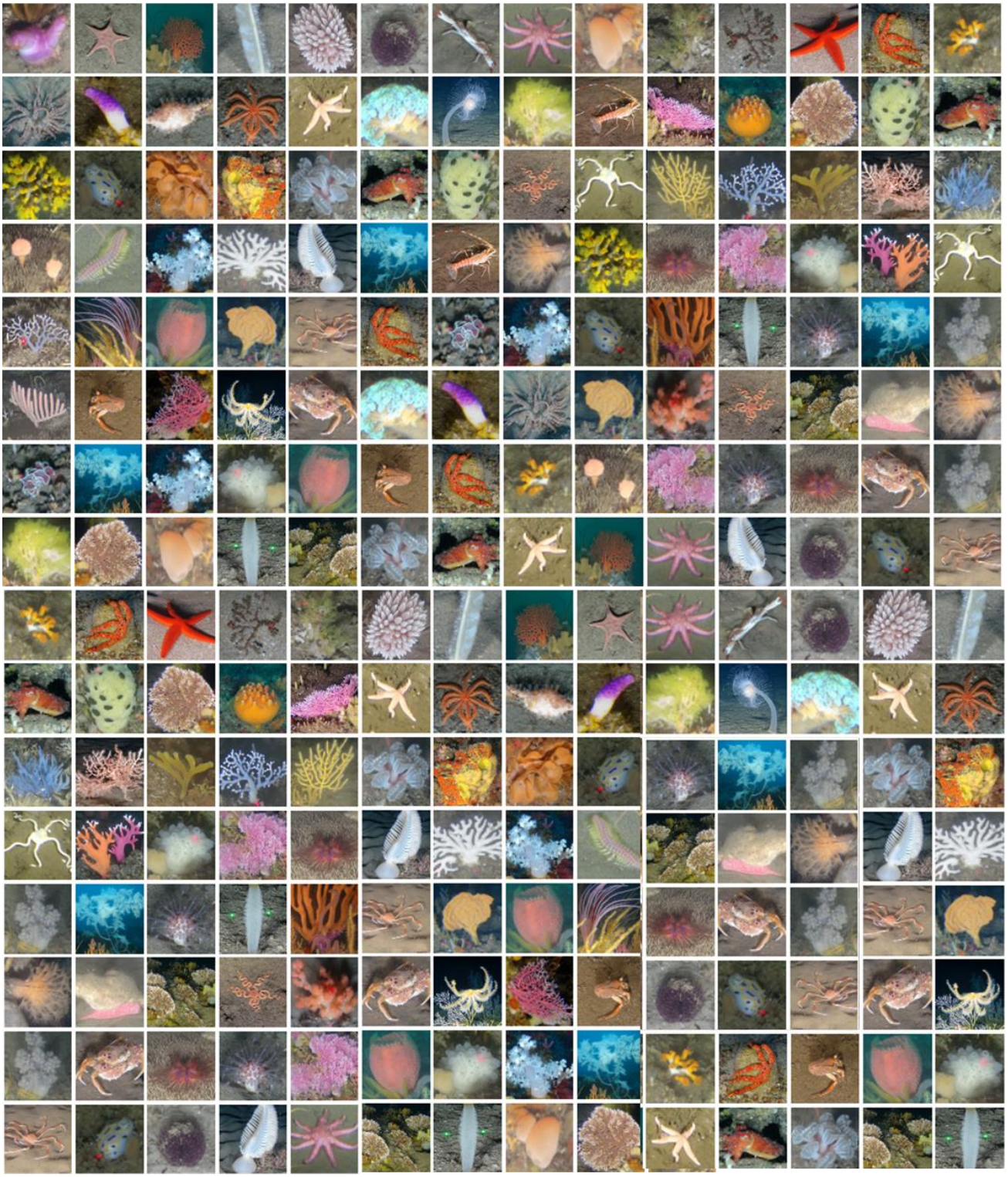
Advancing the Southern African Marine Biodiversity Reference Image Collection



Advancing the Southern African Marine Biodiversity Reference Image Collection

31 July 2024

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Executive summary

The Southern African Marine Biodiversity Reference Image Collection is a database of benthic invertebrate morphospecies observed from underwater visual surveys. The database was developed in South Africa through the One Ocean Hub with support from Kerry Howell (Plymouth University) and draws from the SMarTaR-ID framework for cataloguing representative marine fauna observed in situ. This framework aligns with the Darwin Core Standard for metadata, ensures standardised naming of taxa and allows for dataset integration, inter-opearbility and comparability.

The catalogue was developed by 12 researchers from five institutions over a 5-year period, drawing from multiple projects that surveyed the seabed using Remotely Operated Vehicles, towed cameras, a submersible and benthic lander. Imagery was derived from at least eight projects of the African Coelacanth Ecosystem Programme, SAEON biodiversity surveys, the dedicated One Ocean Hub capacity development cruise and recently, environmental baseline studies conducted by a petroleum company. As of 31 July 2024, the South African reference image database has 670 operational taxonomic units across 14 phyla of marine invertebrates. The catalogue was developed from imagery collected by remotely operated vehicle surveys, towed camera surveys and baited stereo-video landers. In total, 204 taxa have been identified to species level and a further 380 to genus level. The remaining taxa have been identified to family or higher taxonomic classifications. Imagery spans the northwestern boundary of South Africa's oceans to the northeastern boundary along the Mozambican border and covers depths from 30m to 4633m.

The reference images also initiated and catalysed the development of computer vision object detection models to facilitate reference image extraction and ecosystem classification work in South Africa. Future endeavours will continue to add to this database from new visual surveys. A total of 3607 occurrence records were generated with further work underway on deep sites (600-3000m) from recent surveys conducted by the petroleum industry. Further taxonomic work is needed to verify identifications, but this reference image database will soon be made freely available and accessible online to support future research, student theses, practitioners with environmental impact assessments and enhance foundational biodiversity data collected in the Southern African region.

Recommended citation

Adams L, Sink KJ, Shibe S, Rylands S, Sethebe K, Atkinson LJ, Franken M, Forgus JJ, Nefdt L, Bernard A, Palmer RM and Currie JC. 2024. Advancing the Southern African Marine Biodiversity Reference Image Collection, 31 July 2024. Technical report, South African National Biodiversity Institute. Cape Town.

Background

As **underwater cameras** become more cost effective and accessible, the use of cameras mounted on a range of platforms to record observations of marine biota is expanding rapidly, both globally and in South Africa. Their use in the study of marine ecology frequently requires the identification of marine biodiversity from images or video, without a physical sample that can be scrutinised by trained taxonomists. As such, the identification of organisms from videos and photographs is an important step and skill that influences the efficacy of studies and monitoring programs that rely on underwater imagery. Even without the identification to species level, taxonomic units or morpho-species can contribute valuable assemblage and ecosystem information, if they can be consistently discerned. Without intervention, marine benthic species or morpho-species (discernible taxonomic units) identified from underwater imagery are usually assigned different names by various research groups or projects. As a consequence, the resulting outputs are not compatible for comparison of results among projects or regions, nor in terms of combining the data for broad-scale analyses.

The creation of a **standardised reference image database** across a broad region (or globally) has multiple advantages, which include the utility it provides in training students in para-taxonomy; the ability to easily extract information for creating an identification guide for a certain area or taxonomic group; improved data quality and consensus on difficult faunal identifications; and greatly improves scope for integrated datasets and broad-scale analyses if everyone calls the same organism by the same name. For this reason, we initiated the creation of a regional underwater reference image database for Southern Africa. The catalogue was initiated for marine invertebrates with potential inclusion of fishes at a later stage. Historically, there have been far more resources and capacity to support the identification of fish than marine invertebrates and One Ocean Hub researchers (Sink, Atkinson and Howell) elected to focus on marine invertebrates to strengthen capacity for these groups. The image catalogue compliments the Offshore Marine Invertebrate Field Guide (Atkinson and Sink 2018) which features ex-situ trawled invertebrates that often look very different to live, in-situ animals. The initiation of the reference image catalogue was supported by funding and collaborations facilitated through the One Ocean Hub with the first emerging researcher appointed part-time in 2020 to initiate and extract faunal images from the towed camera footage collected during the west coast visual survey (Currie et al. 2019), identify the organisms and enter the data into two tables as per the recommendations of Howell et al. (2019).

Underwater visual surveys beyond SCUBA diving depth in South Africa were initiated in the 1980s with first submersible surveys in 1991 and first remotely operated vehicle (ROV) surveys in 2005 (Sink *et al.* 2019). Submersible surveys were first conducted in the hopes of finding a coelacanth (none observed) during surveys in the East London area in 1991 but additional surveys were conducted by diamond companies on the western margin. The discovery of coelacanths at Sodwana Bay in 2000 catalysed the African Coelacanth Ecosystem Programme (ACEP), which held three submersible expeditions (2002, 2003 and 2004). In 2005, ACEP hired an ROV and conducted the first ROV-based research expedition (Sink and Scott-Williams 2005). It's success led to the acquisition of the ACEP ROV which has been used to conduct visual surveys since 2011. DFFE and SAEON acquired tow

cameras in 2012 and 2013 (Figure 2), with DFFE first using a jump camera configuration for Southern Ocean surveys. These cameras, rated to 700m, have been used to conduct foundational research on the outer shelf and slope including in supporting a benthic trawl experiment on the western margin and are supporting multiple postgraduate research projects. Both tow cameras and their associated technicians contributed valuable baseline surveys of the outer shelf and slope of the Agulhas ecoregion as part of the ACEP Deep Secrets cruise in 2016 and in 2019 and 2023, the SAEON system supported similar deep-sea research in the Southern Benguela (Currie et al. 2019). In addition, the SAEON tow camera conducted the first deep-sea surveys in the Prince Edward Islands supporting post graduate studies and the recent National Biodiversity Assessment (Whitehead et al. 2019).

Baited cameras have been widely used in South Africa to survey demersal fishes and large mobile scavenging macroinvertebrates across the continental shelf (5-100m) since 2007. Traditionally, these stationary camera systems operate independently of the research vessel and rely on ropes and surface marker buoys for deployment and retrieval. This greatly increases the sampling efficiency as numerous systems can be deployed simultaneously at different locations. However, the drag forces acting on the ropes limits the maximum operation depth, especially in high current conditions, like those encountered in the Agulhas Eastern Boundary Current. This challenge led to the development of deep-sea baited stereo-camera lander systems that eliminate the need for rope and buoys, freeing equipment from the effect of the currents when on the seafloor. A **deep-sea lander** is essentially a platform that allows scientists to remotely deploy and retrieve scientific payloads to the deep-sea for varying periods of time and across broad depth ranges. The essential components are non-compressible floats, a load of sacrificial ballast, an acoustic release for communication and a satellite beacon for relocation when the lander is on the surface. The acoustic release allows communication from the vessel to the lander to trigger the release mechanism. Triggering the release drops the ballast which then changes the buoyancy of the lander from negative to positive. When the ballast is attached to the lander its mass counteracts the buoyancy from the floats and the lander sinks to the seafloor. When the release is triggered and the ballast is discarded the lander becomes positively buoyant and floats back to the surface. During the **OOH Capacity Building Cruise**, we were successfully able to demonstrate the effectiveness of the baited stereo-camera landers in sampling seafloor environments in the Agulhas Current down to depths of 1000 m.

A **map of the visual survey efforts** used to develop the catalogue is shown in Figure 1. Geographically, imagery spans from the north-western boundary of South Africa's oceans to the north-eastern boundary along the Mozambican border and covers depths from 30m to 4633m (Figure 1). Most surveys have been conducted on the shelf with towed cameras and landers extending the depth range. In 2022, a petroleum company conducted the first ROV surveys beyond 300m and in 2023, South Africa acquired a new ROV rated to 1000m which has yet to be deployed.

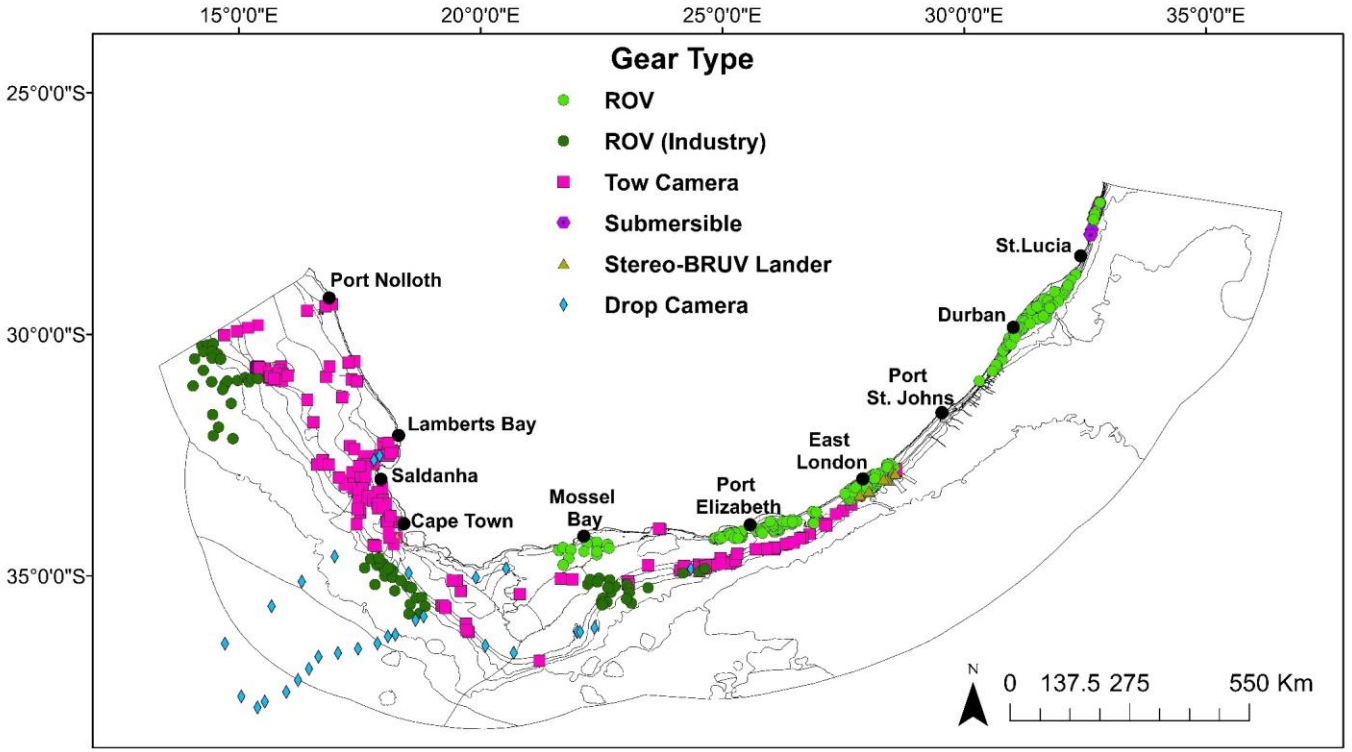


Figure 1. Overview of visual survey stations (above) with using various underwater camera survey platforms over more than two decades from 11 research projects on the continental shelf and slope of South Africa. Zoomed maps are reflected below, labelled Figure 1A-E from West to East.

Figure 1A

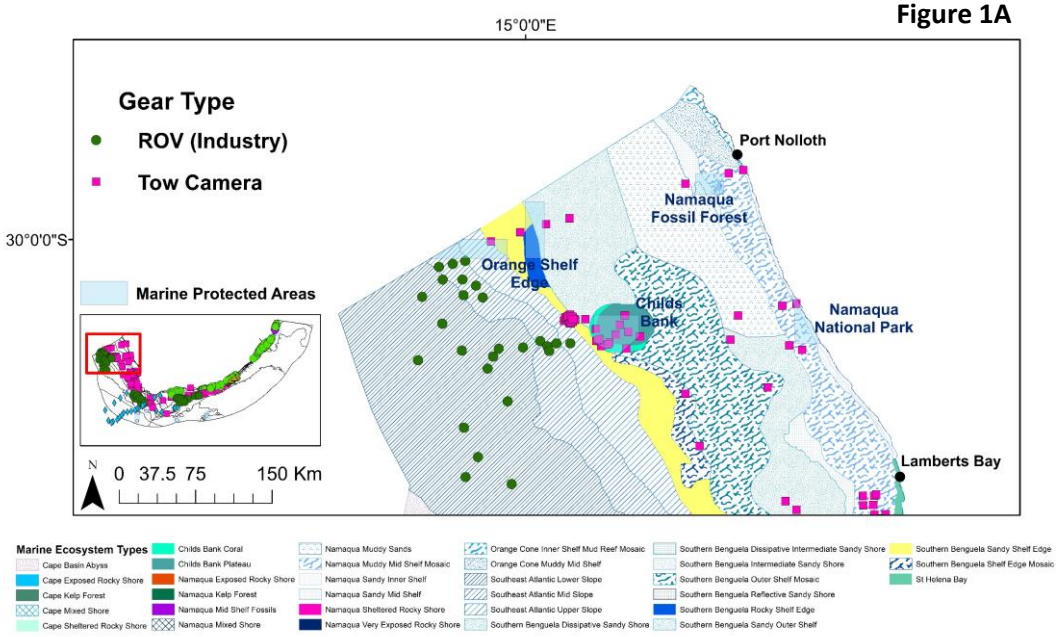


Figure 1B

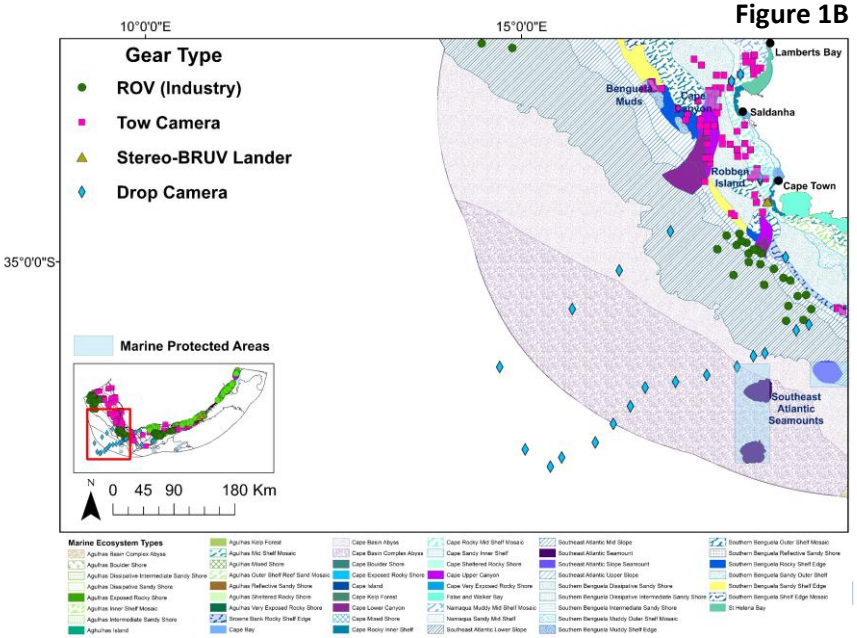


Figure 1C

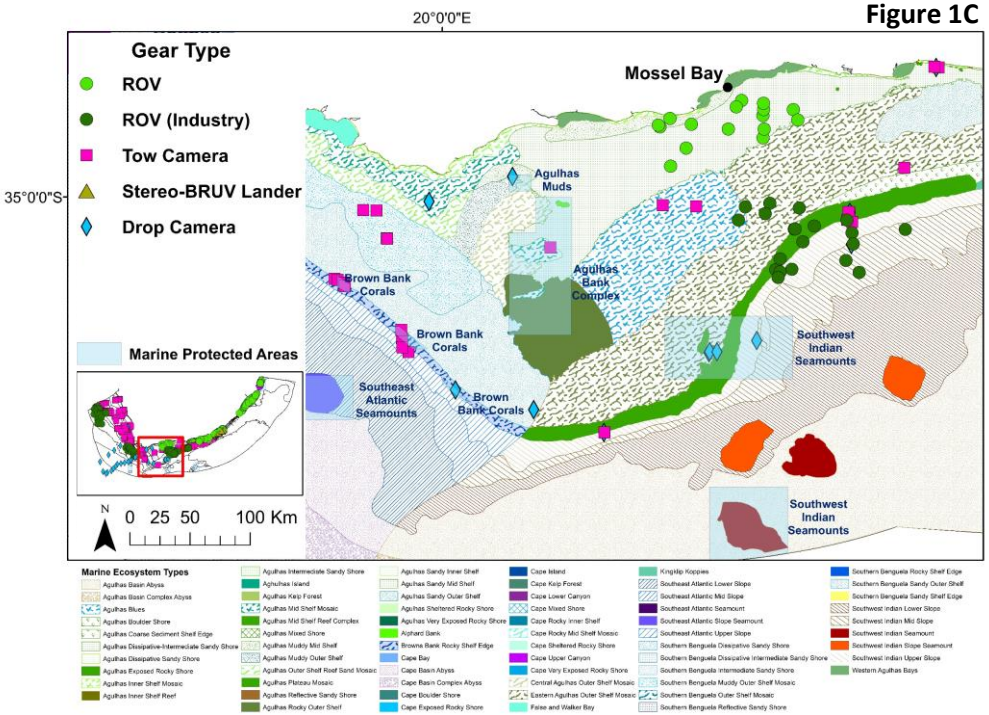


Figure 1D

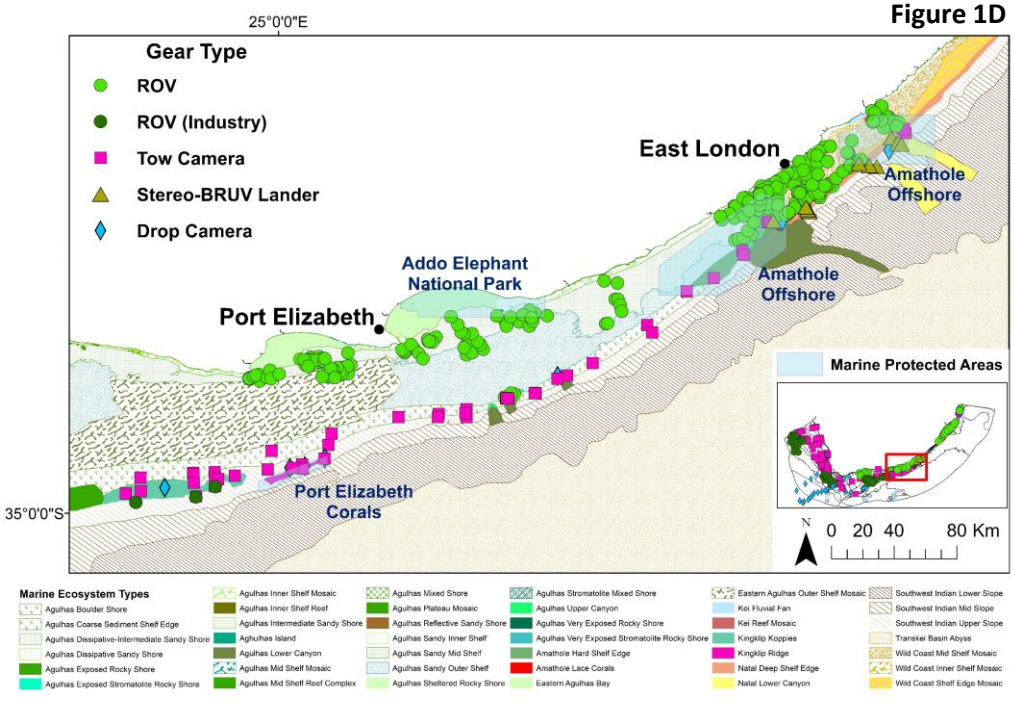
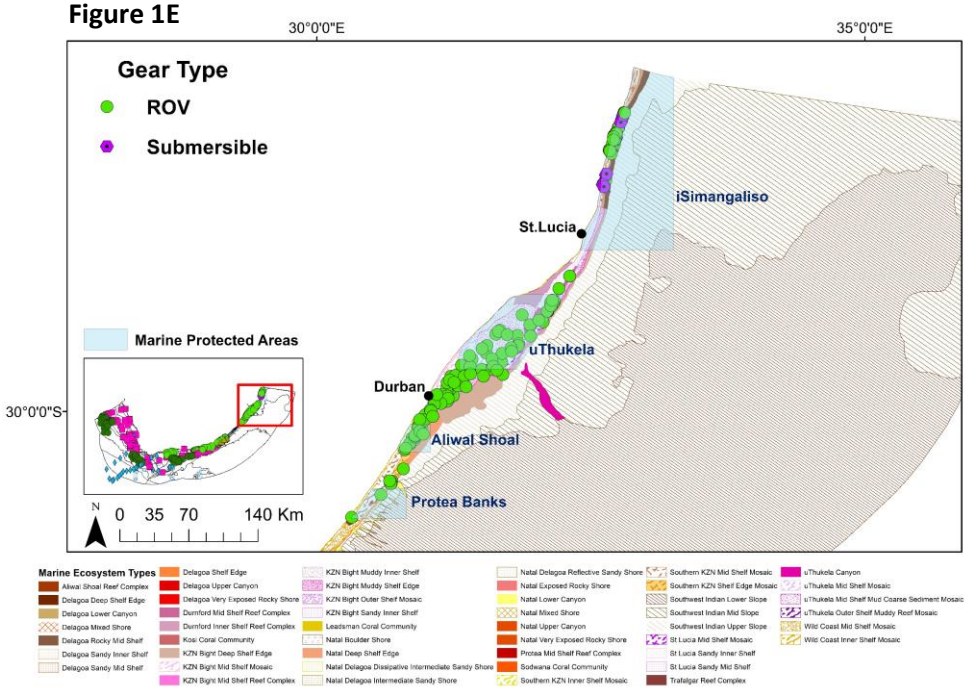


Figure 1E



Development of Reference Image Collection

Reference Images and associated data tables

Following recommendation and examples by (Howell et al. 2019), two data tables were created with two meta-data tables that describe their fields (See Appendix 1 below). The first table is the **taxon table** (for taxon or 'operational taxonomic unit'; OTU) table, which contains columns that describe the taxonomic unit, including its lowest possible phylogenetic classification and associated 'LSID' number from the World Register of Marine Species (WoRMS) (Appendix 1). It allows inclusion of a morphospecies name for cases where the identification is not certain to species level. Identification features for the animal and the name or link to an iconic image can be included here too. This table documents the distinguishable taxa and fields map predominantly to the Darwin Core classes "Taxon" and "Identification" (Howell et al. 2019). For details, see the OTU meta-data table included in the Appendix (Table A1). Certain fields are best auto-populated from WoRMS, which can be done with a batch spreadsheet upload & download via the website or from R using the 'worms' package (Holstein 2018).

The second table, referred to as the **image table**, captures information relevant to individual reference images, such as the filename of the (usually cropped) image in question, their context (date, location, depth), identification certainty and sample details if a sample was collected, source and ownership (See Appendix 2). The OTU number is a taxon-specific code that links the multiple images detailed in the image table to one taxon (or OTU) in the taxon table. For details of the image table, see the meta-data table in the appendix (Table A2). The OTU code used is to some degree arbitrary, as long as it always remains unique to a specific OTU.

The imagery and these two tables constitute the **Southern African Marine Biodiversity Reference Image Collection (SAMBRIC)** which can be used to generate a catalogue. The collection is never complete but will built upon over time if resources can be secured to continue this work. Ideally, the collection can feed into global initiatives.

Contributing research and projects

The **contributing researchers** that compiled this image collection and associated data tables are reflected in the author list with key contributions by emerging researchers shown in Table 1. Kholofelo Sethebe was the first emerging researcher to work on the database when she was appointed during the covid 19 pandemic. She was provided with a hard drive of imagery from the 2018 west coast visual survey (WCVS; (Currie et al. 2019) and tasked to create a reference image dataset from that project footage. Jock Currie assisted in the adjustment of table structures developed by Howell et al. (2019) and provided guidance of how to go about data capture, the management of images and accessing assistance with identification of fauna. Kholofelo and Jock had several meetings, concentrated predominantly in the early part of the appointment, to address queries and ensure the data capture and management approaches were accurate and effective. The work-flow followed by emerging researchers consisted of reviewing imagery from each station, extracting cropped images of fauna from existing images and/or taking screen captures from video footage and then cropping them. The newly-created cropped images, i.e., reference images, were saved to phylum-specific project folders and renamed in a meaningful way that captures a project

code, station code and the original source file name. From there, the data for each image was entered in the image table and also into the taxon table for each new taxon encountered. Kholofelo continued this work through to the end of January 2021, at which point she had completed the WCVS stations.

Shakirah Rylands was then employed by SANBI to start the same process using remotely operated vehicle imagery beginning with the **ACEP Deep Forests project**. Thereafter, Luther Adams was employed by SANBI (September 2021 to February 2022) to continue the efforts of Shakirah with the ACEP Deep Forests project. Thereafter he was employed at SANBI with funding from Mission Atlantic (March 2022-2023), the FBIP SeaMap project (April to July 2023) and SANBI (August 2023 to March2024) and focused efforts on the **ACEP Imida Frontiers project**. Sinothando Shibe was also employed as an emerging researcher funded by the One Ocean Hub (2023) and Mission Atlantic (1 month in 2024). The One Ocean Hub also funded Luther, Sinothando and Kerry to integrate further advance the reference image database at Mbotyi for a week in 2023 and 2024 (4 days). Mission Atlantic provided funding for Shakirah to add additional images from ACEP Agulhas Bank Connections and Deep Secrets in 2024.

Table 1. Team members that captured key data for the two tables for the reference image data set. Operational Taxonomic Unit contributions by emerging researchers to the South African Marine Biodiversity Reference Image Collection are indicated.

Name (Period)	Contribution	Co-funding	Current activities
Luther Adams[1] (January 2021 - March 2024)	Processed ACEP Imida footage (R1-56). Then conspicuous taxa from ACEP Deep Forests (East London) & Deep Connections. A total of 211 OTUs added.	Mission Atlantic	PhD student at Rhodes University.
Sinothando Shibe[2] (June2023-June 2024)	Processed entire Canyon Connections ROV dataset & part of Imida & Deep Forest datasets. Reference images (26 OTUs) & occurrence records generated. An additional 109 OTUs were drawn from deepsea petroleum footage in June / July 2024. Initial processing of One Ocean Hub (OOH) baited lander video footage for OTUs underway.	Funded by One Ocean Hub then Mission Atlantic.	Employed at SANBI on Mission Atlantic. MSc graduated in 2023. Currently processing deepsea images from TEEPSA project.
Shakirah Rylands (February 2021 (RA) April- June 2024 (OOH), July 2024 (Mission Atlantic	Initiated ACEP Deep Forests (36 OTUs) in 2021. In 2024, Shakirah collated Agulhas Bank Connections (ABC) footage & reference images from Leila Nefdt from ACEP Deep Secrets for inclusion. Processed & generated occurrence records for ABC & OTUs with reference images from both data sets. Systematically analysed all ABC sites. Initial processing of One Ocean Hub baited lander video footage for OTUs underway.	Funded by One Ocean Hub then Mission Atlantic.	Employed at SANBI on Mission Atlantic. MSc in review.
Mbotyi team[1,2,3] 2023/2024 (June and July 2023, 2024)	168 OTUs added from ACEP KZN projects (Surrogacy, Spatial Solutions & review of multiple projects.) Cleaned records & added missing data. Taxonomic training provided by Sink. Seafan reference images compiled for expert taxonomic review.	NA	NA
Kholofelo Sethebe (July 2020 - January 2021)	Worked through all footage from the WCVS cruise (19 successfully surveyed stations) & captured data for 391 images, linked to 64 OTUs.	NA	Employed at Sentinel Ocean Alliance
Jock Currie (June 2020-present)	Data scientist that initiated and provided oversight of data tables, liaison with Plymouth, training of emerging researchers in data capture & curation.	One Ocean Hub, SANBI, Claude Leon fellowship.	Marine Spatial analyst at SANBI.

The South African Marine Biodiversity Reference Image Collection was compiled from multiple projects and initiatives that collected seabed imagery by remotely operated vehicles, tow and drop cameras, submersible and baited landers (Table 2, Figures 1-3).

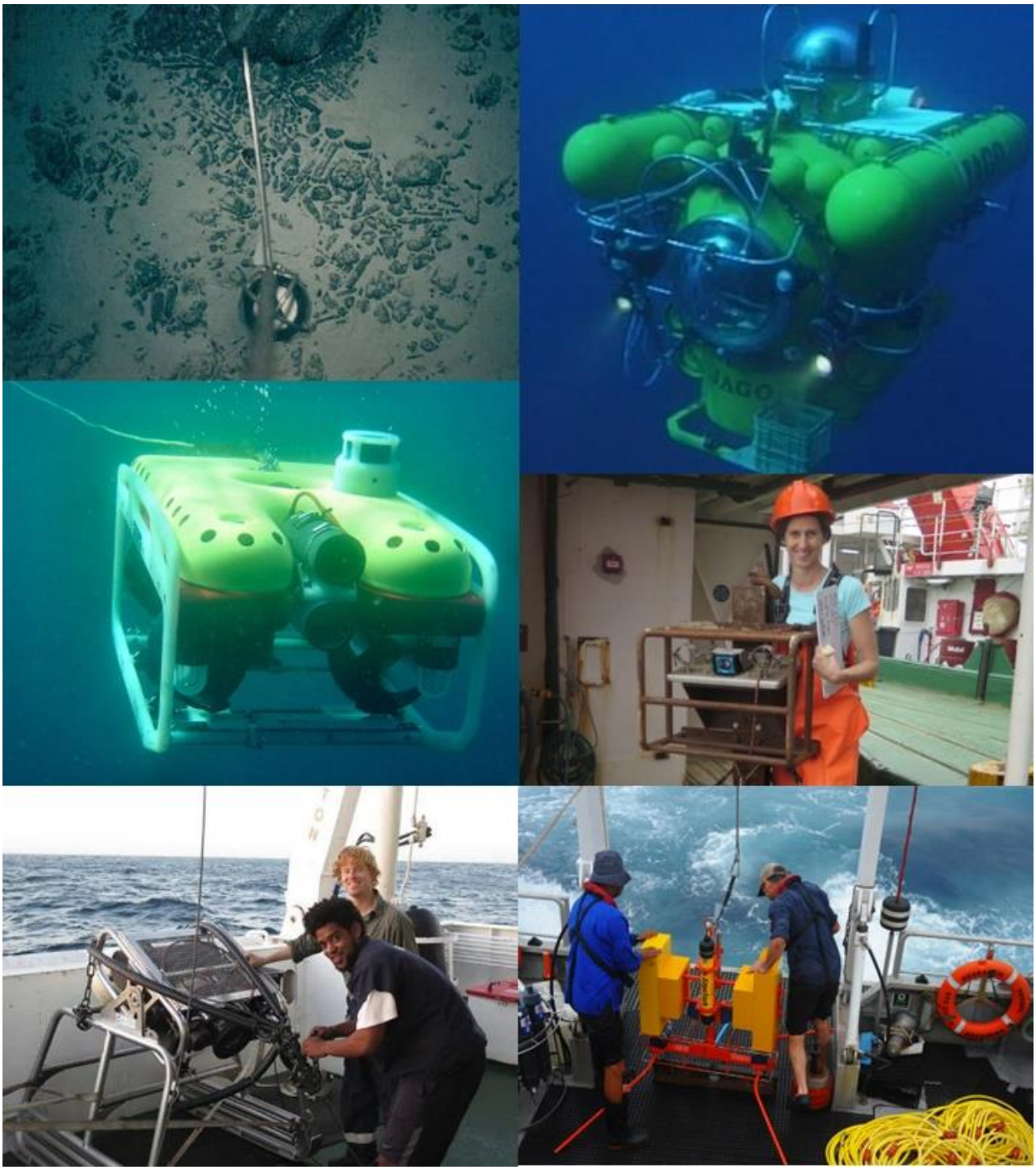


Figure 2. Camera platforms used for deep water visual surveys in South Africa. Prof John Rogers undertook drop camera surveys including in very deep water (see Figure 1) during the 1980s (top left). Submersible surveys were conducted by the Jago team in 1991, 2002, 2003 and 2004. ROV research work was initiated in 2005 (centre left). The Deep Secrets team surveyed depths up to 940m using a go-pro in a housing in 2016 (centre right). SAEON and DFFE acquired new deepsea cameras in 2012/13 (bottom left) and SAIAB have extended baited stereo cameras onto the slope since 2019.

Table 2. Contributing projects or potential projects that have or could still contribute to the image database. Projects listed chronologically from most recent to oldest. Positions of surveys are available in SANBI's visual master shape file which is regularly updated.

Project	Year	Area and depth	Description	Notes
ACEP Deep Connections	2022-2024	Mesophotic and slope off Mzumbe, Ifafa, Durban, Mgeni, uThukela and iSimangaliso (Chaka to Nine-mile canyon) 40-275m.	151 ROV surveys	61 sites processed (Adams). 366 records generated. (Students – Oliver, Shibe, Anderson).
SAEON SeaMap biodiversity survey (EK221)	May 2023	Western margin, Cape Point offshore to St Helena, 63-414m including Robben Island, Benguela Mud and Cape Canyon MPAs.	21 tow camera stations	SAEON team to process.
One Ocean Hub Capacity (ROV)	Feb 2023	Kenton to Kei 43-230m.	29 ROV surveys	26 sites processed (Adams). 165 records generated. Adams PhD will complete this.
One Ocean Hub Capacity (Lander)	Feb 2023	Gxulu to Kei 230-1035 m.	10 Lander surveys	Initial processing by Rylands and Shibe. Occurrence records can still be generated.
Deep Water Orange Basin petroleum industry survey	2022	Western margin, off Port Nolloth to Lamberts Bay, 815m – 2897m.	26 ROV surveys	92 epifaunal taxa recorded. A total of 96 OTUs from across all 3 deepwater surveys have been added to the catalogue with further processing underway.
Block 5, 6 and 7 petroleum industry survey	2022	Southwestern margin, off Cape Point to Gansbaai, 667 - 2848m.	23 ROV surveys	141 epifaunal taxa recorded (10-40 per transect)
Block 11/12 petroleum industry survey	2022	Southern margin, off area between Mossel Bay and Cape St Francis, 667 - 1779m.	23 ROV surveys	357 epifaunal taxa recorded, many rocky stations
ACEP ABC Project	2021, 2022	Still Bay to Mossel Bay north, 46-100m.	28 ROV surveys	194 occurrence records to date.
West Coast Visual Survey	2019	Offshore of Robben Island to Cape Canyon to offshore of Pearly Beach, 83-696m.	19 stations	Kholofelo captured data for 391 images, linked to 64 OTUs.
ACEP Canyon Connections	2018, 2019	Cave Vidal to Island Rock to iSimangaliso, 33-236m.	28 ROV surveys	All sites processed by Shibe. 90 records from 6 stations
ACEP Deep Forests	2019, 2022	St Francis – Cintsa including the Amathole MPA, 30-300m.	163 ROV dives	Records generated by AI. 776 records (Adams, Rylands, Shibe, Bull and Besseling).
Benthic trawl experiment	2014-2018	Demersal trawl blocks362 and 372 Also surveys at Child Bank, and in the Benguela Mud MPA. Depth range approximately 280-630m.	5 annual surveys	SAEON adding reference images into the catalogue. Many occurrence records could be generated over this small area.
ACEP Imida	2017	Hamburg - Kei mouth, 25-270m.	100 ROV surveys	56 sites analysed comprehensively (Adams). Many sites annotated. A total of 1682 records generated with 995 of these extracted manually from IMD01 to 56). Button and Coetzee have analysed fish.

Project	Year	Area and depth	Description	Notes
ACEP Spatial Solutions	2016, 2017	Carpenters Reef (uThukela MPA to Aliwal Shoal	61 stations -	34 sites processed (Adams), 260 records, Makwela MSc ORI delivering additional SeaMap records.
ACEP Deep Secrets	2016	Agulhas ecoregion, spanning the shelf edge-slope transition from the western edge of the Agulhas Bank to offshore of the Kei River mouth, 120-700m depth.	29 towed camera sites	Nefdt processed 855 images, identifying 173 morphospecies. 49 OTUs have been added to the reference image database from a subset of images. Additional processing underway by Rylands.
ACEP Dorrington Projects	2014-2016	Algoa Bay- Cape Recife area. Thunderbolt reef, Riy Banks and Evan's Peak.	14 sites	Not processed. Footage and stills requested from Dorrington. Engage with Parker Nance in medium term.
ACEP Surrogacy & Protea Banks	2014, 2015	Zinkwazi to Pennington (33-88m) and Trafalgar Reef Complex and Protea Banks including 2 canyons, 30 to 160m.	35 sites	Processed by Mbotyi team, 75 records. Franken honours thesis describes epifaunal assemblages.
Gombessa Isimingaliso Coelacanth expedition (French team)	2013	Island Rock Canyon to Chaka Canyon iSimangaliso 45-140m.	21 stations	A few additional invertebrates were added but Deep Connections provided higher quality images. Fish analysed by Geldenhyus.
Second ACEP ROV survey	May 2011	iSimangaliso. Jesser canyon and surrounding area, 40-120m.	9 stations.	Not processed. Request footage from SAIAB.
PetroSA project	2005-2009	Agulhas Bank including petroleum infrastructure associated with the Oribi-Oryx fled and FA platform. 2009 surveys 68-134m. Saturation divers also collected specimens.	9 ROVs in 2009. Historical efforts need consolidation.	Not re-processed and better imagery available for most taxa. Only record of *Metridium senile* invasive anemone. See Sink et al. 2010.
First ACEP ROV survey (Sink and Scott Williams).	2005	iSimangaliso Jesser-Diepgat canyon and adjacent mesophotic reef and dune field. 40-120m.	14 ROV surveys	Not processed. Request footage from SAIAB.
ACEP Jago surveys	2002-2004	Chaka- Island Rock Canyon, iSimangaliso. Depths- 46m-309m.	46 survey dives totalling 166 hours	Footage processed by Sink. Images stored in folders per family (SANBI M drive). Further work needed to integrate into the reference image database and generate occurrence records.
Jago dives	1991	East London, Tsitsikamma Middlebank Reef and off Cape Point. Also Cape Canyon and Child's Bank. 50-300m.	At least 14 dives	Images acquired from Diamondfields international with further data and field notes provided by Mike Bruton. Imagery digitised and archived by Sink at SANBI. Positions must be added to visual master.
John Rogers deep water geoscience survey	1980's	Off Cape Point and Six Mile Bank to the Atlantic Abyss and 6 adjacent sites between the EEZ boundary (-45 to -4663 m) and adjacent high seas area including Wyandot Seamount. 4619 to 4852 m.	Drop camera images, 12 stations.	Images provided by Prof John Rogers. Few biota recorded by these are being included among reference images and occurrence records. Positions included in 2024 visual master.

Overview of image collection

A total of 670 operational taxonomic units across 14 phyla of marine invertebrates were derived from ROV surveys, towed camera surveys and baited landers from the margin of South Africa (Figures 1-3). In total, 204 operational taxonomic units have been identified to species level and 380 to genus level. The remaining taxa have been identified to family and higher taxonomic classifications. Algal contributions to the database are the smallest. The phylum with the most contributions were Cnidaria followed by Porifera and Echinodermata (Figure 4). Majority of the contributions came from depth zones shallower than 200 m. To date, the database comprises contributions from 11 underwater visual survey projects mainly using remotely operated vehicle (Figure 3), additional towed camera survey project contributions from the shelf edge and slope of South Africa are in progress.

A total of 3134 manually cropped images currently constitute the reference image collection. Of these, 1623 images come from remotely operated vehicle surveys whereas other camera platforms make up the remaining 1309 images. Computer vision was also used to facilitate and semi-automate cropped image extraction with more than 100000 additional cropped images extracted to date.

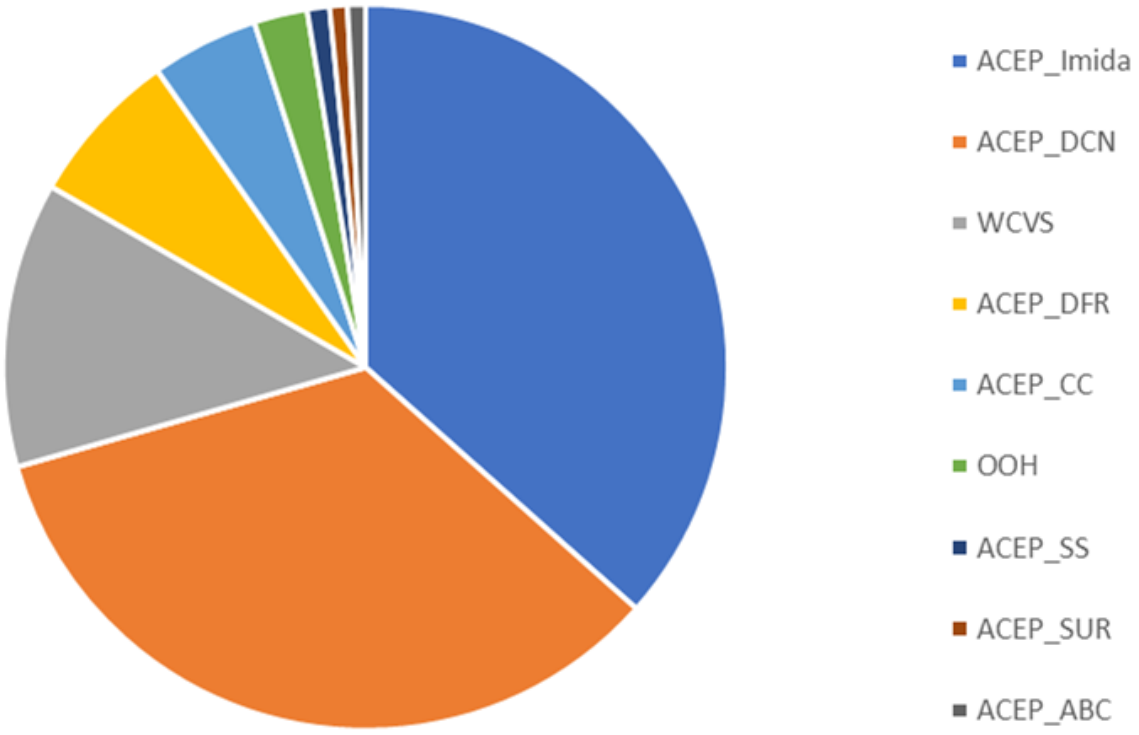


Figure 3. Proportions of Operational Taxonomic Unit (OUT) contributions per major contributing project in South Africa. OTUs collected after June 2024 are excluded from this figure. WCVS is a towed camera survey and all other surveys used the remotely operated vehicle.

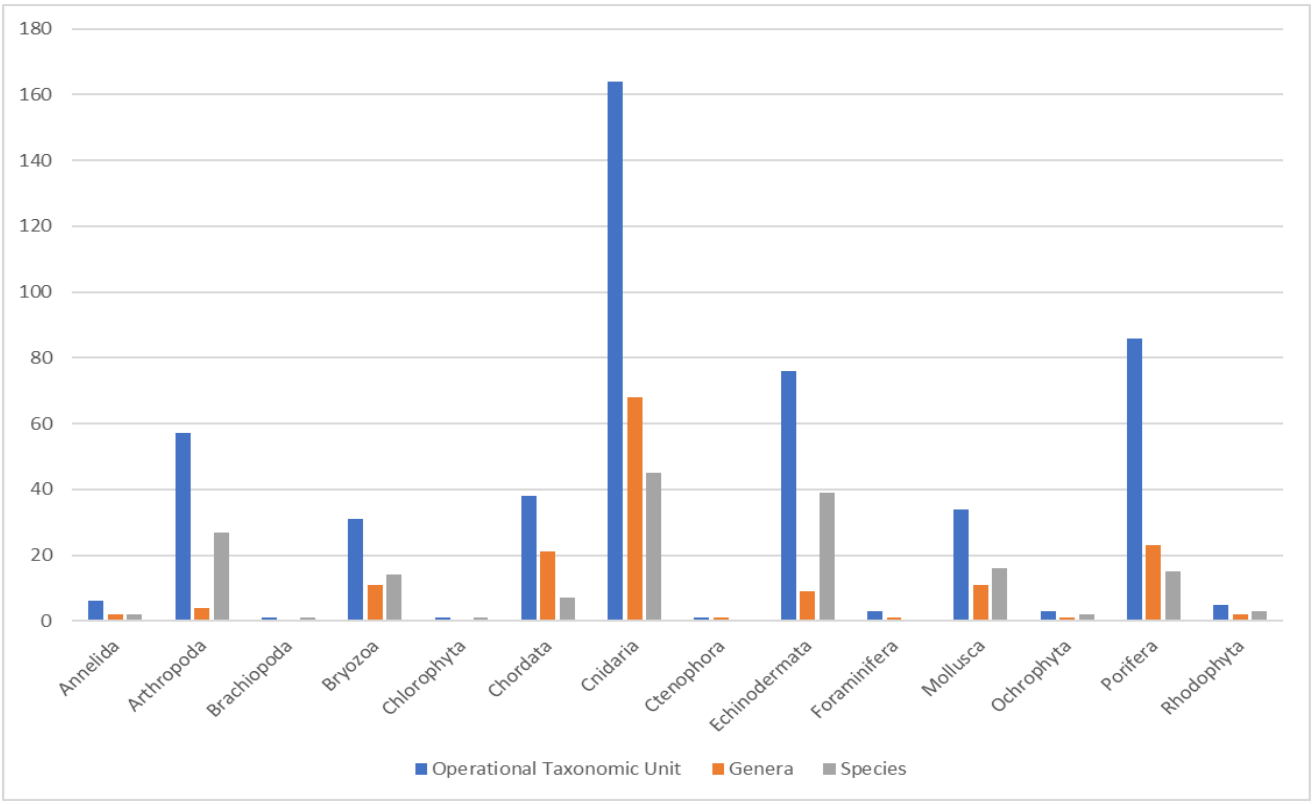


Figure 4. The number of operational taxonomic unit contributions per phyla according to morphotaxa, genera and species from remotely operated vehicle and towed camera surveys.

Application of reference collection

The reference image collection has supported the extraction of **species occurrence records** and catalysed the development of **computer vision object detection models**. The initiation of the development of object detection models is facilitating reference image extraction, occurrence record extraction and novel approaches to ecosystem classification work in South Africa (Figure 5a-e). Emerging researcher, Luther Adams, is pursuing a PhD in this area of work where the reference images together with computer vision are being applied in ecosystem classification and mapping efforts.

In terms of species occurrence records, a total of 3607 records covering 231 taxa were delivered to the **SeaMap project** in June 2024 in support of a more data-driven ecosystem map for South Africa. Students Sinothando Shibe and Shakirah Rylands contributed to the reference image collection and will cite the collection in publications in preparation to further support data standardisation and dissemination of this work. In terms of object detection models, these were initiated for habitat forming taxa that are indicators of Vulnerable Marine Ecosystems including *Pheronema* sponges (Franken and Adams; Figure 5a) and seapens (Shibe; Figure 5b). Multi-species models for starfishes (Figure 5c), seafans (Figure 5d) and a model for more than 150 taxa (Figure 5e) were created to explore and pilot a regional scale object detection model for marine invertebrates.

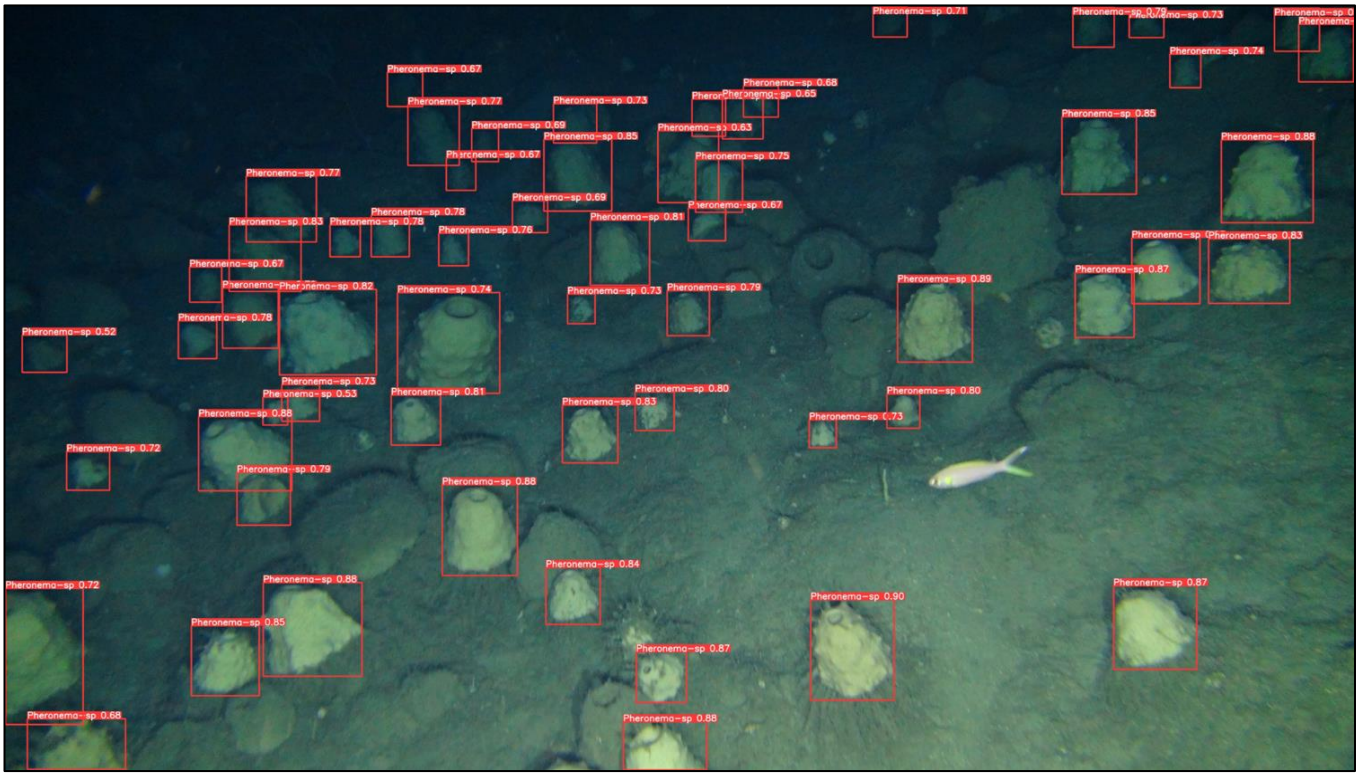


Figure 5a Example of a single class object detection model result of the VME indicator taxon *Pheronema.* Approximately 4000 annotations supported the training of this model.

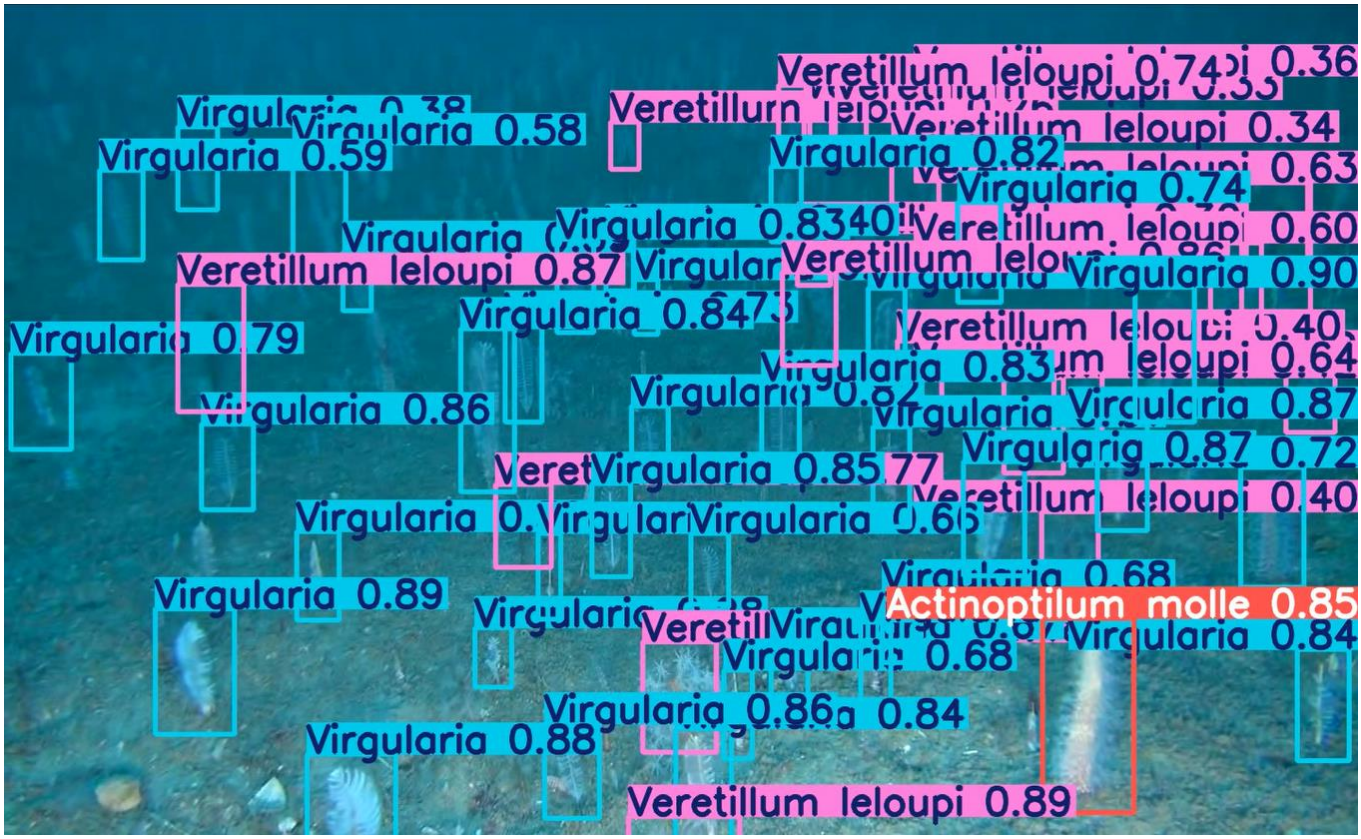


Figure 5b Example of a multispecies object detection model of the VME indicator taxa *Virgularia*, *Actinoptilum* molle and *Veretillum leloupi*.

Figure 5c. Cropped image detections of a single target species showing false positive detections on other starfish species that need to be included in the model to improve detection performance. This work is underway.

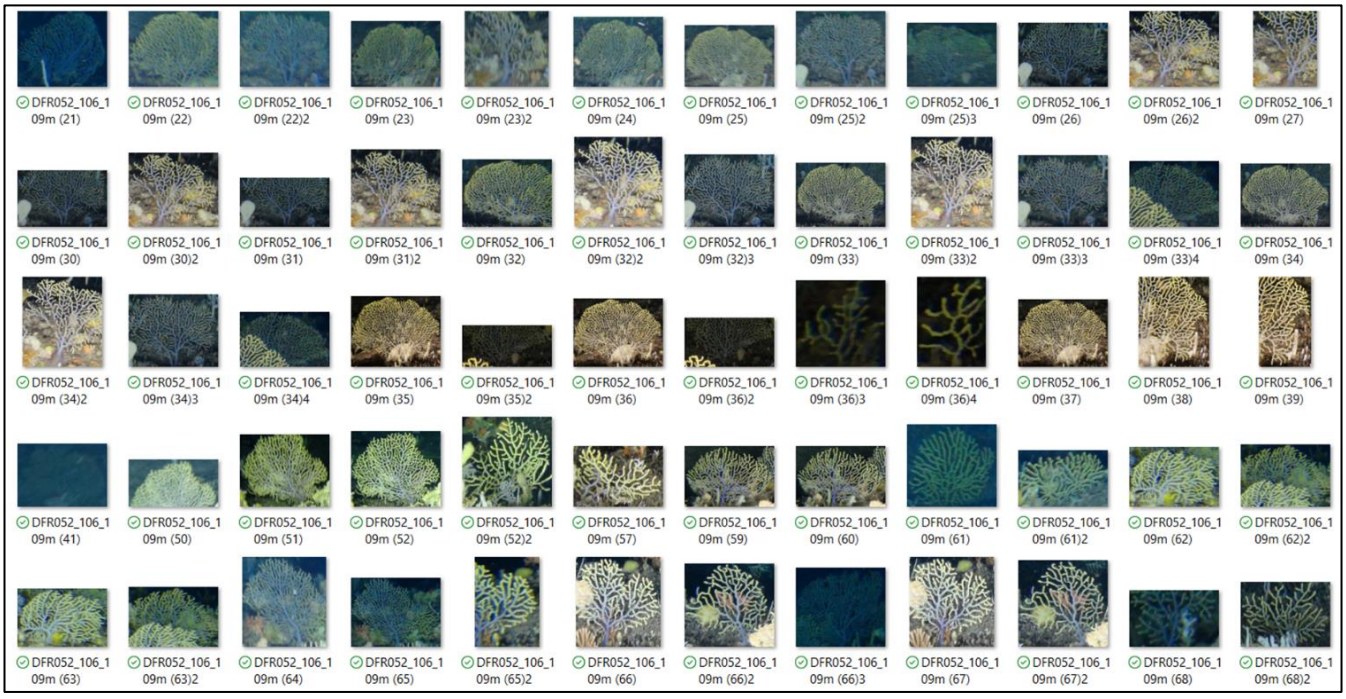


Figure 5d. Cropped image detections of the seafan species *Astromuricia fusca* from a multi-class model of 16 seafan species.

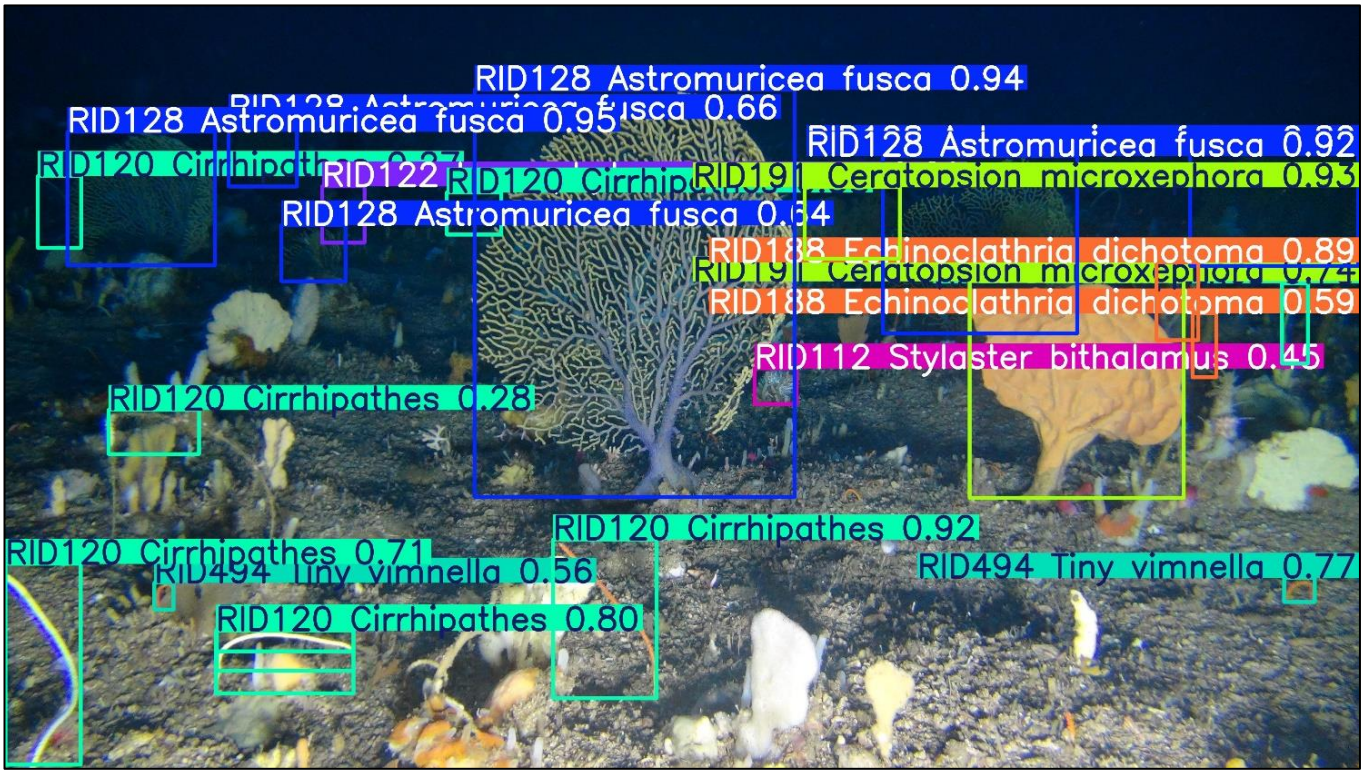


Figure 5e. Example of a multispecies object detection model containing more than 120 taxa from the reference image database were created to explore and pilot a regional scale object detection model for marine invertebrates on the eastern continental margin of South Africa.

Capacity development

South Africa lacks capacity in benthic invertebrate taxonomy and para-taxonomy. The requirement for initiating a regional reference image dataset and the provision of OOH funding were married to create a specific position for an enthusiastic emerging researcher Kholofelo Sethebe. The opportunity fostered **skills development** in the identification of marine invertebrates and fish, together with important data management principles for multiple young researchers, students and interns. Kholofelo Sethebe worked on the project between July 2020 and January 2021, part-time, guided by Jock Currie. Her work on this project came to an end when she gained a position at the Parley Ocean School in Hout Bay. Also guided by Jock Currie, Luther Adams worked on the project between December 2020 to March 2024 and has since pursued a PhD. These early career researchers along with support from more established scientists have made considerable contributions to the database over the past few years (Table 1).

An **instructional/training workshop** was held with Kholofelo Sethebe and five other students and researchers (Sinothando Shibe, Mari-Lise Franken, Luther Adams, Arno Botha, Anthony Bernard) on 17 July 2020 to discuss the Howell et al. (2019) article and the adoption of the methods and data structure proposed in that paper. Discussions covered the approach to cropping reference images, file-naming conventions and adherence to standardised data protocols. The workshop included discussion of the meta-data tables proposed by Howell et al. (2019) and adjustment of some fields to suit the current objectives. Building on the initial workshop, Luther Adams has enhanced the capacity of his fellow emerging researchers and interns including Shakirah Rylands, Sinothando Shibe, Lauren Bull, Natasha Besseling and Mari-Lise Franken. This was done by using the reference image database as a foundation to develop regional computer vision models for benthic invertebrates (see Application). One-on-one training

sessions were held with the emerging researchers to demonstrate the application of the reference image database alongside training the object detection models.

A two day "Introduction to image annotation and computer vision for marine ecology" **training workshop** was held on 7-8th March 2024 and leveraged the reference image collection (Figure 6). It was intended to be a small (<10 person) training workshop to introduce image annotation and computer vision to emerging researchers who process benthic imagery. The training was conducted by Luther Adams. Although a total of 90 participants indicated that they would participate, 32 participants attended. Participants ranged from post-graduate students and researchers to government technicians and scientists. Participants spanned many disciplines in marine science ranging from marine invertebrate taxonomy, benthic ecology, genetics and fisheries science. Day 1 covered image annotation using BIIGLE, setting up projects, managing volumes, creating label trees, the benefits of a reference image collection, an annotation session and exporting data of annotated images. Day 2 built on the annotation efforts of day one and introduced computer vision model development. Code relevant to marine ecologists was downloaded from the GitHub page of the Deep Sea Conservation Research unit University of Plymouth. This accessible and easy to follow code for You Only Look Once (YOLO) v5, along with the comprehensive instructions and explanations, empowered all the participants to follow along the entire computer vision model process. Participants created models for a critically endangered reef fish species and twelve seafan species using the reference image collection. Each day ended off with a two-hour questions and answers session. Some participants of the course have already explored and applied the skills learnt to their own research outside of benthic ecology e.g. fisheries catch monitoring and pelagic zooplankton microscopy.

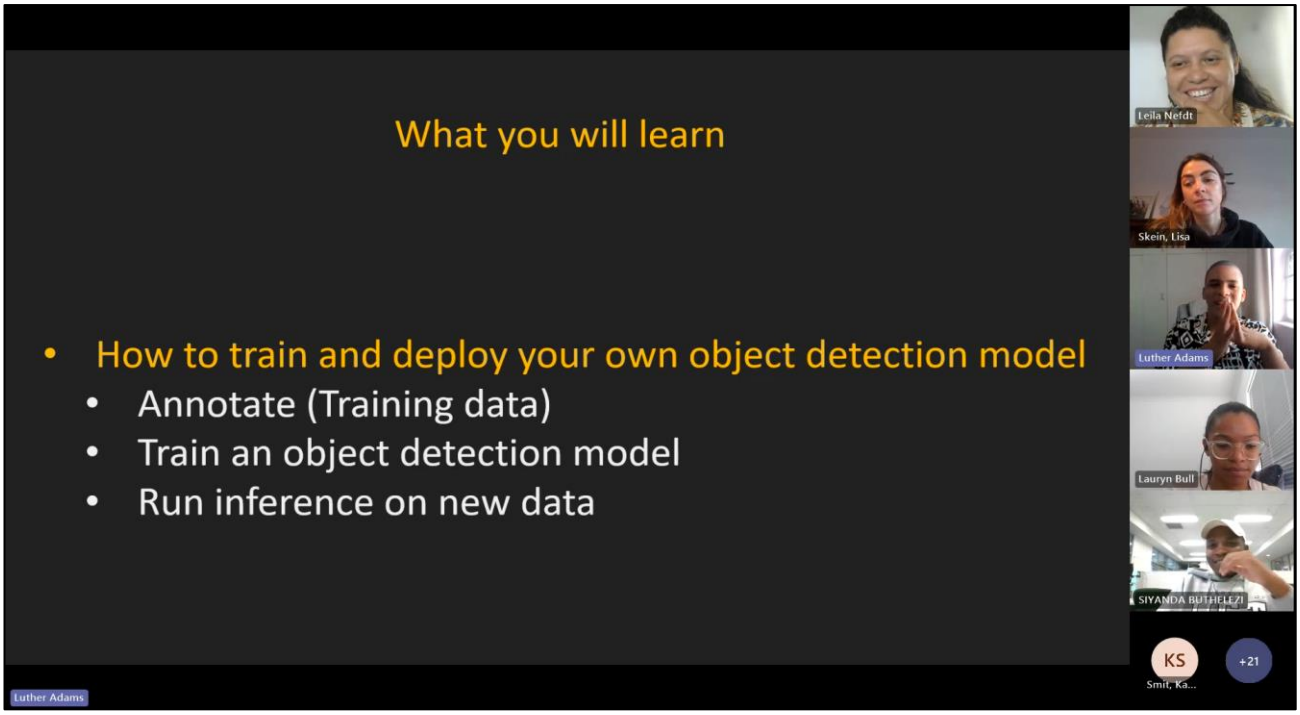


Figure 6. Screenshot from a 2-day fish and invertebrate image annotation and computer vision training workshop with 32 participants ranging from post-graduate students and researchers to field technicians and government scientists.

Lessons learnt, recommendations and next steps

The main challenge of this work was the steep learning curve associated with **para-taxonomic skills** required to identify diverse fauna from images and video. In the context of Covid-19 restrictions and limited connectivity resources in the 'working-from-home' environment, interactions with and assistance from expert taxonomists or para-taxonomists was a significant limitation in the first phase of this work. This was also the case for emerging researchers working from other provinces (e.g., Sinothando Shibe based in KwaZulu-Natal). Ideally, contributors would have been accommodated in a research group or lab where they would have far greater access to researchers and students working on the relevant biota and where computer and internet resources would not add additional challenges.

This effort represents the initiation of a large and long-term regional effort that will require **coordination among research groups and institutions** across country borders. We are aware of approximately 700 visual survey stations (not including historical JAGO footage) conducted in South Africa in recent decades, representing many hours of video and thousands of images yet to be added to this collection. Researchers and students have frequently created their own ad-hoc reference image sets and where possible, these are being integrated into this regional reference image dataset, with a standardised structure. Clearly there is opportunity to greatly increase and improve on this initial effort, but doing so will require resources to support those efforts. It is recommended that organisations should initially build on existing image catalogues or informal species guides (e.g., images in folders) and use the SMarTaR-ID framework to develop a database to better catalogue and manage the images. Regional coordination between different organisations may fast-track the development of the database. The improved standardisation will improve future data integration exercises.

The growth and long-term efficacy of this standardised reference image dataset hinges on its **dissemination and adoption** among researchers in the region. It is critical, therefore, to share it widely and convince researchers working with underwater imagery to contribute past or future efforts at creating their own reference images to the dataset.

Students or emerging researchers working on this problem in future would greatly benefit from any (formal or informal) **para-taxonomy training** opportunities that could be made available to them. As it develops, the reference image dataset itself could be used to produce such training material.

Persons working on these reference image collections should have access to **cloud storage services** and appropriate data bandwidth so that the image collections are easily stored and shared online, thereby facilitating easier access to taxonomic assistance. This was especially critical in the context of lockdown conditions as were associated with the Covid-19 pandemic.

Targeted collections of commonly observed but unidentified taxa or potential new species should be facilitated and **barcoded** to further strengthen and integrate foundational biodiversity datasets. ROVs can be used to accomplish such collections with reference images taken prior to collections. This will improve the resolution of operational taxonomic units within the database.

Next steps

The proposed next step to advance this work is to leverage funding for long-term human capacity. This can ensure momentum can be maintained, taxonomic validation can be conducted, critical training can be conducted to support broader input and application, and the reference images can be made publicly available. Such investment could contribute to job creation for young scientists, a national priority for South Africa.

Acknowledgements

Funding to support this work is gratefully acknowledged from the One Ocean Hub, an independent programme for collaborative research for development, funded by UK Research and Innovation through the Global Challenges Research Fund. (UKRI GCRF Grant NE/S008950/1).

Jock Currie was also supported by a Claude Leon Foundation Postdoctoral Fellowship during part of this work and hosted by SANBI. Luther was funded by Mission Atlantic Grant No. 862428 for 16 months and by the FBIP SeaMap Project for 3 months where he supported the progress of the reference image database NRF Grant number 138572. Mission Atlantic also provided support to Rylands and Shibe in the last month of data collation and reporting. Luther Adams acknowledges Lauryn Bull and Natasha Besseling for support in generating occurrence records.

The ACEP/ SAIAB marine platforms are acknowledged for facilitating much of this work and the many ACEP projects as listed above. We thank SANBI and SAEON for their contributions over the long term and the many research teams, vessel captains and crew who have facilitated surveys.

References

Currie J, van der Heever G, Franken M-L, Nefdt L, Bernard A, Sink K, Atkinson L (2019) Cruise Report: Voyage 185 of the Ellen Khuzwayo, West Coast Visual Survey.

Holstein J (2018) worms: Retrieving Aphia Information from World Register of Marine Species.

Howell KL, Davies JS, Allcock AL, Braga-Henriques A, Buhl-Mortensen P, Carreiro-Silva M, Dominguez-Carrió C, Durden JM, Foster NL, Game CA, Hitchin B, Horton T, Hosking B, Jones DOB, Mah C, Marchais CL, Menot L, Morato T, Pearman TRR, Piechaud N, Ross RE, Ruhl HA, Saeedi H, Stefanoudis PV, Taranto GH, Thompson MB, Taylor JR, Tyler P, Vad J, Victorero L, Vieira RP, Woodall LC, Xavier JR, Wagner D (2019) A framework for the development of a global standardised marine taxon reference image database (SMarTaR-ID) to support image-based analyses. PLOS ONE 14:e0218904. doi: 10.1371/journal.pone.0218904

Sink KJ, Atkinson LJ, Kerwath, S and Samaai, T. 2010. Assessment of offshore benthic biodiversity on the Agulhas Bank and the potential role of petroleum infrastructure in offshore spatial management. Report prepared for WWF South Africa and PetroSA through a SANBI initiative pp. 78

Sink KJ, van der Bank MG, Majiedt PA, Harris LR, Atkinson LJ, Kirkman SP, Karenyi N (eds). 2019. South African National Biodiversity Assessment 2018 Technical Report Volume 4: Marine Realm. South African National Biodiversity Institute, Pretoria. South Africa.

Appendix 1

Table 1 Metadata for the **taxon table** which contains columns that describe the taxonomic unit, including its lowest possible phylogenetic classification and associated 'LSID' number from the World Register of Marine Species.

Field name	**Field required**	**Instruction for field use**	**Darwin Core Class**	**Comments**
Number	required	GUID (primary key to be assigned by database manager)	n/a	simply sequence 1, 2, 3, ...; can be altered/updated later; must be unique to each row.
OTU	required	Operational taxonomic unit number—number assigned to that taxa—no order needed, simply used as a reference number for the taxon.	n/a	use 'OTU' and a sequence number; may be updated when different projects are combined; NB that this number is unique for each line in the taxon table and matches exactly the OTU field in the image_table!
ScientificName	required	scientificName should contain the name of the lowest possible taxon rank that refers to the most accurate identification. E.g. if the specimen was accurately identified down to family level, but not lower, then the scientificName should contain the name of the family. This field should always contain the originally recorded scientific	Taxon	NB to copy spelling from WORMS - make sure it exists there in that exact spelling and at the same time you copy the AphiaID needed in the next field.

Field name	Field required	Instruction for field use	Darwin Core Class	Comments
		name, even if the name is currently a synomym. This is necessary to be able to track back records to the original dataset. **Do not add sp, spp, cf or any other extras.**		
ScientificNameID	required	The WoRMS LSID for the corresponding scientificName	Taxon	look up in WORMS, linked to scientificName field above; called 'AphiaID' in WORMS; for now don't bother with the entire LSID, which is something like 'urn:lsid:marinespecies.org:taxname:' and the aphiaID number
ScientificNameAuthorship	autopopulate from WoRMS	Taxonomic authority for the corresponding scientificName	Taxon	Leave blank - autopopulated later from WORMS
TaxonRank	autopopulate from WoRMS	Level of taxonomic hierarchy given in scientificName, e.g. “family”	Taxon	Leave blank - autopopulated later from WORMS

Field name	Field required	Instruction for field use	Darwin Core Class	Comments
Morphospecies	required	Allows the extra detail distinguishing between different morphs e.g. msp1, msp2, msp3, or in the case of sponges: encrusting, vase, fig, sponge, massive globose etc.	Identification	Maps onto identificationQualifier in Darwin Core; keep concise but descriptive if possible. Not something like 'orange spotted sponge' because 'Porifera' or lower classification will already be included in scientificName, so it could be 'orange spots', which will then become 'Porifera orange spots'. Best to use typical morphometric identifying characteristics where possible and colour may not be a robust characteristic in many cases.
CombinedNameID	autopopulate	scientificName + Morphospecies	Taxon	Maps onto TaxonConceptID in Darwin Core; created with spreadsheet equation =CONCATENATE(C5," ",G5), where C5 and G5 are 'scientificName' and 'Morphospecies' columns respectively
PreviousName	optional	This field is intended to capture previous CombinedNameID. A list (concatenated and separated) of previous assignments of names to the Organism. The recommended best practice is to separate the values with a vertical bar (' | ').	n/a	only if the name (or identification) of a taxon is updated, until then leave empty

Field name	Field required	Instruction for field use	Darwin Core Class	Comments
IdentificationFeatures	optional	Free text remarks on why the taxon is what it is.	Taxon	Typical visual identifying characteristics for the taxon, usually taken from a field guide or reference book. Maps onto TaxonRemarks in Darwin Core
IconicImage	optional	The best example of image(s) of this OTU. If more than one, separate with vertical bar (' | ').	n/a	This can be filled in time, when you come across especially nice example images of the animal. Typically it will always be one of your reference images, so simply use the same filename here as you do for that image in the image_table. If it is an external image for some reason, then I suggest include in the name the 'path/to/filename.jpg' and add an explanation to the comment field
ExSituImage	optional	Example image of the organism outside of its natural habitat e.g. trawl, dredge, microscope image.	n/a	
Comments	optional	Comments on any aspect of this taxon record	n/a	To note any peculiarities relating to any of the fields; Can also be used for temporary comments or queries that require checking/feedback.

Field name	Field required	Instruction for field use	Darwin Core Class	Comments
IdentificationReferences	optional	Reference of book, guide, paper or thesis used to identify organism	n/a	

Table 2 Metadata for the **image table** which contains columns captures information relevant to individual reference images of each operational taxonomic unit.

Field name	Field required	Instructions for field use	DarwinCoreClass	Field name in Darwin Core if different	Comment
Number	required	GUID (to be assigned by database manager)	n/a		simply sequence 1, 2, 3, ...; can be altered/updated later, as long as unique to each row.
OTU	required	Operational taxonomic unit number	n/a		must match exactly to OTU number used in the taxon table. This is how the two tables are linked! Avoid any leading or trailing whitespaces
InsituImageName	required	Name of in-situ Image including file extension. If more than one image the recommended best	Occurrence	associatedMedia	Suggested format is to create project_date_station_originalImageName.ext filename? NB to only include multiple images here if they are of the same individual animal!

Field name	Field required	Instructions for field use	DarwinCoreClass	Field name in Darwin Core if different	Comment
		practice is to separate the values with a vertical bar (' | ').			(and if they are useful to include, i.e. different angles, zoom or animal posture).
ExsituImageName	Optional	Name of ex-situ Image including file extension. If more than one image the recommended best practice is to separate the values with a vertical bar (' | ').	Occurrence		Similar to InsituImageName but used only for lab or on-deck pictures of the same animal if it was sampled after the in situ images were taken. Most of the times this will be left blank.
PhysicalSample	required	This is a Yes/No field.	n/a		Was the animal (from InsituImageName) sampled? Yes/No; Potentially could map to 'basis of record' field.
ImageCredits	required	The credit for the image, how it should read in a display.	Occurrence	associatedReferences	e.g. 'Lara Atkinson' or 'ACEP Deep Forests' or 'SAEON'? Needs to be ascertained from the data/imagery owner.
IdentifiedBy	required	Who provided the identification.	Identification		Name of person who identified; keep standard format, e.g. 'Lara Atkinson' throughout, not switching between 'Dr Atkinson', 'L Atkinson', 'Lara' etc.

Field name	Field required	Instructions for field use	DarwinCoreClass	Field name in Darwin Core if different	Comment
DateIdentified		Use the ISO 8601:2004(E) standard for date and time e.g. 1973-02-28T15:25:00	Identification		
IdentificationRemarks	Optional	Free text notes field	Identification		Identifying or peculiar characteristics relevant to the image (if any). No need to fill if nothing special to add.
IdentificationVerificationStatus	required	Score of the quality of the identification. 1 = identified from image only, 2 = identified from image and physical specimens sampled from the same region, 3 = identified from image and that specific physical specimen.	Identification		Will be '1' most of time, but when reviewing images with the experts, ask whether any physical samples collected from the region, as it may be '2' sometimes (and very rarely '3', though such images would be most valuable to add when they are available!).

Field name	Field required	Instructions for field use	DarwinCoreClass	Field name in Darwin Core if different	Comment
TypeStatus	Optional	Holotype, syntype, etc	Identification		Can leave empty most of the time, although the holotype/syntype etc is important to taxonomists, so keep the field.
RawImage	required	This is the path and filename of the original image from which the species was cut.	Event	eventID	As this file is not moved with the reference image dataset, include the entire path/to/file.ext; If a screenshot is taken from a video, suggestion is to save the screenshot in a 'screenshot' subfolder with an informative filename that includes the original filename and a timestamp, e.g. 'project_date_station_originalfilename.ext_mm-ss.jpg'
Locality	required	Concise name or description of submarine geological feature or area.	Location		Howell etal suggest using Use established MarineRegions (http://www.marineregions.org/gazetteer.php?p=search), however, this makes only two SA mainland and a third PEI regions: 'South African part of the South Atlantic Ocean' (Agulhas westwards), 'South African part of the Indian Ocean' (Agulhas eastwards) or 'South African

Field name	Field required	Instructions for field use	DarwinCoreClass	Field name in Darwin Core if different	Comment
					(Prince Edward Islands) part of the Indian Ocean', which was considered not very useful in SA context and can easily be added later by GIS. Instead the submarine feature suggested, e.g. Brown's Bank, Cape Canyon, central Agulhas Bank, etc.
LocationID	Optional		Location		MRGID' relating to above 'marine regions', i.e. 25516 (west coast to Agulhas), 25551 (east of Agulhas) or 25546 (Prince Edward Islands) respectively
LocationRemarks	Optional	Free text field for more detailed description of location	Location		eg. 'east of Robben Island', 'southern shelf edge of Agulhas Bank'
DecimalLatitude	Optional	In decimal degrees N	Location		If it is a transect, use start coordinates; keep to decimal degrees and no other units, e.g. '-34.59837'
DecimalLongitude	Optional	In decimal degrees E	Location		If it is a transect, use start coordinates; keep to decimal degrees and no other units, e.g. '24.62474'

Field name	Field required	Instructions for field use	DarwinCoreClass	Field name in Darwin Core if different	Comment
MinimumDepthInMeters	required	Value in meters of the depth the image was taken at. Use positive values. If exact depth known please put same value in both fields	Location		do not include units, only depth in m, e.g. '425'
MaximumDepthInMeters	required		Location		do not include units, only depth in m, e.g. '425'
InstitutionID	required	An identifier for the institution having custody of the object(s) or information referred to in the record.	Record-level		SAEON/SANBI/DEFF/etc? Check with the rights holder of the images
CollectionID	Optional	Identifies the collection or dataset within that institute This could identify a specific catalogue e.g. Howell & Davies 2010.	Record-level		If the images were taken from a specific project or lab or publication that can be cited; otherwise leave empty
BibliographicCitation	Optional	Citation for the original image database e.g. Howell & Davies, 2010.	Record-level		If images taken from someone else's thesis/project database, e.g. Franken 2015

Field name	Field required	Instructions for field use	DarwinCoreClass	Field name in Darwin Core if different	Comment
Modified	autopopulate	The most recent date-time on which the resource was changed. It is required to use the ISO 8601:2004(E) standard, e.g. 2020-02-28T15:25:00	Record-level		In a database one could set this up to autopopulate but in spreadsheets it will have to be manually entered.
Dcterms:license	required	A legal document giving official permission to do something with the resource.	Record-level		path/to/subfolder/containing/licence.pdf to point to document giving permission to use the images from the rightsHolder (owner of original images).
Dcterms:rightsHolder	required	A person or organization owning or managing rights over the original image resource.	Record-level		
Dcterms:accessRights	required	Information about who can access the resource or an indication of its security status. Access Rights may include information regarding access or restrictions	Record-level		Does access to the images come under any terms (I think this refers to the original images, does it also apply to the cropped images? perhaps needs to be specified?); check with rights holder of images.

Field name	Field required	Instructions for field use	DarwinCoreClass	Field name in Darwin Core if different	Comment
		based on privacy, security, or other policies.			
PreviousIdentifications	Optional	This field is intended to capture changes in opinion on the OTU number of the animal in the image. A list (concatenated and separated) of previous assignments of OTU to the organism in the specific image. The recommended best practice is to separate the values with a vertical bar (' | ').	Organism		The "PreviousName" field is not intended to document recombinations of taxonomic nomenclature as this is captured and managed in WoRMS [90]. Rather, this field is to capture changes to the assigned identity of the OTU. For example, where Brisingidae msp1 was later confidently identified to a lower taxonomic level (e.g. Brisinga msp4). This field would capture its former "CombinedNameID". This implies that a record (OTU) in the taxon table should never be deleted or re-purposed, but rather a new taxon record created and then the OTU numbers of relevant image(s) should be updated to point to the new taxon record (and this 'previousIdentifications' record should be updated).
CatalogNumber	Optional	Museum collection catalog number	Occurrence		If the catalog number does not identify it, add the museum to the comments column.

Field name	Field required	Instructions for field use	DarwinCoreClass	Field name in Darwin Core if different	Comment
AssociatedSequences	Optional	For example Genbank ID	Occurrence		If the photographed animal was sampled for DNA sequencing.
Habitat	Optional	Ecosystem type from the NBA	Event		Howell et al suggest 'A category or description of the habitat in which the Event occurred (e.g. seamount, hydrothermal vent, abyssal hill, etc.). Where possible use classes given in Greene et al., 1999. A classification scheme for deep seafloor habitats. Oceanologica acta, 22(6), pp.663-678.', but Kerry/Lara suggest the ecosystem type, which will be added later using the coordinates (in GIS), so no need to fill this.
SubstrateType	Optional	Concise & standardised description of substrate type(s) seen in the image using the CATAMI substrate classifications.	n/a		Howell etal suggest 'There is no consensus on the way in which substrate is interpreted from image data. Some use EUNIS, others use modified Folk classification or % of Wentworth classes. It is recommended to use the Wentworth scale, if more than one category is used, recommended best practice is to separate the classes and their respective % with a vertical bar (’|’)'

Field name	Field required	Instructions for field use	DarwinCoreClass	Field name in Darwin Core if different	Comment
Size	Optional	Approximate size of animal in cm	n/a		only the number, no units (but based in cm); only try to add a size if you have laser dots or something else to inform scale
SubstrateMethod	Optional	e.g. CATAMI, Folk, Wenthworth, EUNIS, Other.	n/a		
ProjectName	Optional	e.g. DeepLinks, CoralFish, SponGES	n/a		DeepForests, SeaKeys, etc.
LinkExternalDatabase	Optional	For example link to another non merged online species guide	n/a		
Comments	Optional	Any image-specific comments to add that help explain decisions or data.	n/a		This can also be used to flag queries, but they should be deleted once resolved.