarized in Part I.H above.

36. Participants exchanged insights and views, highlighting:

a) In face of the recognized global shortage of deep-sea professional taxonomists and limited job opportunities, it is necessary to develop capacity in deep-sea taxonomy. Capacity-building and training in image-based taxonomic identifications should consider both remote (video tutorials) and in-person training modalities, including access to physical specimens for observation of morphological features that are difficult to recognize in imagery data. Training opportunities should be varied to consider different levels of capacity development needs (e.g. post-graduate studies under the ISA Contractors' Training Programme, ISA-Ifremer postdoctoral fellowship) and flexible to allow wider participation of candidates with different time availability (employed and unemployed participants). Training may also be required for specific taxa (e.g. copepods

or deep-sea fish), as well as for use and analysis of image-based biodiversity data to support environmental monitoring and impact assessments.

b) Reviewing and updating the list of professional taxonomists, originally collated through the International Network for Scientific Investigation of Deep-Sea Ecosystems initiative would be a first step to establish a network of deep-sea taxonomic expertise to provide community support in image-based and traditional taxonomy.

c) Development of morphological keys that align with taxonomic classification, following the example of the SMarTaR-ID project, is needed to bridge the gaps between image-based and specimen-based identifications. These will aim at becoming multi-entry keys, rather than dichotomous, to ease identification where important morphological features may be obscured in images. It was noted that aligning morphology and taxonomy may not always be possible. In such cases, new morphological keys that do not necessarily align with traditional taxonomy may be required to support image-based identification. The inclusion of open nomenclature (i.e., temporary names that have not been formally published) in the WoRMS database is currently being considered by its steering committee.

d) Standardization of image acquisition, both *in-situ* and *ex-situ* was emphasized, and the documentation of best practices into the IOC-UNESCO Ocean Best Practices System was suggested to support delivery of consistent data sets. Involving taxonomists at the image acquisition phase was considered important to ensure that imagery would support species identifications. Details of the image acquisition workflow (e.g., set up used in offshore laboratory specimen imagery) should be recorded (photographs, notes, protocols, etc.) as part of metadata associated with image data.

e) It was noted that image surveys could focus on priority taxa to be determined based on scientific criteria such as the value for assessing ecosystem change. An example for identifying those priority taxonomic groups that are likely to be informative for biodiversity monitoring and impact assessment was provided for the Australian Integrated Marine and Coastal Regionalization process.[25]

D. Roadmap to promote effective integration of deep-sea taxonomic knowledge into ISA's work on the protection of the marine environment in the Area

37. Luciana Genio, ISA Secretariat, introduced the short-, medium- and long-term priority actions, identified by the previous taxonomic standardization workshop in 2020 for the effective integration of deep-sea taxonomic knowledge into the work of ISA on the protection of the marine environment in the Area (*see* Annex IV).

[25] Marine Biodiversity Hub, Expanding our spatial knowledge of marine biodiversity to support future best practice reviews, Tim O'Hara, Museums Victoria.

38. Participants exchanged insights and views, highlighting:

a) ISA's Sustainable Seabed Knowledge Initiative (SSKI) will provide the framework to implement the priority actions for taxonomic standardization across all mineral provinces where exploration is currently taking place.

b) While SSKI aims to contribute to the UN Decade of Ocean Science for Sustainable Development and the global knowledge base through scientific research associated with mineral exploration activities, in line with the mandate of ISA to promote marine scientific research in the Area, it is not a prerequisite for regulatory functions of ISA in relation to regional or local environmental baselines.

E. Identifying partners, donors and relevant initiatives for the effective generation, use and sharing of deep-sea taxonomic information

39. The following experts shared ideas and insights on ongoing and future initiatives that will contribute to the effective implementation of collaborative activities to advance deep-sea taxonomy (*see* Annex IV):

a) Ward Appeltans, IOC-UNESCO

b) Tammy Horton, WoRMs

c) Muriel Rabone, Natural History Museum of UK

d) Daniela Zeppilli, Ifremer

e) Aurore Maillet, European Commission

40. Participants exchanged insights and views, highlighting:

a) The importance of linking and cross-referencing *in-situ* imagery, *ex-situ* specimen imagery and voucher specimens in registered collections was highlighted to assist taxonomic identifications. Likewise, the importance of building robust environmental DNA (eDNA) libraries and linking these to images was emphasized. These efforts should align with other global initiatives such as the Darwin Tree of Life[26] and Earth Biogenome[27] to avoid duplication and strengthen synergies.

b) The growing number of new species described from the CCZ, one of the most sampled deep-sea regions, demonstrates the value of scientific research being undertaken through collaborative activities among ISA Contractors and scientific communities. It also highlights the need to expand such collaborative efforts to other regions. Within the context of ISA Action Plan in support of the United Nations Decade of Ocean Science for Sustainable Development, including through SSKI, ISA can pursue its efforts to establish a partnership framework to support science-industry collaborations globally, in a transparent and inclusive manner, including developing States Members of ISA.

[26] Darwin Tree of Life, Reading the genomes of all life: a new platform for understanding our biodiversity.
[27] Earth BioGenome Project.

F. Summary and conclusion

41. The Chair provided a summary of the workshop results, including suggested approaches to promote coherent, collaborative and scientifically robust ways and means for enhancing taxonomic knowledge of biodiversity in the Area. Some key points are summarized below:

a) Taxonomic identification of deep-sea species is a topic that has attracted much interest in recent years and is fostering innovative developments of automated technologies such as those based in imagery. There are several challenges to be addressed at the various stages of image and video data workflow for enhanced accessibility and interoperability of data to support scientifically and statistically robust biodiversity assessments.

b) During the technical session of this workshop (see Part I of this report), current developments in image data acquisition, archiving, processing and reporting were shared and possible means to improve data standardization were suggested through collaborative activities drawing on existing initiatives. Use of deep-sea imagery data beyond scientific purposes was highlighted and examples of education and public engagement activities were provided.

c) The need to support training and capacity-building in image-based deep-sea taxonomy was also emphasized, not only to assist with standardization of images annotations but also to ensure quality control and assurance of data sets that can be used for AI-based methodologies for species identifications. A series of activities were suggested, including web-based and in-person training opportunities.

d) Short, medium and long-term collaborative efforts to address priorities for deep-sea taxonomic standardization will make a critical contribution to the work of ISA on protection of the marine environment in the Area. A global partnership framework is established in the scope of ISA SSKI, providing the financial and technical means to advance deep-sea biodiversity knowledge in line with the strategic research priorities identified in the ISA Action Plan in support of the United Nations Decade of Ocean Science for Sustainable Development.

G. Closure of the open session

42. Part II was closed at 10:00 (GMT-5) on Thursday, 14 October 2021.

ANNEX I

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ANNEX II

Summary of theme presentations

Part I: technical session

Presentations delivered under agenda item 2

Workshop background, scope and expected outputs

Luciana Genio, ISA Secretariat

Protection of marine environment from harmful effects which may arise from activities in the Area is at the core of the mandate of ISA. ISA also has the duty to promote and encourage the conduct of marine scientific research in the Area and to coordinate and disseminate the results of such research and analysis when available. In 2020, in line with ISA Strategic Plan and High-Level Action Plan for 2019-2023, the Assembly adopted the ISA Action Plan in support of the United Nations Decade of Ocean Science for Sustainable Development to formalize the contribution of ISA to the United Nations Decade. This workshop addresses one of the six strategic research priorities identified in the Action Plan, focusing on standardization and innovation of methodologies for deep-sea biodiversity assessment, including taxonomic identifications and description in the Area.

ISA has undertaken several activities to address standardization of methods and analysis for biodiversity assessments, including technical studies, series of intercalibration workshops and the biodiversity synthesis for the CCZ region. In particular, ISA hosted a virtual workshop on taxonomic standardization in September 2020 to discuss strategic collaborative approaches for advancing deep-sea taxonomic knowledge. Addressing requirements of taxonomic identifications based on image data and the need to establish reference image libraries were identified as key priorities for enhancing deep-sea species identification and quantification, as well as increasing capacity and literacy in deep-sea taxonomy.

This workshop aims to identify technical means and key elements for a standardized model necessary to facilitate effective sharing and use of image data in the context of ISA. The various steps of the image data workflow, from acquisition to archiving and exchange, processing and annotations, and the creation of image data products for multiple users will be the focus of expert deliberations. The workshop is expected to support Members, Contractors and other relevant stakeholders of ISA to explore opportunities to collaborate on innovating methods and tools for image-based deep-sea species identifications, effectively sharing images and image-based assessments, and promoting capacity-building efforts in the field of deep-sea taxonomy.

Presentations delivered under agenda item 3

The challenges faced in using image and video data

Kerry Howell, University of Plymouth, UK

The workflow of image-based data comprises the following steps: (i) the collection of images/videos and associated data, (ii) storage of raw images/videos and data, and onward use for non-scientific purposes

(e.g., education and outreach), (iii) quality control and cleaning of images/videos and data, (iv) analysis of image-based data to extract biodiversity information and (v) storage of annotated and biological data. Each step in this pathway presents challenges to those who generate and use these data. Different images and videos produced by different gear types can undermine the ability to discriminate animals in the imagery, which leads to challenges in comparing biodiversity data across surveys. Raw data files from survey cruises are not usually archived in a systematic manner and may only be archived locally by individual researchers or institutions undertaking the surveys. Therefore, image-based data rarely subscribes under the FAIR principles. There are no common naming formats for imagery and metadata files, no common folder structures for archiving, no common metadata standards, and data is not currently machine readable.

In addition, there are no common standards around the analysis process, and there are no common standards for naming morphotaxa due to the lack of global morphotaxa/species reference library. Different software is currently available and used for imagery annotation and there are currently no agreed quality control procedures in image-based data analysis. Quality control for data generated by different observers is needed. It has to be checked if identifications are accurate and whether they conform to yet-to-be-agreed standards. As the final step, effective storage of processed data needs to be considered. Annotated data is very useful for training both humans and machines. Well-archived annotated data sets can be used to support the development of deep-learning, AI-based tools to speed up the annotation process. At present, there is no global database to archive this sort of data which often consists of temporary names or morphotaxa information. This workshop aims to address the challenges associated with each of these steps in the collection, use and storage of image-based data, and identify possible ways forward considering new innovations.

Presentations delivered under agenda item 4

Image surveys of benthic communities

Daniel Jones and Erik Simon-Lledó, NOC, UK

Image-based assessments are increasingly common. Imaging is a relatively quick, quantitative and non-destructive approach for assessing benthic megafaunal communities. Effective survey requires clear scientific objectives. Several are highlighted in the ISA Legal and Technical Commission's guidance to contractors for the assessment of the possible environmental impacts arising from exploration activities in the Area (ISBA/25/LTC/6/Rev.1). The most common objective, "assessments of abundance, biomass, species structure and diversity of megafauna," highlights three primary requirements, each with multiple considerations: 1) unbiased estimates of the sample population under investigation, 2) consistent results that are comparable between and within surveys and 3) results at the appropriate level of accuracy and precision for the assessments required.

For 1) it is important to define an appropriate sampling design, identify the sample population and obtain unbiased and independent estimates of it. For 2) it is important to be consistent in the size of organisms assessed (often megafauna is considered >10 mm in size), the taxonomic resolution and the morphospecies identified (both within and between surveys). Finally, for 3) the sample unit size (single images are very rarely an effective sampling unit) and the number of replicates is important. These requirements are different for different parameters (abundance, biomass, species structure, etc.) and influence the potential for testing changes (e.g., those associated with monitoring of mining disturbance). Once these considerations are documented, it is easier to select appropriate imaging methodologies. In our experience, benthic assessments are more straightforward with downward looking still images. For example, thousands of high-quality photographs usually need to be obtained by whatever effective platform for these benthic assessments in the CCZ. Software platforms for image annotation, such as BIIGLE, facilitate this laborious task and greatly improve the potential for quality control. The use of standardized image catalogues is also important, such as the one developed by NOC for the CCZ.

Imaging surveys of pelagic communities

Dhugal Lindsay, Japan Agency for Marine-Earth Science and Technology, Japan

Cameras and lights on crewed submersibles, ROVs or towed camera systems are invariably optimized for imaging benthic organisms. Lights are normally directed in the same direction as the cameras for furthest light penetration and maximum range. The highly reflective seafloor is much brighter than the marine snow particles between it and the camera, allowing clear images of benthos to be obtained. Altimeter data and/or spaced laser beams provide an estimate of organism sizes. Such a set-up is sub-optimal for imaging-based surveys of midwater fauna. Many larger midwater organisms are gelatinous and reflect light poorly due to either transparency (jellyfish) or light-absorbing pigments (many fish). It is also much harder to successfully target a 1 cm diameter, translucent jellyfish with a laser-based sizing system than it is to hit somewhere on the seafloor. Imaging needs and requirements for midwater surveys include side lighting for highest contrast, high resolution to see fine details and fast frame rates to use behavior to help with species identifications. Image files should ideally be recorded at 10- or 12-bit depth with lighting that seems a little dark to the human eye using low image/file compression rates that preserve the various shades of black to record the mostly transparent or black-pigmented animals against their black background. An example of an acceptable setup would be video at >4K resolution, 60 frames per second recorded in Progressive recording mode, Apple PreRes 4:2:2 codec. This combination facilitates species identification. However, imaging needs are even greater for quantification. Since a laser pointer system does not work in midwater, high-resolution stereo video cameras, synchronously recorded, are needed for organism size and population density calculations. Many smaller animals cannot be imaged by video cameras. Instruments that give size-accurate images, such as shadowgraph cameras or the Underwater Visual Profiler can be useful as attached to a conductivity, temperature and depth rosette for collecting quantitative data on plankton and marine snow, while sampling water for eDNA analyses and gathering environmental data (temperature, salinity, oxygen, etc.). All imaging systems need to be synchronized, preferably to GMT, to combine image data sets for the same "packet" of water. Environmental data parameters and platform/camera metadata (depth, altitude, zoom ratio, etc.) should be logged at each instrument's native rate and pinned to GMT, rather than logged at the rate of the slowest instrument. In addition to preserving and storing the physical samples, net-caught plankton should be imaged by a system that allows accurate size measurements (ZooScan plankton scanner) and curated in a system (EcoTaxa).

Microscopic observations, including 3D imagery

Daniela Zeppilli, Valentin Foulon and Catherine Borremans, Ifremer, France

Meiofauna communities (small organisms living in the sediments) comprise some of the most diverse groups of organisms on Earth and possibly one of the best bio-indicators in the context of the rapid increase of anthropogenic pressures in the deep sea. However, due to their very small size and their huge diversity, only a small part of the diversity of this group has been described and knowledge of their biology and ecology is fragmented. Furthermore, the lack of reference genetic information in public depositories hampers the use of rapid fingerprinting techniques for this important benthic compartment. In the last decades, new technological developments in different imaging fields (electronic, industrial or biomedical processes) using different kinds of microscopy and camera (Brightfield, Confocal, Axio Zoom, SEM, flow imaging, etc.) have allowed 3D-imaging of very small entities with a very high resolution. All these technologies can also be adapted and used for recognition of small organisms. The combination of very high-resolution imaging with assistance of AI classification by convolutional neural networks can allow identification of small organisms at a pace with which human eyes and brains cannot compete. Additionally, the synergy of staining techniques (fluorescence *in situ* hybridization) and microscopy can allow the visualization of biological features, providing important functional information associated to species identifications. The development of a standardized method for ecological and

biodiversity surveys, in the context of deep-sea mineral exploration and future exploitation, needs further development of images acquisition automation, including on one hand high-resolution imaging associated with genetic assignment, widely shared in open-access depositories and, on the other hand, the development of faster low-resolution imaging associated with eDNA/metabarcoding approaches.

Presentations delivered under agenda item 5

Image and video data management in ISA DeepData database

Sheldon Carter, ISA Secretariat

In 2019, ISA launched its database called "ISA Deep Seabed and Ocean Database" (DeepData).[29] DeepData is an integrated database system designed to serve as a geospatial data management system. It holds centralized repository of public and private information on marine mineral resources and environmental baseline data acquired by ISA Contractors during their exploration activities. The environmental data, including biological, physical and geochemical parameters of the seafloor and water column ecosystems, is accessible to the public. The Geographic Information System capabilities of the system allow users to navigate a map and identify the specific location at which samples were observed. The Contractors are required to submit the metadata and results of their sample analysis from exploration surveys in contract areas, using the digital reporting templates recommended by the Legal and Technical Commission. The relationship between sample information, station information and the photo/video file name details is established in the metadata template. The photo and video file names are also recorded in both the environmental and geological reporting templates, associated with the results of the biological, geochemical and geological analysis. The DeepData website acts as a storage medium for photo and video files along with their associated metadata. It can provide annotated photo and video files and make them available for download. However, the major challenges include the absence of metadata to complement the photo and video gallery ISA currently has, without which it has proven difficult to make these files quarriable on the DeepData website. Currently DeepData can only associate one image to each sample/result, but the ability to visualize multiple photos for each sample (by simply scrolling through each photo of the sample) has been discussed as an upgrade of the database. The need to further annotate the current photo and video inventory and facilitate sharing such files with a broader range of members of the scientific community was highlighted.

Imagery data in OBIS

Pieter Provoost, IOC-UNESCO

OBIS is a network of over 30 regional and thematic nodes promoting open access to marine biodiversity data and the use of biodiversity data standards and vocabularies. OBIS collaborates on community biodiversity data standards with Biodiversity Information Standards, historically known as the Taxonomic Databases Working Group (TDWG), and the Global Biodiversity Information Facility (GBIF). The Darwin Core body of standards, which includes a glossary of terms and guidelines for sharing data aligned with these terms using different file formats is central to this. Data sets are organized in core and extension tables and packaged together with metadata documents in so called Darwin Core Archives. Typically, Darwin Core Archives do not contain media files, but rather URLs linking occurrences to image or video resources hosted elsewhere. There are several options for referencing images and including image metadata in biodiversity data sets. While it is possible to add image URLs in the associated *Media* field in the occurrence core, dedicated Darwin Core extensions such as the *Simple Multimedia* extension or the *Audobon Media Description* extension allow for more rich image metadata to be included. Some recent additions to the *Audubon Media Description* extension make it particularly suited for sharing image and video annotations. The extension now includes the fields *xFrac*, *yFrac*, *widthFrac*, *heightFrac*,

[29] ISA, DeepData.

startTimestamp and *endTimestamp*, which allow for the definition of spatial and temporal regions of interest within media resources.

FathomNet: a global underwater image database for enabling AI in the ocean

Kakani Katija, Monterey Bay Aquarium Research Institute, USA

Ocean-going platforms are integrating high-resolution 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 analyze them. Recent advances in AI and machine learning enable fast, sophisticated analysis of visual data, but have had limited success in the ocean due to lack of data set standardization, insufficient formatting and aggregation of existing, expertly curated imagery for use by data scientists. To address this need, we have created FathomNet, a public platform that makes use of existing, expertly curated data built on FAIR data principles that uses community-recognized Darwin CORE archive data formats. FathomNet has over 160,000 localizations of 1,400 midwater and benthic classes and contains more than 70,000 iconic and non-iconic views of marine animals, underwater equipment, debris, etc. All submitted annotation data are licensed under a Creative Commons Attribution - No Derivatives 4.0 International License; images are licensed under a Creative Commons Attribution - Non-Commercial - No Derivatives 4.0 International license and all images may be used for training and development of machine learning algorithms for commercial, academic, non-profit and government purposes. In addition to the database and website, FathomNet includes an ecosystem of services with instructional guides, code and machine learning models aggregated on GitHub. Additional terms of use involve contributing enrichments where the user contributes to the FathomNet ecosystem either by defining workflows, sharing trained models, contributing data or validating existing data and restricting use to benevolent purposes in ways that are consistent with the United Nations Sustainable Development Goals. As FathomNet continues to develop and incorporate more image data from other oceanographic community members, this effort will enable scientists, explorers, policymakers, storytellers and the public to understand and care for our ocean.

Presentations delivered under agenda item 6

Image annotation tools

Timm Schoening, GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany

Image annotation is the process of manually or automatically adding semantic information to image data (photos or videos). The manual process is highly labor intensive; hence, efficient software tools are required to make the workload of annotating big image data sets feasible. Several such tools have evolved for the marine image domain over the past years. Three are prominently used and actively developed: VARS, Squidle and BIIGLE.[30] At present, BIIGLE appears to be the most actively developed, most widely used and most efficient tool for the task. It enables annotation of photo and video, entire images or pixel regions in images by points, polygons or many other shapes. It features quality assurance and control functionality for creating robust and verified annotations, has an open AI backend to incorporate automated image analysis methods, provides reference image catalogues and is connected to the WoRMs catalogue of marine names and the CATAMI classification scheme. It is web-based and thus enables worldwide access to images and annotations, where access to the data can be managed by the data owners. To achieve the principle of FAIRness of the entire marine image analysis workflow, BIIGLE is currently extended to adhere to FAIR principles to become a key tool in the image data workflow. Metadata standards like Audubon and those incorporated in SmartarID (Dublin Core and Darwin Core standards), will be available for ingest and export from BIIGLE in the near future. Furthermore, BIIGLE will be the first software tool to provide the most comprehensive marine image metadata standard (image

[30] BIIGLE.

FAIR digital objects)[31] as a means to not only capture technical and semantic metadata of images, but also scientific information on the accessibility, reusability and interoperability of images and annotations created by BIIGLE.

The CATAMI classification scheme

Candice Untiedt, Commonwealth Scientific and Industrial Research Organization, Australia

Due to the ethical concerns of using extractive sampling in sensitive habitats, the ability of image-based methods to sample larger areas and collect qualitative and quantitative data, imagery is increasingly used in deep-sea surveys. Despite these advantages, one of the main challenges of using imagery as the source of biodiversity data is the difficulty in accurately identifying fauna. This has led to the development of alternative, often morphologically based classification schemes for the identification and annotation of marine fauna from imagery. The CATAMI classification scheme was developed in Australia through a collaborative and consultative process that included scientists, taxonomists, managers and image annotators. It comprises a hierarchy of standardized, descriptive terms, each with a definition and unique numerical code, Codes for Australian Aquatic Biota, for annotating faunal units in imagery. The CATAMI scheme is designed to be used by non-experts; thus, classification within groups is based on morphology, which aligns well with taxonomy in some Phyla. In a recent study, we developed a dual annotation method where we used a specific taxonomic identifier and a standard morphological identifier (CATAMI) together to annotate black corals and octocorals. Effectively, this generated two separate data sets with differing resolutions and applications. In an effort to move closer towards global standardization, the use of a standardized classification of morphospecies (e.g., CATAMI) and a taxonomic scheme to classify fauna from imagery would be beneficial. This has the advantages of generating standardized annotations suitable for sharing across various research groups and regionally specific, high resolution taxonomic biodiversity data. It also gives flexibility in applying multiple morphotypes to the same operational taxonomic unit (OTU); thus, it accommodates the morphological plasticity and variability inherent in several faunal groups.

SMarTaR-ID: creating a global standardized marine taxon reference image database

Kirsty McQuaid, Kerry Howell, Jaime Davies and the SmarTaR-ID team from the Plymouth University, UK and the South African National Biodiversity Institute, South Africa

SMarTaR-ID is a community-driven project aimed at standardizing reference image catalogues for image-based fauna identification. The current lack of standardization has led to problems with observer bias, merging data sets and application to fields like AI. SMarTaR-ID provides a solution whereby image catalogues from different individuals, institutions or nations are standardized to one common reference catalogue. This ensures that across research groups, morphospecies identified in imagery are assigned consistent and unique OTU identifiers. The workflow proposed by SMarTaR-ID involves: 1) submission of reference catalogues to SMarTaR-ID using a standard template, 2) review, quality control and standardization of the catalogue to align with SMarTaR-ID OTUs, 3) merger of quality-controlled images with the main database, 4) supply of images to the web interface and 5) export of end products as required. The SMarTaR-ID web interface allows users to search images of different animal groups, using both taxonomic and morphological filters, identify animals in their own data sets and apply the standardized OTUs. This is supported by downloadable information pages for each OTU which contain details on morphological features to support identification. The end products will include a downloadable e-guide which can be used at sea, links to image annotation software (BIIGLE) and training materials to support image-based identification. Importantly, SMarTaR-ID strives to move beyond just a reference image catalogue to also provide materials such as morphological keys and guides for various taxa. These morphological classification keys are produced by taxonomists and relate to taxonomy as far as

[31] iFDOs.

is possible. SMarTaR-ID is first applied to the North Atlantic where a beta launch is planned for late 2021. Standardization of catalogues in the South Atlantic and Indian oceans are also under development; expansion to other areas is in the planning.

Presentations delivered under agenda item 7

The Atlas of Megafauna

Kamila Mianowicz, IOM, Poland

The online Atlas of Megafauna results from the study undertaken by IOM aimed to determine abundance, composition structure and distribution pattern of deep-sea megafauna in the exploration block H22 of IOM contract area in the CCZ.[32] This forms part of the baseline research on deep-sea biological communities conducted in accordance with the relevant Recommendations of the Legal and Technical Commission. Pictures of the seabed were taken during the IOM-2014 cruise in the contract area. Overall, almost 44,000 organisms were recognized and identified by a para-taxonomist on more than 32,000 images of seabed from nine photo-profiles of a total length of more than 580 km. Only 544 organisms belonging to 30 taxonomic groups were included in the Atlas. The main criterion was image quality. Taxonomic identification was done to the lowest possible taxonomic category but, since the identification was performed by a para-taxonomist, the current status of taxonomic identification is "lowest ID stet." or "lowest ID indet." The plan for the following year includes: 1) identify all stet. organisms, 2) ensure that all taxonomic names are in accordance with global best practices (Darwin Core) for which we seek collaboration and cooperation with external experts, 3) supplement imagery data with metadata and 4) identify and publish selected images from the IOM-2019 cruise.

Deep Sea ID

Adrian Glover, Natural History Museum, UK

The Deep Sea ID is an iOS and Android application that can be downloaded from mobile app stores.[33] Its backbone is the thematic database World Register of Deep-Sea Species (WoRDSS) hosted by WoRMs, currently containing over 28,000 deep-sea species. Essentially, Deep Sea ID is the app version of the WoRDSS website. However, its unique features include many beautiful images of deep-sea species, particularly screen grabs, images from ROVs and specimen photographs of macrofauna and megafauna. The Deep Sea ID's interface is very user-friendly, allowing users to scroll easily through the taxonomic hierarchy of organisms. A list of organisms is quickly populated upon entering the first few letters of an organism's name due to its highly efficient search function. The Deep Sea ID is useful for verifying the accuracy of spelling, confirming the taxonomic rank, the position in the phylogenetic tree and vernacular names of an organism. These features are accessible online and offline making the app useful for at-sea work. The app is operative; further development is envisaged (upgrade to version 1.3) for which financial support is sought. The updated version would be compatible across all devices, reflect an updated database sourced from WoRMS and include 200 (already sourced) new images. It is anticipated that a future version (v 1.5) would be released over time providing users with new images and improved features.

Image platform for public outreach

Youngdawng Moh and Jinwook Back, MABIK, Republic of Korea

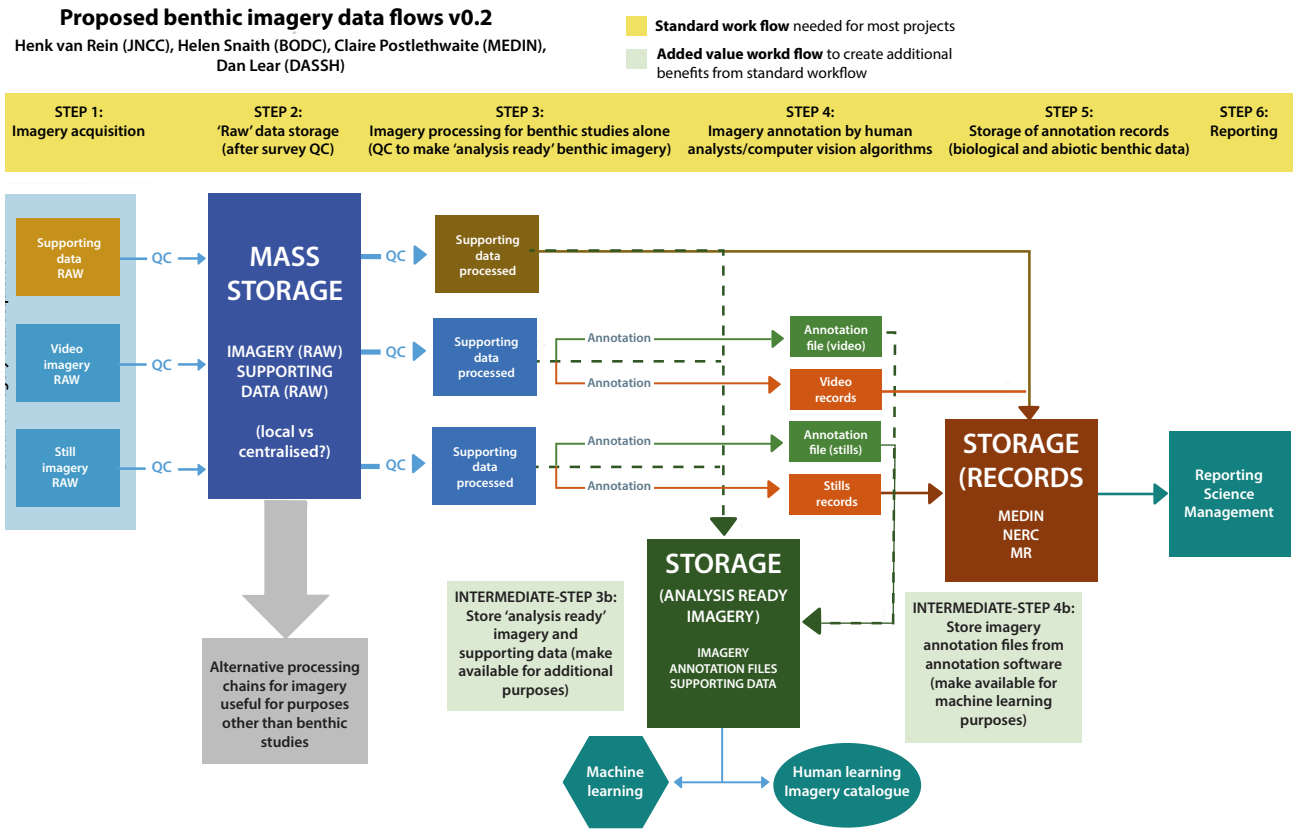
Public outreach is a key activity of MABIK, as set in its Act on Establishment and Articles of Association. Promoting public outreach helps to establish a shared recognition of a certain social problem among the

[32] IOM, Megafauna Atlas.
[33] WoRDSS.

members of society, which can lead to a policy demand and initiate a new policy process. The motivation behind MABIK's digital image platform for public outreach includes geographical disadvantage, lack of awareness due to its short history and travel restrictions due to the COVID-19 pandemic which limited public access to the MABIK museum. Several challenges were encountered while building an image platform for public outreach, including scoping and assessing the public's demands, establishing internal protocols for image resolution, naming and categorization of files, assigning responsibility for the uploading process and image ownership. Also, the effectiveness of the delivery method (YouTube, MABIK website) also needed to be considered for increased impact. In replication of MABIK's experiences in building a deep-sea image platform for public outreach, identification of a legal basis would be crucial. Article 244 of UNCLOS could provide this legal basis because it requires States and competent international organizations to publicize and disseminate knowledge and actively promote the flow of scientific data and information. The fact that the general public cannot directly access the deep sea could serve as another supporting argument for a deep-sea image platform for public outreach. It is important to bear in mind that there will be more far-reaching challenges than those accounted by MABIK. A larger number and wider diversity of public would need to be considered and would possibly require a more elaborate process for collaboration among institutions, including establishing protocols for image sharing (ownership, image size, resolution) and securing financial support.

ANNEX III

Image data workflow for biodiversity assessements



Modified from Figure 3, JNCC Report 686, Proposed benthic imagery data flows v0.2 (Van Rein, Snaith, Postlethwaite, Lear)

ANNEX IV

Summary of theme presentations

Part II: open session

Presentations delivered under agenda item 4

Roadmap to facilitate the integration of taxonomic knowledge into ISA's efforts to protect marine environment in Area

Luciana Genio, ISA Secretariat

Robust scientific basis resting upon the best available data is essential to effectively develop and implement environmental management tools and approaches. To this end, the ISA Secretariat is preparing a roadmap to facilitate the integration of taxonomic knowledge into ISA's efforts to protect the marine environment in the Area, drawing on the results of the previous ISA workshop on deep-sea taxonomic standardization held in September 2020. Enhanced data sharing, innovative tools, networks of experts and organizations, and dedicated capacity-building and literacy initiatives on deep-sea taxonomy figure among the priority actions to advance taxonomic knowledge and its effective use for the protection of the marine environment. The geographic scope of these actions extends to all mineral provinces and deep-sea habitats where current exploration and potential future exploitation activities, in close linkage with the REMP process, are taking place. A range of relevant organizations and scientific institutions have been engaged to develop technical and financial collaboration (*see* presentations under agenda item 5) for the operationalization of the proposed priority actions. These partnerships were established within the SSKI framework, designed by the ISA Secretariat, together with relevant scientific groups and stakeholders for advancing the knowledge of deep-sea environments and ecosystems in support of the mandates of ISA. SSKI aims to support the generation of new biodiversity data and development of innovative and cost-effective methodologies for faster and more accurate biodiversity assessments. SSKI will also support capacity-building initiatives at both individual and institutional levels on deep-sea taxonomy research and facilitate cross-sectoral collaboration and holistic efforts to enhance global knowledge underpinning effective protection of the marine environment in the Area.

Presentations delivered under agenda item 5

OBIS and connection with ISA DeepData database

Ward Appeltans, IOC-UNESCO

For the past 21 years, IOC-UNESCO has been building a central global data platform that provides free access to the world's ocean biodiversity and biogeographic data. The OBIS system has grown by 20 million records last year and will grow even more rapidly in the coming years as new innovative observation technologies are put in place, such as eDNA and automated imaging devices. OBIS is one of the main building blocks for the development of an integrated ocean observing system aimed at developing key indicators to report on the health of our oceans and their natural resources. As such, OBIS is already one of the primary sources of information to support activities under the Convention on Biological Diversity, assessments under the United Nations Regular Process for Global Reporting

and Assessment of the State of the Marine Environment, including Socioeconomic Aspects,[34] and the Intergovernmental Platform on Biodiversity and Ecosystem Services. In May 2021, ISA joined the OBIS network of 32 regional/thematic OBIS nodes connecting OBIS with the thousands of data-providing institutions and scientists. ISA OBIS node offers additional capabilities for combining, visualizing and analyzing deep-sea biodiversity data. However, available options in OBIS for storing metadata related to image-based observations are still limited. Currently, they only support linking to an online image using the Darwin Core term "associated media." Future Darwin Core extensions (e.g., simple multimedia and Audubon media description extensions) are in development by the Biodiversity Information Standards group, which OBIS will follow closely and contribute to, for ensuring that (meta)data from images can also be published in OBIS using internationally supported community standards.

WoRMS

Tammy Horton, Chair of the Steering Committee of WoRMS

WoRMs[35] provides "an authoritative classification and catalogue of marine names", openly accessible to all.[36] Use of WoRMS names can help ensure taxonomic consistency for ISA by providing the most up-to-date name of the species encountered in faunal surveys. Taxonomic expert editors are the driving force of WoRMS. They are supported by the Data Management Team at the VLIZ in Belgium; this collaboration is fundamental to the success of WoRMS. The ISA Secretariat and WoRMS have discussed the development of collaborative activities. WoRMS recommended the use of its nomenclature as a global standard to provide a robust and standardized taxonomy, provided advice on the use of its tools such as "Taxon Match" and discussed the incorporation of Open Nomenclature into ISA DeepData database.[37] Formal partnership is still being discussed. However, it is likely that such a partnership would focus on the following main collaborative activities: 1) ensure the quality of deep-sea taxonomic information through a periodic scientific review (two-way comparison between DeepData and WoRDSS), 2) facilitate the development of toolkits (WoRDSS keys and guides, Deep Sea ID app) for enhanced use of taxonomic information generated from activities in the Area and 3) develop training and sensitization activities for providers and users of taxonomic data related to activities in the Area with a view to standardizing the data, enhancing data sharing and raising the awareness of deep-sea biodiversity. The collaboration between WoRMS and the ISA Secretariat will include seeking financial support to prioritize this work. With these aims in mind, WoRMS look forward to a productive collaboration with the ISA Secretariat, which will improve access to high quality taxonomic information for the deep sea globally.

Getting to the bottom of it: current state of biodiversity knowledge for the CCZ

Muriel Rabone and Adrian Glover, Natural History Museum of London, UK

Although exploration activities for polymetallic nodule mining have been underway in the CCZ since the 1970s, there is a well-documented lack of biodiversity knowledge about the region. These knowledge gaps urgently need addressing for effective environmental management of the CCZ. With the launching of the ISA DeepData database in 2019, the key repository of Contractor's data and a large body of data recently published in the scientific literature, it is time to review the baseline taxonomic data currently available for the CCZ. In this study, done in collaboration with the ISA Secretariat with the financial support of PEW Charitable Trusts, benthic metazoan taxonomic records published in DeepData, from all faunal

[34] Division for Ocean Affairs and the Law of the Sea | (un.org).
[35] WoRMS.
[36] Horton et al. (2017). Improving nomenclatural consistency: a decade of experience in the World Register of Marine Species. Eur. J. Taxon. 389: 1-24. (https://hdl.handle.net/10.5852/ejt.2017.389); Vandepitte et al. (2018). A decade of the World Register of Marine Species – General insights and experiences from the Data Management Team: where are we, what have we learned and how can we continue? PLoS ONE 13(4): e0194599.
[37] Horton, T. et al. (2021). Recommendations for the standardisation of open taxonomic nomenclature for image-based identifications. Frontiers. (https://doi.org/10.3389/fmars.2021.620702).

size classes, have been analyzed together with records available in other databases (OBIS and GBIF) and the published literature. Over 40,000 records have been published in the ISA DeepData database from 25 cruises, over 2,000 in OBIS and GBIF and over 4,000 in the literature from about 47 cruises. The literature reviewed consisted of 123 publications containing taxonomic information published since 2000, including 166 new species descriptions, 28 new genera and three new families. The majority of the CCZ taxonomic literature has been published in the last decade, particularly the last five years. New species were mainly arthropods and annelids, but significant numbers of species have been described for nematodes, bryozoans and sponges. The compilation of a CCZ checklist is in progress; it will include 848 named species records from all published sources (including potential pelagic species for which names are currently reviewed). Approximately 20-25 per cent of species recorded from the CCZ are new. Regarding known names, over 4,000 morphospecies were recorded in the databases, particularly DeepData and the literature, highlighting that many species are yet to be described. Chao1 species richness estimates exceed 5,000 with a species accumulation curve far from an asymptote, indicating that species-level sampling is far from complete and that there are still many species to describe in the region. These findings provide a biodiversity knowledge basis that can be iteratively improved, as new biodiversity data from the CCZ region is collected.

Biodiversity underestimation in our blue planet: AI REVOLUTION in benthic taxonomy - the BLUE REVOLUTION project

Daniela Zeppilli, Abdesslam Benzinou, Catherine Borremans, Valentin Foulon, Ifremer, France and the BLUE REVOLUTION team

In face of the growing anthropogenic pressures on marine ecosystems, there is a scientific and moral obligation to find ways for accelerating biodiversity description. The BLUE REVOLUTION project will develop *in-situ*/onboard/in-the-field methods (holographic microscopy and 3D-fluorescence imaging) linked with classification tools for high throughput analysis, using accurate automated taxonomic classification based on AI. These methods will enable generation of quantitative, genetic and functional data of benthic communities at speeds unseen before. The project will also develop a standardized method for building open-access reference libraries/data repositories of benthic diversity together with fast and reliable tools for rapid and accurate impact assessments and biodiversity surveys. The project will provide training and education opportunities for the next generation of benthic taxonomists/ecologists to develop skills in species identification, including strong hypothesis-based research programs and the ability to employ cutting-edge techniques. The BLUE REVOLUTION developments will be particularly useful for assessing deep-sea ecosystems (owing to the reduction of animal size with increasing water depth) and monitoring a wide range of human impacts including the future exploitation of mineral resources. With the support of ISA, an 18-month postdoctoral fellowship has been announced within the framework of the BLUE REVOLUTION project, for candidates from developing States Members of ISA. The position will focus on developing and testing new methods and technologies of 3D-imaging techniques for the identification of meiofauna organisms of deep-sea ecosystems found in areas currently explored for mineral resources.

Enhancing knowledge of deep-sea ecosystems – SSKI

Aurore Maillet, European Commission, Belgium

SSKI is developed within the context of ISA in alignment with the Sustainable Development Goals of the United Nation's 2030 Agenda, more specifically SDG 14 – Life Below Water. The outcomes of SSKI will also be relevant for several intergovernmental discussions on preservation of the marine environment by the Convention on Biological Diversity, the Intergovernmental Conference on an internationally legally binding instrument on the conservation and sustainable use of marine biological diversity of areas

beyond national jurisdiction (BBNJ) and fulfilling regulatory mandates by ISA. The initiative is also well aligned with the European Union (EU) policy framework through the EU's Green Deal, which spans many fields of the green transition, as well as its precautionary principle, and affirms that additional research and knowledge is needed to clearly demonstrate no serious harm to the environment before marine mineral exploitation in the Area begins. It is against this premise that the EC has funded other initiatives aimed at identifying and mitigating the impacts of future deep-seabed mining on the marine environment, developing environmentally friendly mining technologies and assisting ISA to develop REMPs for the Area of the northern Mid-Atlantic Ridge. The main research program of the EU, Current Horizon Europe, spans over seven years and involves the dedication of EUR14 million to the monitoring and supervising system for exploration and future exploitation activities in the deep sea. EU collaboration with ISA on SSKI will focus on identification of new species, the development of species identification apps and toolkits and underwater image reference libraries with a pilot test in the Mid-Atlantic Ridge area. Bringing together collective efforts from ISA Members, contractors and independent scientists, SSKI will benefit from the best available expertise in an inclusive and transparent manner.

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