Innovations in marine biodiversity monitoring using small unmanned underwater vehicles: ROVs & AUVs

E.M. Kingma, M. Sokolova, G. Dogruer & O.G. Bos

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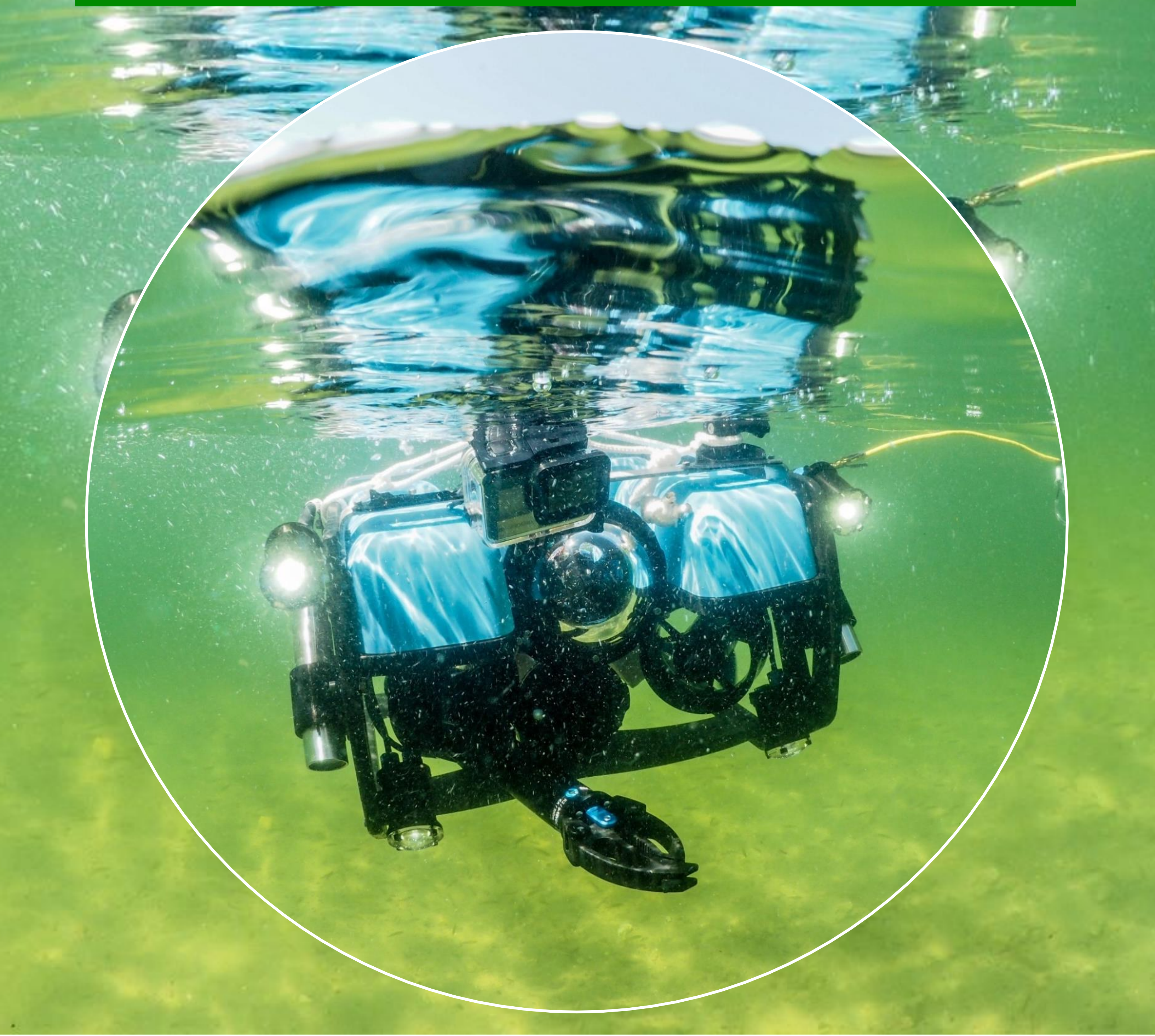

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Content

Summary

Monitoring is an essential component within the field of marine ecological research to help understand and manage marine ecosystems. The rapid developments in offshore wind energy and infrastructure, marine aquaculture, and nature conservation and restoration efforts, has driven a growing demand for marine ecology data to evaluate their impact and/or effectiveness. Traditional monitoring methods include for instance diver inspection, ship-based side-scan sonar and multibeam or use of industrial (work-class) Remotely Operated Vehicles (ROVs). These methods work well, but are often very costly.

Rapid advancements in small handheld Unmanned Underwater Vehicles (UUVs), along with innovations in sensor and remote grab technologies, have the potential to create new marine monitoring possibilities. UUVs, often described as mobile platforms, come in various forms. This report focuses on inspection-class ROVs and smaller Autonomous Underwater Vehicles (AUVs). Gliders and Extra Large Unmanned Underwater Vehicles (XLUUVs) are not included in the scope of this report, as their operation requires more specialized resources and infrastructure.
Compared to work-class ROVs and larger AUVs, these smaller vehicles are lighter, easier to operate, and typically do not require launch systems. They also do not need large specialized vessels making deployment more flexible while reducing operational and monitoring costs. Equipped with add-ons such as robotic arms and diverse sensor types, these platforms can offer accessible and cost-effective monitoring solutions, even in challenging environments. Despite their potential, the full range of applications for these platforms remains largely unexplored in marine research. Therefore, this report examines available technologies, sensors, and UUVs, alongside case studies, user perspectives, and operational challenges to support the development of effective monitoring frameworks. Furthermore, the report includes a brief introduction to Artificial Intelligence (AI), specifically Computer Vision (CV) techniques, to illustrate how optical (video, photo, sonar, etc.) imagery from UUVs can be analysed.

The goal of this project is to provide an up-to-date overview of innovative tools available for habitat mapping and biodiversity monitoring using:

- Handheld UUVs: inspection-class ROVs and small AUVs
- Sensors and acoustic techniques that can be mounted on mobile platforms
- Artificial Intelligence: Computer Vision

A general overview of inspection-class ROVs and small AUVs is provided in this report. We do not attempt to compare the various models of ROVs and AUVs, since many can do similar tasks and can be customised by adding add-ons such as sensors (e.g., cameras and sonar) or robot-arms. Therefore this report includes a chapter on add-ons with links to technical specifications on the manufacturers websites. Furthermore, since a lot of monitoring requires some form of data processing using AI, a small overview is given of the various options for image analysis.

The practical use of ROVs and AUVs for ecological monitoring is demonstrated by a step-by-step approach presented in different user cases about monitoring biogenic and geogenic reefs in the North Sea, coral reefs in the Caribbean, artificial reefs and Nature Inclusive Designs (NIDs), and aquaculture. The annexes provide technical specifications of small ROVs and AUVs.

1 Introduction

1.1 Need for an overview of innovative monitoring methods

In recent years, marine ecological monitoring has advanced significantly due to developments in fields such as Artificial Intelligence (AI) and Computer Vision (CV), remote sensing, and autonomous technologies. These innovations have made previously costly or complex monitoring methods more accessible and efficient, opening up new research opportunities (de Lima et al., 2020). In this report we will elaborate on the use of small Unmanned Underwater Vehicles (UUVs) equipped with sensors, sampling equipment, and imaging devices as a tool for marine ecological monitoring.

UUVs can be classified into various categories. This report specifically focuses on inspection-class Remotely Operated Vehicles (ROVs) and small Autonomous Underwater Vehicles (AUVs) (Figure 1). Other types, such as gliders and Extra Large Unmanned Underwater Vehicles (XLUUVs), are not included due to their specialized operational requirements. AUVs are fully autonomous and can carry out pre-programmed missions without human intervention, making them ideal for long-duration surveys and large-scale environmental monitoring. In contrast, ROVs are tethered systems controlled in real-time by operators, allowing for direct intervention, detailed inspections, and sampling. The choice between these systems depends on the specific monitoring objectives, environmental conditions, and logistical constraints of the research project.

Figure 1. *Example small model AUV: Seaber Yuco*[1] *(left), and inspection-class ROV: exail R7*[2] *(right).*

The demand for innovative and cost-effective habitat and biodiversity monitoring in the Dutch North Sea and the Dutch Caribbean is increasing. This is largely driven by the rapid expansion of the offshore wind sector, which requires for instance monitoring of hard substrate benthic communities on wind turbines, scour protection, cable crossings, and Nature Inclusive Design (NID) elements. Additionally, the development in offshore aquaculture (often integrated within offshore wind farms), such as mussel and seaweed farming, requires monitoring of both aquaculture production and its impact on biodiversity. Moreover, the increasing focus on nature conservation and restoration has further increased the need for monitoring reef habitats.

Traditional seabed mapping techniques, such as side-scan sonar and multibeam surveys, remain important instruments in habitat mapping. Similarly, large work-class ROVs, which have long been used in the oil and gas sector, are now also deployed for offshore wind infrastructure inspections. However, these large systems require specialized operators, costly vessels, and extensive logistical support, making them less suitable for smaller scale ecological monitoring efforts.
Within academic research, ROVs and AUVs have been used for some time. A European infrastructure[3] has been established to facilitate knowledge sharing on these platforms, and new systems are being

[1] https://seaber.fr/
[2] https://www.exail.com/product/r7-remotely-operated-vehicle
[3] https://aquarius-ri.eu/research-infrastructures-catalogue/

developed by institutions such as the Dutch NIOZ[4] and the Belgium VLIZ[5]. However, most of these systems remain large, expensive, and primarily used in large-scale projects. For smaller ecological studies with limited budgets, the use of work-class and academic ROVs and AUVs are often not an option. Recent advancements however, have led to the development of more affordable handheld UUVs, creating new opportunities for marine researchers. The market for these smaller mobile platforms is growing fast, offering various configurations with sensors and add-ons such as cameras, loggers, and grabbers.

Despite these advancements, many marine ecologists remain unaware of the capabilities and availability of handheld UUVs for research. To address this gap, this report provides an overview of commercially available inspection-class ROVs and small AUVs and how they can be used for monitoring. Additionally, it introduces how Artificial Intelligence (AI), particularly Computer Vision (CV), can be used in tasks such as habitat classification and species identification from imagery data obtained by these mobile platforms. The report focuses on momentary monitoring techniques and does not include permanently deployed systems such as eco-buoys, loggers, or long-term sensor arrays.

To support ecological research applications, a structured step-by-step approach is outlined and demonstrated through five case studies covering different ecosystems in the Dutch North Sea and Dutch Caribbean: biogenic reefs and sandy seafloors, coral reefs, geogenic reefs, artificial reefs and NIDs, and aquaculture. Finally, the annexes provide an overview of inspection-class ROVs and small AUVs to help researchers in selecting suitable platforms for their work.

1.2 Goals

The goal of this project is to deliver a current overview of innovative tools for marine ecological monitoring, focusing on habitat mapping and biodiversity assessment. Using:

- Handheld UUVs: inspection-class ROVs and small AUVs
- Sensors and acoustic techniques that can be mounted on mobile platforms
- Artificial Intelligence: Computer Vision

1.3 Research questions

- Which handheld UUVs are currently available on the market and can be deployed for marine ecological research?
- What are the experiences of marine ecologists in using UUVs?
- How can AI (CV) be used to analyse imagery data acquired using UUVs?
- How can UUVs (and CV) be used in typical ecological research user cases?

[4] https://www.nioz.nl/en/news/new-innovative-equipment-for-national-marine-research
[5] https://www.vliz.be/en/what-we-do/infrastructure-supply/robotics

1.4 Terminology

Term	Meaning
AI	*Artificial Intelligence*
ASVs	*Autonomous Surface Vehicles*
AUV	*Autonomous Underwater Vehicles*
CV	*Computer Vision*
ML	*Machine Learning*
MBES	*Multibeam Echosounder*
LARS	*Launch And Recovery System*
MGST	*Marine Growth Sampling Tool*
NID	*Nature-Inclusive Design*
ROV	*Remotely Operated Vehicle*
SSS	*Side-Scan Sonar*
UUV	*Unmanned Underwater Vehicle*

1.5 Delimitations

- This report provides an overview of handheld UUVs, add-ons and AI tools, but does not aim to be complete.
- The overview of ROVs and AUVs provided in this report is limited to inspection-class ROVs and small AUVs that are commercially available. Larger industrial ROVs and AUVs, as well as AUVs and ROVs developed by scientific institutes such as the Belgian VLIZ or Dutch NIOZ are not taken into account.
- The use of AI for data analysis are mostly based on the experiences obtained in recent projects of Wageningen Marine Research.
- The user case studies are based on projects executed by Wageningen Marine Research and partners.

2 Methodology

The research objectives, data requirements, and monitoring environment during a project determine the setup of a suitable mobile platform and configuration in monitoring surveys. To help researchers in selecting an appropriate platform configuration, this report presents a step-by-step approach for developing a monitoring program.

2.1 Step-by-step approach for new monitoring projects

To guide the reader in setting-up monitoring using handheld UUVs, we have provided a step-by-step approach (Box 1 & Figure 2).

Box 1: Step-by-step approach for setting up a monitoring project using inspection-class ROVs or small AUVs

1. **Prepare a project outline:**

During the preparation phase, describing the monitoring objective and outlining the project is important. Although this report does not cover this step in detail, it should address key factors that influence the monitoring process, including:

- What needs to be monitored and why
- Monitoring location
- Environmental conditions
- Timing of monitoring
- Monitoring period
- Etc.

2. **Determine the parameters to be monitored**

Next, the parameters to be monitored need to be determined (*Chapter 3*).

3. **Select a mobile platform (ROV, AUV)**

Depending on these parameters, as well as the monitoring location and the timing of monitoring, different ROVs or AUVs may be suitable or not for the monitoring campaign (*Chapter 4*).

4. **Select add-ons:**

Next, additional tools or sensors for the mobile platforms for specific monitoring tasks need to be selected (*Chapter 5*). Frequently, selecting the add-ons also happens before choosing the mobile platform (previous step). This is often determined by the objective of the study.

5. **Processing data:**

Collected data requires further processing using for instance AI and CV systems (*Chapter 6*).

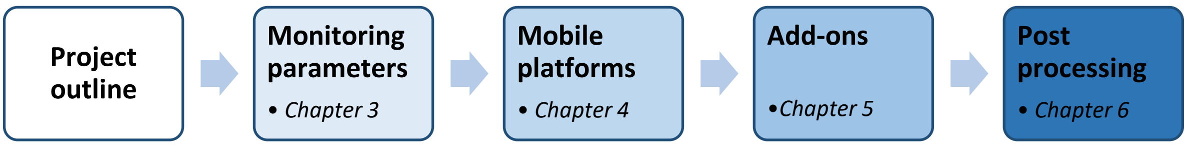


Figure 2. *Step-by-step monitoring approach.*

We have included several user cases (e.g., monitoring biogenic reefs and NIDs) that serve as examples to illustrate this step-by-step process (*Chapter 7*).

2.2 Data sources

To compile an overview of handheld UUVs and explore available acoustic techniques, sensors, and add-ons, a review of manufacturer websites and relevant literature was conducted. In addition, a questionnaire was sent to ROV and AUV manufacturers to gather insights (8 respondents: Annex 1). The questionnaire covered various topics, including the specifications of their deployed ROVs/AUVs, operational presence in Europe, availability for rental or purchase, data output formats, required deployment equipment, and their involvement in marine ecological monitoring. Furthermore, the 2024 Oceanology International Conference[6] in London was attended to gather information on commercially available mobile platforms.

2.3 User cases

To provide insight in the use of ROVs and AUVs in current research of Wageningen Marine Research, we have described a number of user cases for the Dutch North Sea and Dutch Caribbean:

1. Biogenic reefs and sandy seafloors
2. Coral reef biodiversity monitoring
3. Geogenic reefs
4. Artificial hard substrate reefs and NID monitoring
5. Offshore aquaculture monitoring (mussel and seaweed farming)

2.4 User findings and knowledge gaps

A second questionnaire was distributed among end-users within the field of marine biology to assess the current use of UUVs in marine ecological research outside of Wageningen Marine Research (22 respondents: Annex 2). The questionnaire for the end-users included questions on which types of inspection-class ROVs and small AUVs they had experience with and how they contributed to their research, which improvements they would like to see, and which challenges they faced.

Based on all acquired information (user cases, both questionnaires, and literature review), limitations (knowledge gaps) of the current available systems for marine research to a great extend were identified, as well as possible ways to overcome these. This offers insights into the future use of sensors and advancements in mobile platforms for marine ecological monitoring.

[6] https://www.oceanologyinternational.com/london/en-gb.html

3 Monitoring parameters

Once the scope of a research project has been defined, the first step is identifying the parameters that need to be monitored. Commonly targeted parameters in biodiversity monitoring and habitat mapping campaigns are presented in Table 1, along with the corresponding equipment and add-ons that can be used to measure them.

Table 1. *Overview of common monitoring parameters and the sensors/add-ons used to measure them.*

Parameter	Sensor type/Add-on	Chapter
Abiotics and Backgound		
Temperature, Oxygen, Salinity/Conductivity, Depth, Turbidity.	Various sensors	*5.3*
Seabed bathymetry	Multibeam echosounder, side scan sonar	*5.2/5.2.4*
Seabed composition (sediment, habitats)	Samplers, Multibeam echosounder, side scan sonar, (acoustic) camera, laser	*5.1/5.2/5.2.4*
Habitat presence (biotic and abiotic)	Multibeam echosounder, side scan sonar, (acoustic) camera, laser	*5.2/5.2.4*
Nutrients	Samplers, Various sensors	*5.1/5.3*
Environmental DNA	Water samplers	*5.1*
Biodiversity and Ecosystem functioning		
Species diversity (species richness, size distribution, density, biomass)	Camera, water samples via robotic arm	*5.1/5.2*
Presence of exotic species	Camera, environmental DNA (eDNA), sample via robotic arm	*5.1/5.2*
Function for species (shelter, habitat, foraging area, breeding area, nursery grounds)	Multibeam echosounder, side scan sonar, camera	*5.2/5.2.4*
Phytoplankton by means of Chlorophyll A (Chl-A)	Chl-A sensor	*5.3*
Production (aquaculture)		
Volume	Multibeam echosounder, side scan sonar, (acoustic) camera	*5.2/5.2.4*
Biomass	Multibeam echosounder, side scan sonar, (acoustic) camera, sample via robotic arm	*5.1/5.2/5.2.4*

4 Unmanned Underwater Vehicles

Over the past half-century, mobile underwater platforms have evolved through military applications and oil and gas research (Capocci et al., 2017). Recently, commercial companies have used these technologies to develop more affordable underwater vehicles. The UUVs discussed in this report can be categorized into two types: AUVs and ROVs. The ROVs can further classified based on their size and capabilities, ranging from inspection-class models to large work-class systems (Figure 3). Smaller ROVs offer flexibility and lower operational costs. Equipped with high-resolution cameras, advanced sensors, and acoustic devices, these platforms can enable detailed underwater monitoring for ecological surveys, biodiversity monitoring, and reef habitat assessments.

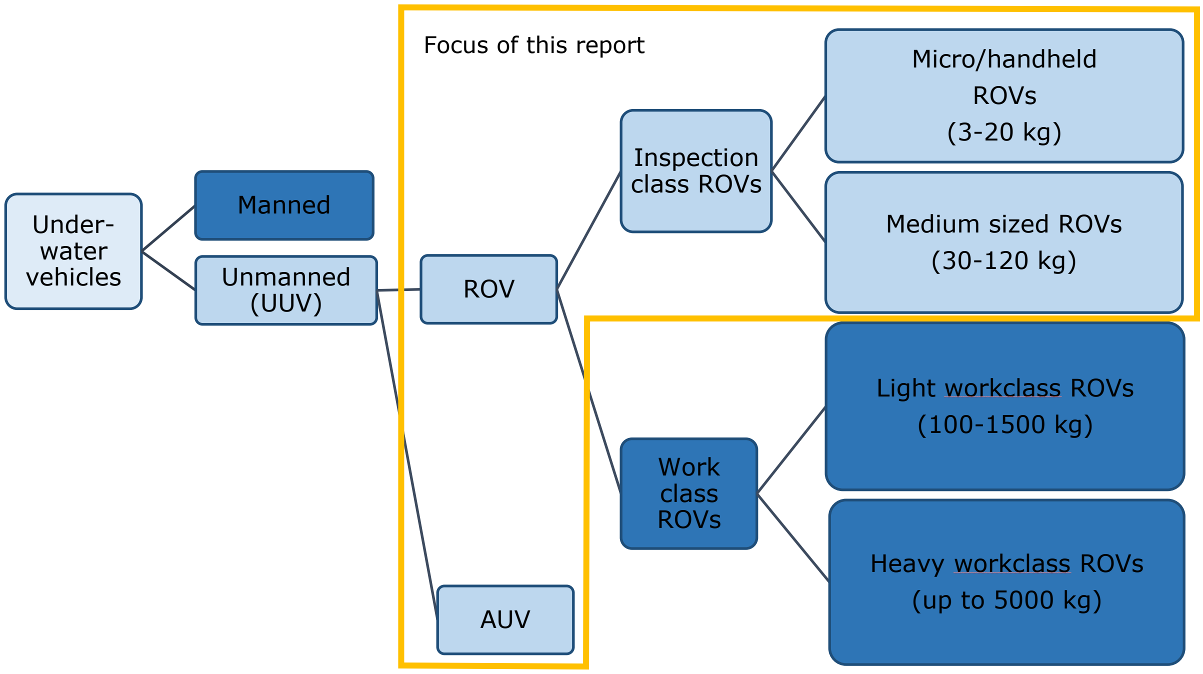


Figure 3. *Classification of underwater vehicles. Lighter blue boxes (orange polygon) is the focus of this research. Figure adapted from Capocci et al., (2017).*

4.1 Work class ROVs

Figure 4. *Compact work class ROV (Saab Seaeye Panther ROV equipped with a 4K resolution SUB-C camera) used for video monitoring of the Dutch North Sea, in a LARS system, onboard the RWS ship ARCA, during the MONS Borkum Reef monitoring in August 2024 (photos: Oscar Bos, WMR).*

Work class ROVs (Figure 4) are robust mobile platforms designed for complex underwater tasks in harsh and deep-sea environments. They are typically divided into light and heavy work-class ROVs (Figure 3). These ROVs are often equipped with powerful manipulators, advanced navigation systems, sonars, and a variety of tools to handle more intricate operations. Light work-class ROVs, weighing between 100 and 500 kg, are used for tasks such as underwater infrastructure inspections and cable and pipeline surveys. They typically operate at depths of up to 3,000 meters. Heavy work-class ROVs, which can weigh over 3,000 kg, are designed for even more demanding tasks in deep waters. They can reach depths of sometimes 6,000 meters (Capocci et al., 2017). These larger ROVs can carry multiple manipulators and are capable of performing heavy-duty tasks such as deep-sea exploration, underwater construction, and industrial repairs, making them important in the offshore industries (oil and gas industries, and deep-sea mining).

Due to their high mass, work-class ROVs require a Launch and Recovery System (LARS) for deployment (Figure 4) and a Tether Management System (TMS) for operation (Capocci et al., 2017). These systems are often large and occupy considerable space on board of a large vessel. Additionally, a highly trained crew is needed to operate these systems. This often results in high operational costs. For marine ecological research applications with a limited budget or in a less challenging environment with respect to current velocity, waves, and water depth, these work-class ROVs may be too expensive and inefficient.

4.2 Inspection class ROVs

Inspection class ROVs can be further categorized into medium sized and handheld/micro sized models (Figure 3). These ROVs are operated through a combination of surface control and advanced technology integrated within the vehicle itself (Figure 5). These systems are more suitable for smaller scale ecological projects with limited budget compared to the larger work-class ROVs. However, this means that there are also more limitations regarding the use.

The operation begins with the deployment of the ROV into the water, tethered by a cable that transmits power, video, and data between the vehicle and the control station on the surface. Operators use a control console, often equipped with joysticks and a display screen, to navigate and manoeuvre the ROV during the surveys. The console allows the operator to control the movement, speed, and direction of the ROV, as well as manipulate any attached tools or robotic arms. Cameras mounted on the ROV provide real-time video feedback, enabling the operator to visually inspect underwater environments. Sonar systems that can be attached on the ROV can assist in navigation and obstacle avoidance.

Figure 5. *Structure and components of a Handheld ROV: BLUEROV2*[7]*.*

[7] https://bluerobotics.com/store/rov/bluerov2/

The navigation of ROVs underwater often relies on a combination of technologies: a key component is the *Ultra-Short Baseline (USBL) system*, which uses acoustics to determine the position of the ROV relative to the surface vessel. The USBL system sends and receives acoustic signals between the vehicle and the vessel, calculating the location of the ROV based on the time it takes for the signals to travel. *Sonar*, another tool, provides real-time imaging and mapping of the underwater environment, helping operators avoid obstacles and navigate complex terrains. Additionally, *Doppler Velocity Log (DVL)* systems are employed to measure the speed of the ROV and direction relative to the seabed or other fixed references by emitting sound waves and analysing their reflections. These technologies, combined with the onboard sensors and cameras of the ROV, enable accurate navigation. Advanced ROVs may also feature automated functions, such as station-keeping, which allow the vehicle to maintain a fixed position autonomously. At the water surface navigation is also supported by Global Positioning System (*GPS)*, however GPS becomes ineffective underwater.

4.2.1 Medium sized inspection ROVs

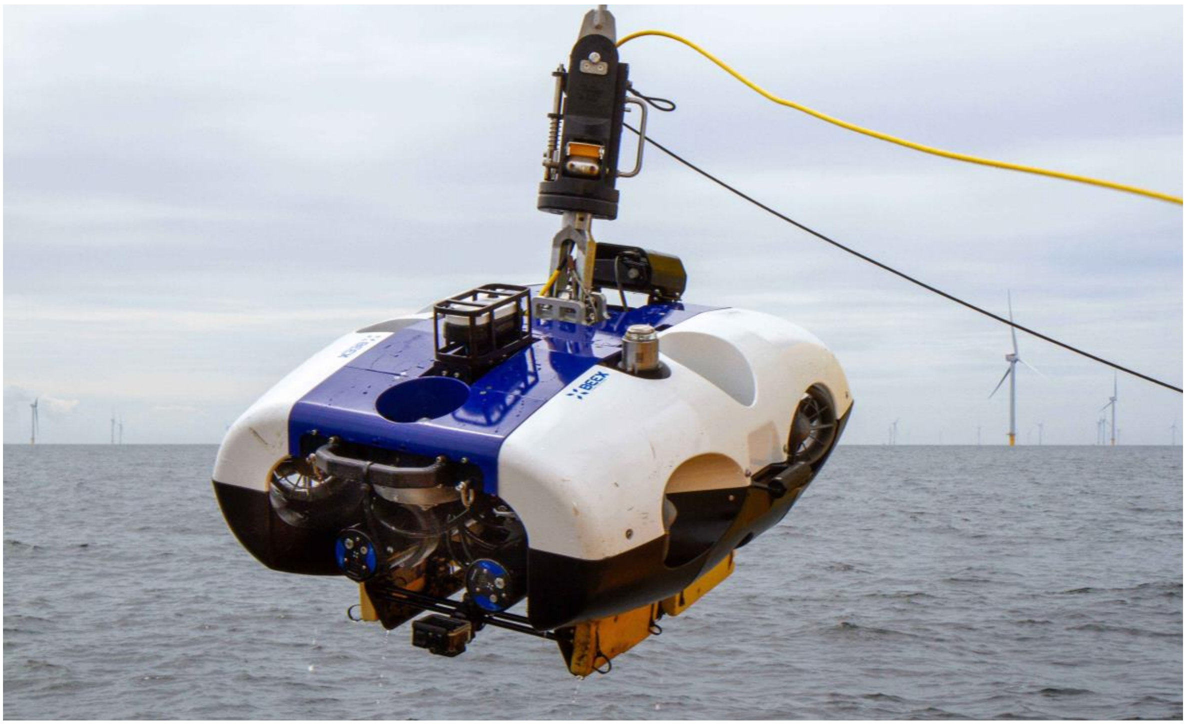


Figure 6. *A.IKANBILIS BEEX in offshore windpark Hollandse Kust Zuid in The Netherlands. The platform can also be used as a hovering AUV. (photo: Oscar Bos, WMR).*

Medium sized inspection ROVs (Figure 6 & Annex 3) typically can be deployed and recovered without additional equipment, although larger vehicles in this category may still require a LARS for operations. Medium-sized inspection ROVs are commonly designed as open-frame models, this makes the addition of extra sensors and small tool skids possible. They are usually powered by a DC supply, with voltages reaching up to 600 VDC and power requirements of up to 6 kW (Capocci et al., 2017). Some models in this category can have high thrust capabilities, enabling them to navigate effectively in challenging conditions despite their larger volume and drag. Beyond inspections, some of these vehicles are capable of performing minor tooling tasks such as cleaning, latching, or recovering objects.

4.2.2 Handheld (micro) ROVs

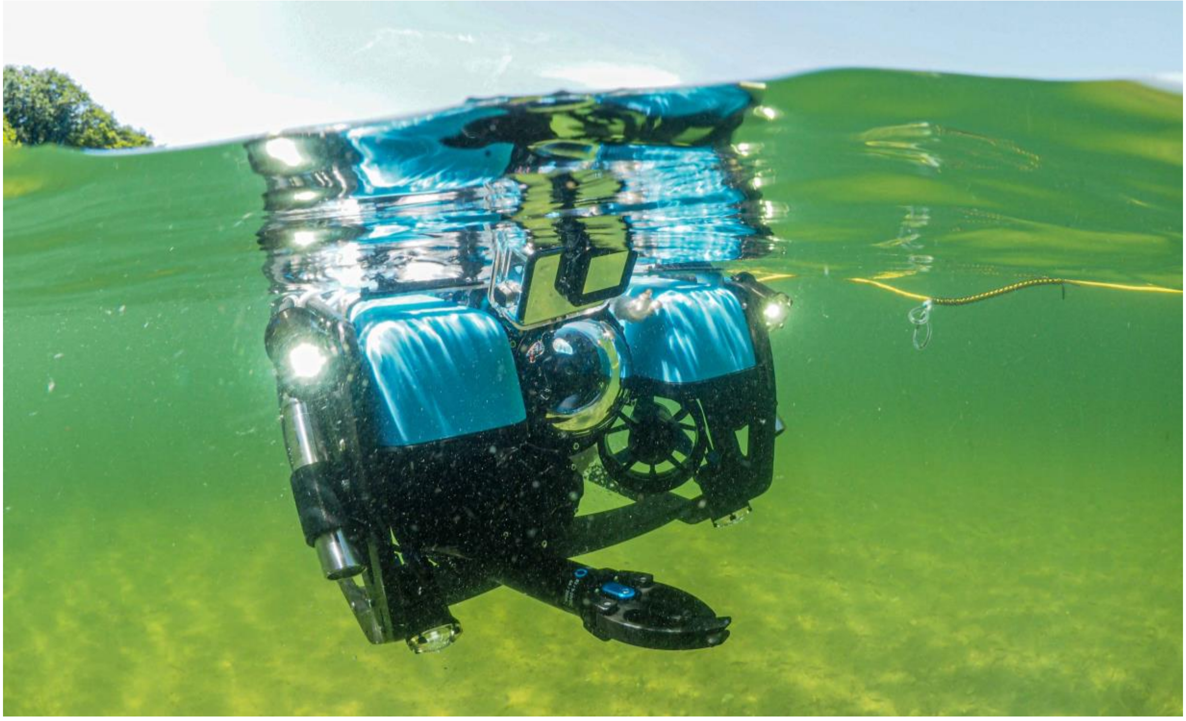


Figure 7. *Test of a BlueROV2 in lake Bussloo in The Netherlands (photo: Oscar Bos, WMR).*

Handheld ROVs (Figure 7 & Annex 3), the smallest ROVs, are designed for deployment and recovery without the need of additional equipment, making them ideal for operations that prioritize reducing operational costs and system complexity. The primary goal of using these ROVs is to complete tasks efficiently while minimizing the need for extensive support. Handheld ROVs come in various configurations, ranging from cube shaped designs to more streamlined models (Figure 8). These ROVs typically operate with lower voltage power supplies, generally ranging between 300 and 1800 watts.

Figure 8. *Overview of some example handheld (micro) ROVs. More ROVs and details on specifications can be found in Annex 3.*

The limited power supply means that handheld ROVs are equipped with smaller, less powerful thrusters, resulting in reduced manoeuvrability and thrust capacity compared to their medium sized ROVs (Capocci et al., 2017). It will likely set limits to the current velocities that the ROV can handle. Depth ratings for handheld ROVs are typically less than 300 meters, as these vehicles prioritize low mass, portability, and affordability. It will also likely sets limits to the current velocities that the ROV can handle. Despite these limitations, handheld ROVs are well suited for various marine ecological monitoring purposes, small scale inspections, and research tasks where large, expensive equipment is unnecessary. Their portability and lower operational costs make them a versatile tool for researchers and operators seeking cost effective underwater monitoring.

4.3 AUVs

Figure 9. *Deployment of the Lobster Scout in a test to monitor the oyster reef in the Voordelta, April 2023 (photo: Oscar Bos, WMR).*

AUVs are typically rocket-shaped cylinders that contain a large battery, navigation systems, thrusters for propulsion and sensors that take measurements (Figure 9 – 11 & Annex 4). Deploying an AUV involves several steps to ensure successful operation. First, the mission parameters, such as waypoints and data collection protocols, are uploaded to the onboard computer of the AUV. Subsequently, the AUV is prepared on deck of a vessel, where its sensors, batteries, and navigation systems are checked and calibrated.

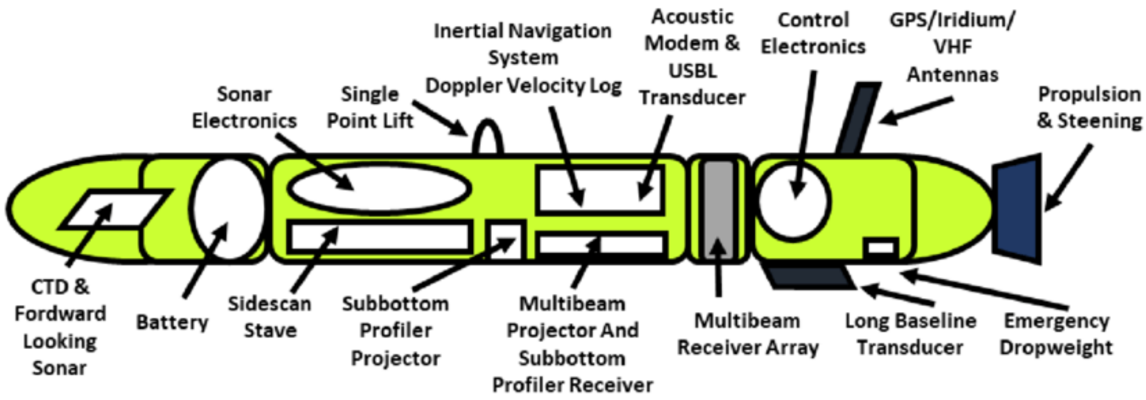


Figure 10. *Structure and components of an AUV (MBARI mapping AUV) (Henthorn et al., 2006; Sánchez et al., 2020).*

Once the pre-deployment checks are completed, the AUV is lowered into the water (sometimes using a lift/crane). The vehicle is then activated, and it begins its autonomous mission, navigating and collecting data according to the programmed instructions (e.g., abiotics, sonar, and visual) (Sánchez et al., 2020). Throughout the mission, the AUV may communicate intermittently with the surface vessel via USBL or radio signals when it comes near the surface. Upon completion of the mission or if an issue arises, the AUV is guided back to the recovery point, where it can be retrieved from the water again and brought back on deck for data download and post-mission processing. AUVs offer several advantages. For instance, they do not require human operators during their mission, reducing the need for constant human supervision. This allows for continuous data collection over extended periods. Additionally, they can reach areas that are difficult or dangerous for human divers, such as deep-sea environments, under ice, or in hazardous conditions (Sánchez et al., 2020; Segovia et al., 2020). Moreover, they can perform faster missions and cover larger areas compared to diver based monitoring.

Figure 11. *Overview of some smaller class AUVs. More AUVs and details on specifications can be found in Annex 4.*

5 Add-ons

The project outline and monitoring parameters determine both the type of mobile platform to be utilized, and the specific add-ons required for effective operation. In this Chapter, an overview is presented of the most commonly used add-ons and sensors mounted to UUVs for ecological research.

5.1 Robotic arms, grippers, and sampling tools

There are different types of arms, grippers, and samplers that are commercially available for inspection-class ROVs, such as simple grippers to pick up items, small sediment samplers, water samplers or even a grab that can pick up dead fish in aquaculture systems (Figure 12 & 13). Sediment samples can for instance be collected for assessing organic matter content and water samples for environmental DNA (eDNA) or nutrient analyses. For work class ROVs, more complicated arms are in use for complicated tasks, such as technical inspections. Also for ecological research more complicated arms to conduct specialized tasks are being developed. For example, to study marine growth on underwater structures such as the surface of offshore wind turbines, a robot arm has been developed by Bluestream and Wageningen Marine Research that is able to take scrape samples in a similar way that Scuba divers would do: the Marine Growth Sampling Tool (MGST) (Coolen, van der Weide, et al., 2024) (Figure 14).

Figure 12. *Examples of grippers and manipulators: Newton Subsea Gripper[8] (upper left) and Newton Sediment Sampler[9] (upper right). DeepTrekker water sampler 2.5 L[10] (lower left) and a DeepTrekker grabber to pick up dead fish in aquaculture systems[11] (lower right).*

[8] https://bluerobotics.com/store/thrusters/grippers/newton-gripper-asm-r2-rp/

[9] https://bluerobotics.com/store/thrusters/grippers/newton-sediment-sampler-attachment/#:~:text=The%20Newton%20Sediment%20Sampler%20Attachment,cups%2C%20or%2010%20fl%20oz.

[10] https://www.deeptrekker.com/shop/products/water-sampler-2-5l

[11] https://www.deeptrekker.com/shop/products/mort-claw

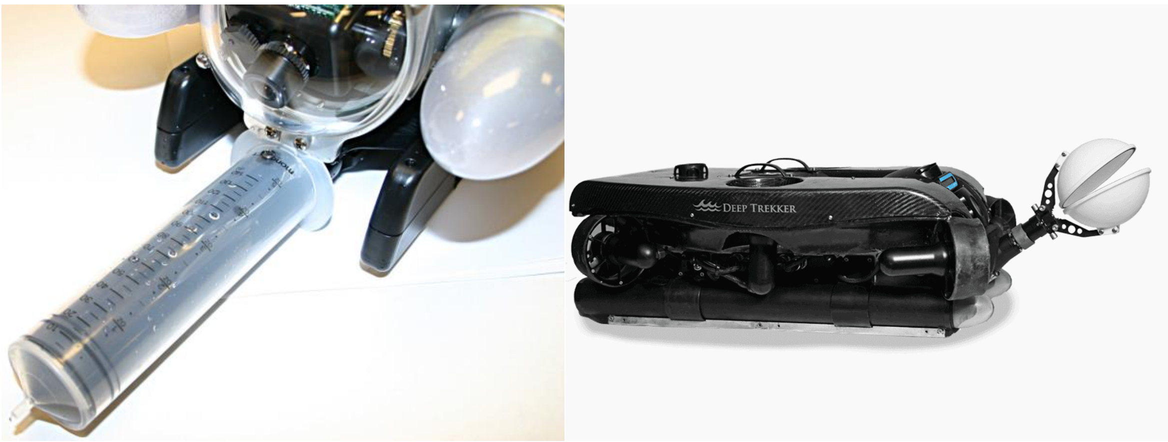


Figure 13. *Configuration water samplers on ROVs: VideoRay water sampler 100 mL*[12] *(left). DeepTrekker water sampler 1L*[13] *(right).*

Figure 14. *MGST mounted under the Saab SeaEye Tiger ROV* (Coolen et al., 2024).

A robotic arm is a mechanical, typically programmable arm, that has a similar functionality compared to human arm. Depending on the robotic arm configuration, components of the arm are connected to each other via joints; the more joints the higher the variation of possible movements. A gripper is a tool attached to the robotic arm that allows to interact with objects in the environment via various manipulations, e.g. picking, moving, and holding.

[12] https://www.videoray.com/images/specsheets/2017_WATER_SAMPLER_-_V2.pdf
[13] https://www.deeptrekker.com/shop/products/water-sampler-1l

In the underwater environment, robotic arms typically consist of one base component with a joint that connects the gripper to the arm. These grippers usually perform single manipulations, e.g. grabbing a rigid object or taking a sediment sample. For seabed composition analysis, it can function as a sediment sampler, offering an alternative to traditional tools like the Van Veen sediment grabber typically deployed from research vessels. Furthermore, various gripper configurations enable additional tasks, such as water sampling, cutting, and scooping.

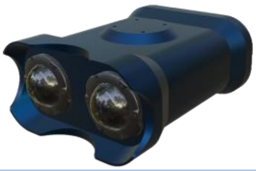
More complex arms and grippers are available on the market as well allowing for more intricate tasks and manipulations. Mounting multiple arms is also an option, however, such configurations increases the complexity of the operation (two operators are required: one for controlling and navigating the ROV and another for the robotic arm and gripper control) increasing operational costs.

5.2 Underwater imaging systems

There are various way to visualise the underwater environment (Table 2). Here we discuss the use of visible-light cameras, laser scanners, and sonar imaging.

Table 2. *Examples of underwater imaging systems (product images taken from their respective websites).*

Company and website	Example	Characteristics
Visible-light cameras		
SubC Imaging *https://www.subcimaging.com*		• Depth: 500-6000 m
DWE *https://dwe.ai/*		• Depth: 400-11000 m • Built-in image enhancement
BlueRobotics *(https://bluerobotics.com/product-category/sensors-cameras/cameras/)*		• Camera for inside the ROV • Built-in image enhancement
Deep Trekker *https://www.deeptrekker.com/shop/products/8k-360-camera*		• QooCam 8K 360° Camera • Depth: 305m • Camera Add-on
GoPro *www.gopro.com*		• Mounted on ROV/AUV • Built-in image enhancement

Laser scanners		
Voyis *https://voyis.com/*		• Depth: 1000-6000m • Provides a 3D point-cloud file as output • Built-in image enhancement
UVision *https://uvision.dk/*		• Depth: 300m • Provides a 3D point-cloud file as output • Built-in image enhancement • Stereo
Sonar (acoustic) imaging		
BluePrint subsea *https://www.blueprintsubsea.com/oculus/*		• Depth: 500-4000 m • Water pressure and temperature built-in sensors (for Velocity-of-Sound calculation) • Built-in image enhancement • Stereo
Sound Metrics *http://www.soundmetrics.com/products/ARIS-Sonars/ARIS-Voyager-3000*		• Depth: 100-4000 m • Concentrator/Spreader lens options • Built-in image enhancement

5.2.1 Conventional visible-light cameras

Conventional underwater cameras rely on natural or artificial visible light to produce visual data and are widely used sensors in (ecological) monitoring programs. Cameras can be used as an add-on to the ROVs and AUVs or can also be integrated with the mobile platforms themselves. Their variety spans from hobby action cameras, like GoPro, which require waterproof housing to make underwater deployment possible, to dedicated ROV/AUV cameras that are built waterproof and include signal amplification sensors that improve collected image quality in low light and turbid conditions (Table 2). These sensors collect visual data, specifically images and videos. Mono cameras produce 2-dimensional (2D) images, while stereo cameras allow for collecting the 3-dimensional (3D) images that include depth perception of objects. In a stereo camera set up, recordings are made simultaneously with two lenses, both focussed on the object but under a slightly different angle.

Underwater imaging is often challenged by observation conditions, such as distortion, low light, and turbidity. Frequently an artificial light source is mounted on the mobile platform to increase visibility, such as diving lights. However, there are multiple options on the market that also address these issues by developing dedicated camera lenses, improved camera sensors and implemented AI-assisted image-enhancement techniques within the device. Low-light sensors and built-in image-enhancement techniques can be particularly useful when the data needs to be collected in low-light conditions and where the use of artificial illumination is not preferred.
To assist scaling of objects recorded in video and camera footage, two laser beams can be used that are set at a fixed distance (Figure 15). Laser beams can also be used to standardize the data processing step, for instance by only counting the organism/objects present between both lines (that usually represents the area with best visibility in general).

Figure 15. *Screenshot from ROV video footage with the laser beams (photo: WMR).*

5.2.2 Laser scanners

Underwater laser scanners elevate 3D imaging by operating independently of any light, due to their integration with a laser source. The term "laser" stands for *Light Amplification by Stimulated Emission of Radiation*, and compared to visible light, lasers enable the capture of high-resolution, highly detailed images. The focused beam of the laser facilitates the creation of precise 3D images, making it useful for applications such as seabed mapping. Additionally, laser scanners offer the advantage of long-range imaging capabilities. For instance, Voyis offer a laser scanner[14] with an imaging range up to 15 meters producing a high resolution point cloud. The device has been used for surveying habitats in marine protected areas in Atlantic Ocean by the Marine Institute of Ireland (Figure 16).

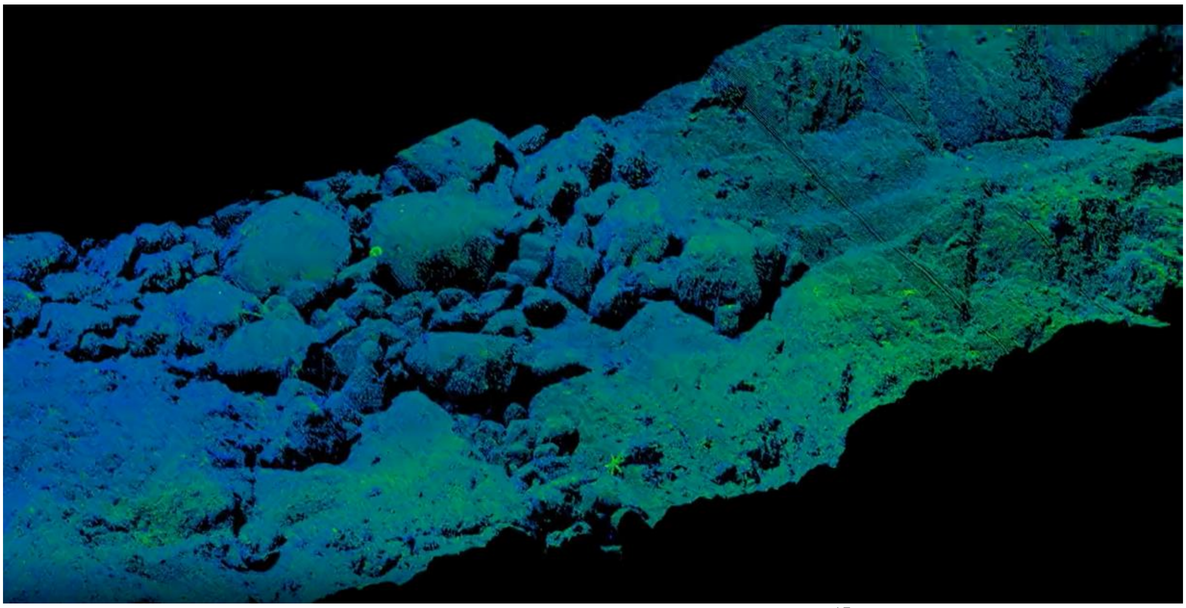


Figure 16. *Example output from the laser scanner used for seabed mapping[15].*

[14] https://voyis.com/insight-pro/

[15] https://voyis.com/case-study-ulster-university/

5.2.3 Imaging sonar

The term "sonar" is a shortened form of Sound Navigation and Ranging. Sonar imaging typically uses multibeam sonar technology, which operates similarly to laser scanners but emits sound fan beams, usually at high frequencies (600-800 kHz), instead of the laser beam. The effective operating range of imaging sonars is around 15-30 meters (Christ & Wernli, 2014) (Figure 17). The advantage of imaging sonar over visible-light cameras and lasers is its ability to produce clear images even in low-visibility or zero-visibility conditions. There are multiple variations of imaging sonars (Table 3), mostly used for real-time close range imaging, ranging from subsea port security and ship hull inspection (Christ & Wernli, 2014) to underwater fish identification (Jones et al., 2021).

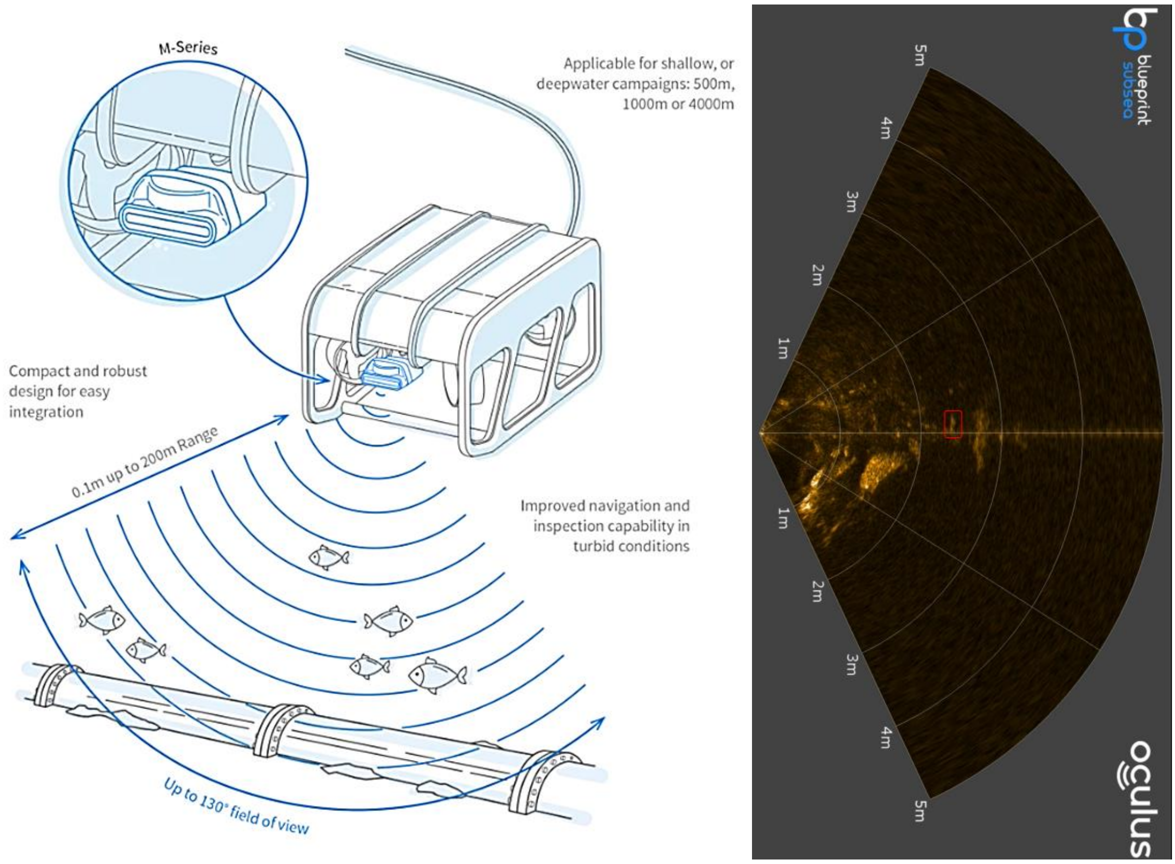


Figure 17. *Example of mounting of Oculus imaging sonar on the ROV and its working principle[16] (left). Example frame obtained with Oculus imaging sonar during the inspection of shipwreck in the harbour of Copenhagen[17]; fish visible in the image marked in red rectangle (right).*

5.2.4 Side-scan sonar and multibeam echosounder

Similarly to imaging sonar, side-scan sonar (SSS) and multibeam echosounders (MBES) operate by emitting sound waves and interpreting the returning echoes. However, they differ from imaging sonar by their broader coverage range at the cost of lower image resolution.

SSS emits acoustic beams sideways typically from a towfish ('fish' that is close to the seafloor and dragged behind the ship). Side-scan sonar does not measure the time of sound return, only the reflection of the sound from different objects and thereby produces 2D images. It is primarily used for seafloor imaging.
MBES, on the other hand, transmits multiple beams downward and measures both the strength and time of return, enabling the creation of high-resolution 3D bathymetric maps. It is especially useful for detailed mapping of the seafloor topography.

[16] https://www.blueprintsubsea.com/oculus/

[17] Marine science and robotics summer school, 2021 DTU Aqua

While SSS and MBES produce coarser resolution images compared to imaging sonar, their greater area coverage makes them useful for large-scale applications such as seafloor mapping and texture analysis. Typical tasks include:

- Seabed imaging (seabed habitat mapping, bathymetry, objects, reefs)
- Search and recovery (e.g. lost containers)
- Inspection (offshore wind assets: e.g. stability of scour protection)

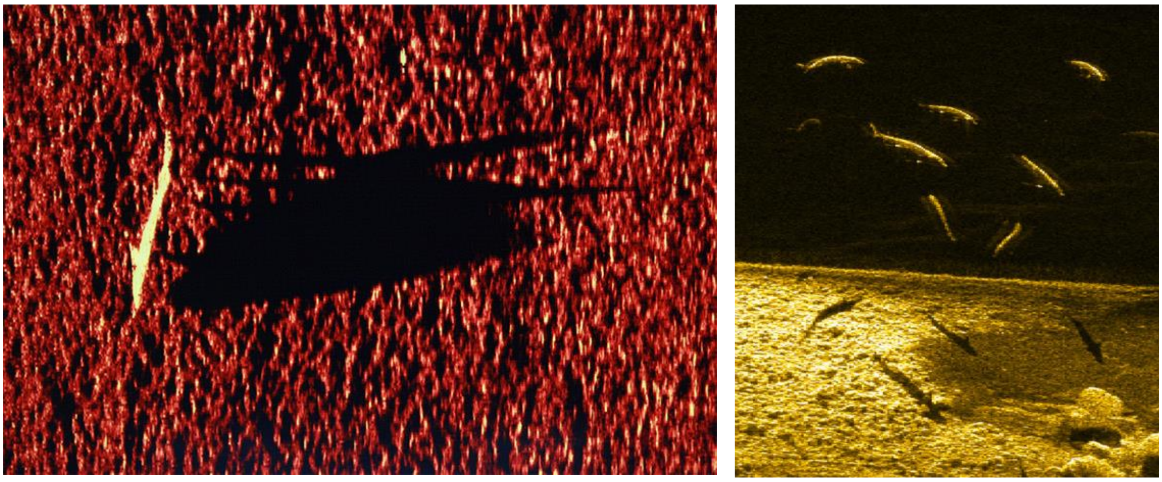


Figure 18. *Example output image depicting fish produced by 4125i SSS[18] (left). Sonar image of fish[18] (right).*

Table 3. *Examples of imaging sonar, SSS and MBES, which can be mounted on a ROV or AUV or used as a fish (product images taken from their respective websites).*

Company and website	Example	Characteristics
EdgeTech *https://www.edgetech.com/product-category/side-scan-sonar/*	 	• Lightweight • Seabed imaging • Search and recovery
BlueRobotics *https://bluerobotics.com/product-category/sonars/side-scan/*		• Seabed imaging • Search and recovery
MarineVision *https://www.marinevision.es/en/diving-pro/tritech/sss_towfish.html*		• Seabed imaging • Inspection duties

[18] edgetech.com

Kongsberg *https://www.kongsberg.com/discovery/seafloor-mapping/sonars/multibeam-sonar-m3-sonar/*		• Imaging and bathymetry • (shallow water surveys on ROV)
Hydro-Tech *https://www.hydro-techmarine.com/*		• Underwater terrain survey, underwater 3D survey & bridge pier scour inspection

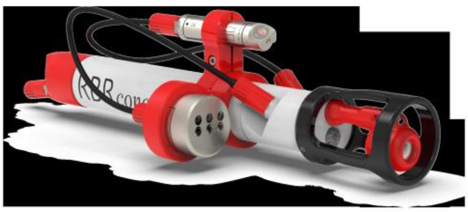
5.3 Environmental sensors

A variety of sensors can be mounted on a mobile platform to measure a wide range of (abiotic) background parameters (Table 4).
One example of an environmental sensor compatible with a ROV is the Aqua Troll 500 multi-parameter sonde, which contains four inter-changeable sensors (Figure 19). The user can choose to measure up to four parameters simultaneously out of 16 available parameters in total (e.g., Temperature, Conductivity, Ammonium, Chloride, Chlorophyll a.).
Depending on the target task, multi-parameter sampling might not be needed. For such cases, individual sensors are available to measure narrower range or single parameters. Conductivity, temperature and depth (CTD) is a widely applied sensor. Single-parameter sensors typically include temperature, oxygen, turbidity and current velocity. The sensors are often available on the market with compatible loggers.

Figure 19. *Aqua TROLL 500 in a skid mounted under a Bluey Robotics ROV*[19].

[19] https://www.blueyerobotics.com/products/aquatroll-environmental-sensor

Table 4. *Examples of environmental sensors, which can be mounted on a ROV or AUV (product images taken from their respective websites).*

Company and website	Example	Characteristics
	Multi parameters	
Aqua TROLL 500 *https://www.blueyerobotics.com/products/aquatroll-environmental-sensor*		The user can choose to measure 4 parameters simultaneously: • Temperature • Conductivity • Dissolved Oxygen (DO) • pH/ORP • Turbidity • Phycocyanin • Phycoerythrin • FDOM • Crude Oil • Rhodamine WT • Fluorescein WT • Ammonium • Chloride • Nitrate • Chlorophyll a
RBRconcerto[3] *https://rbr-global.com/products/standard-loggers/rbrduo-ct/*		Available sensors: • Conductivity (C) • Temperature (T) • Pressure (D) • Dissolved Oxygen (DO) • Optical Dissolved Oxygen (ODO) • Photosynthetically Active Radiation (PAR) • Radiometer (rad) • Turbidity (Tu) • Thermistor string (Tx) • Fluorescence (Fl) • pH • Oxidation-Reduction Potential (ORP) • Methane, Carbon Dioxide • Transmittance • Voltage
	Temperature	
UTBI-001 Data Logger *https://www.onsetcomp.com/products/data-loggers/utbi-001*		• Approx 42,000 measurements • To 300 m depth • 3x4 cm / 19.6 g • Other versions to 1500 m depth

Tinytag-aquatic 2 *https://www.geminidataloggers.com/data-loggers/tinytag-aquatic2*		• Approx 32,000 measurements • To 500 m depth • 50 mm / 90 g
RBRsolo³ T *https://rbr-global.com/products/compact-loggers/rbrsolo-t-2/*		• ~130M measurements • Up to 1700m (plastic) Up to 10000m (Ti) • 240mm / 120g in air, 20g in water (plastic) 320g in air, 220g in water (Ti)
Oxygen		
HOBO U26 Dissolved Oxygen Data Logger *https://www.onsetcomp.com/products/data-loggers/u26-001#specifications*		• 0.2 mg/L accuracy • Optical measurements • Dissolved O2 and temperature • Approx. 21,700 measurements • 3y battery life (at 5 min logging)
RBRduet³ T.ODO *https://rbr-global.com/products/compact-loggers/rbrduet-t-odo/*		• ±2µmol/L or ±1.5% (standard) • 165 thousand measurements
CTD: Temperature, Salinity/Conductivity, Depth/Pressure		
CTD diver *https://www.royaleijkelkamp.com/nl/producten/monitoring/sensoren-en-sondes/waterpeil-sensoren/ctd-diver/*		• Different models: 10-200 m • Approx. 144,000 measurements
SBE 49 FastCAT CTD *https://www.seabird.com/sbe-49-fastcat-ctd/product?id=60762467704*		• Add-on for ROVs and AUVs • Depths to 350, 7000, or 10,500 m
Turbidity		
RBRcoda Tu *https://rbr-global.com/products/sensors/rbrcoda-tu/*		• Max depth 6000m • Measurement range 0 - 1500FTU
Chlorophyll-a		

Deep Trekker ROV Chl-a sensor *https://ocean-innovations.net/companies/deep-trekker/products/sensor-chlorophyll-a/*		• Add-on for ROVs
Valeport Hyperion Chlorophyll sensor *https://www.valeport.co.uk/products/hyperion-chlorophyll-a/*		• Add-on for ROVs and AUVs • Max depth 6000m
Sound		
icListen HF Hydrophone *https://oceansonics.com/iclisten-hf-hydrophone/*		• 900, 3500, or 6000 m deep
Nutrients		
Deep SUNA Ocean Nitrate Sensor *https://www.seabird.com/deep-suna-ocean-nitrate-sensor/product?id=60762467724*		• Add-on for AUVs • Max depth 2000m • Real-time nitrate calculation • Real-time temperature and salinity compensation

6 Photo and video analysis using AI

6.1 Introduction

After monitoring by ROV or AUV, usually a lot of imagery data (video, photo, sonar) is collected from which information, such as presence of species, structures or objects, needs to be extracted. The first data processing step is typically pre-processing. Specifically for imagery data, this step can involve various tasks such as stitching images of seabed to create maps or selecting and subsetting of useful frames.

In the past, imagery data had to be inspected manually to identify specific species and/or objects. This step was a time consuming process as the footage needed to be analysed frame by frame or photo by photo. Recently however, AI-based methods (such as CV) have become more efficient in handling significant portions of the data processing workload. This chapter provides a simplified framework for species identification using CV to help understand and guide the general process.

Box 2: Artificial Intelligence systems

AI is broadly defined as "the capacity of computers or software programs to operate in ways to mimic human thought process, such as reasoning and learning" (Lee, 2020.). Computer vision is a subfield of AI covering the tasks of automated scenes and objects recognition in visual data, including images and videos (Szeliski, 2022).

CV is used for both, visual data post-processing and automated analysis. For example, for seabed mapping, visual data post-processing includes defining key overlapping features in consecutive frames, their matching and alignment. This process is largely accomplished automatically by CV algorithms and the role of a human supervisor lies in defining initial parameters and output quality control.

CV models dedicated to automated analysis of visual data can solve a range of tasks allowing for localization, measurement and quantification of target objects in visual data. One of the most established models solving these tasks are Convolutional Neural Networks (CNNs). To accomplish these tasks, expert knowledge about for instance species determination needs to be transferred to the model. This knowledge transfer step includes data annotation of objects present in frames or images (Figure 20), which is used for model training and evaluation. Data annotation requires marking the target object in the image and defining its label; type of the annotation depends on the target CV task (Figure 21). Depending on the type, annotation step can be labour and time-consuming, especially in the cases when multiple overlapping objects are present in the images and a polygon annotation is required.

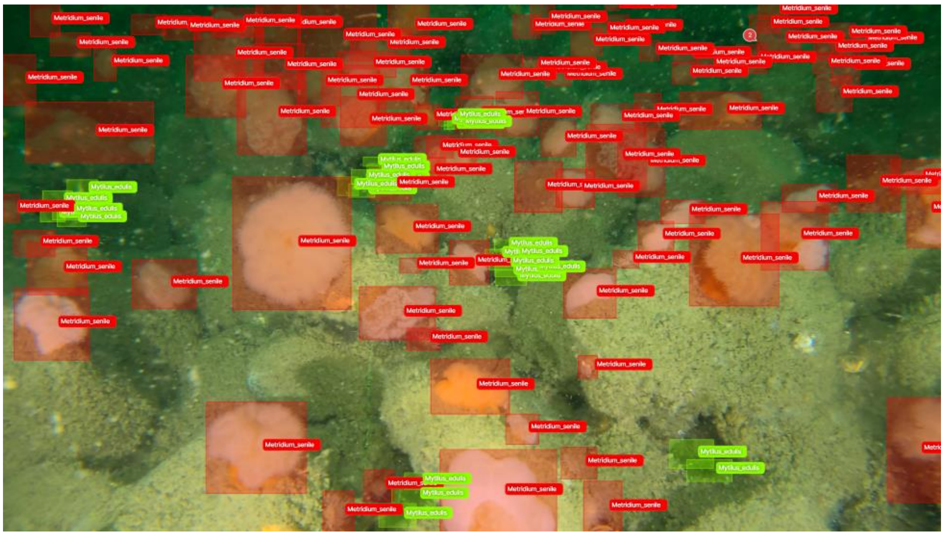


***Figure 20**. Example of annotated benthic species using DarwinV7 annotation software with bounding boxes applied to video frames from the Hollandse Kust Zuid offshore wind farm (photo: Celine Goslinga & Enzo Kingma, WMR).*

6.2 How to analyse visual information in an automated way

Photos and videos may contain relative simple information, e.g. an image of a single species (a crab), or show a mix of features such as different species of fish, or a coral reef covered with different species of corals and sponges. Typically, there are three ways (CV tasks) for automated analysis of such visual data (Figure 21):
(1) Classification; this requires the labelling of objects classes on the level of the whole image.
(2) Object detection; this requires bounding box annotations. Each localized object in a bounding box is assigned to a class.
(3) Instance segmentation; objects are detected using polygons, and each polygon is assigned to a class. This can be useful for determining percent coverage of e.g. colonial species.

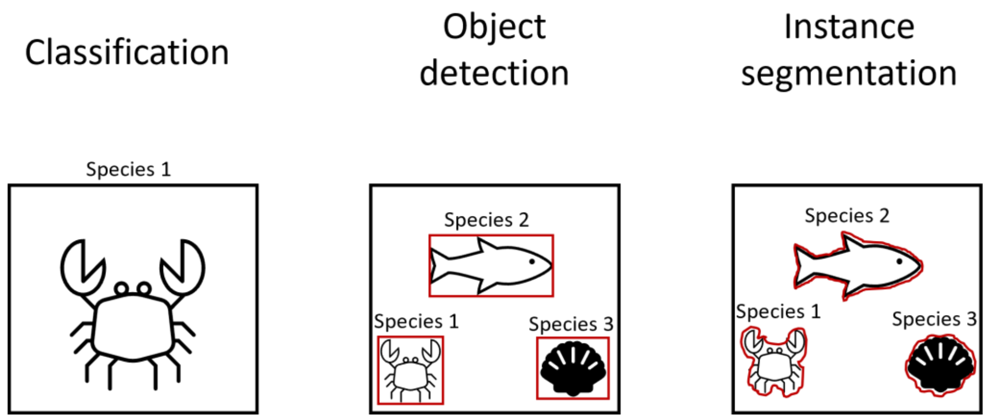


Figure 21. *Three ways to identify species: (1) Classification, (2) Object detection, and (3) Instance segmentation.*

6.2.1 Classification (whole image or image crop)

Classification answers the question if the target object is present in the image or not. This task typically requires a single object to be present in the image. A label for the target class (e.g. 'crab') is assigned to the image. Singh & Mumbarekar (2022) present an example of using a classification CNN[20] to identify six different taxonomic groups of benthic animals in colour images (Figure 22). Prior to classification, a general object detector isolated the area of the image containing the object of interest (crop).

[20] https://www.analyticsvidhya.com/blog/2020/02/learn-image-classification-cnn-convolutional-neural-networks-3-datasets/

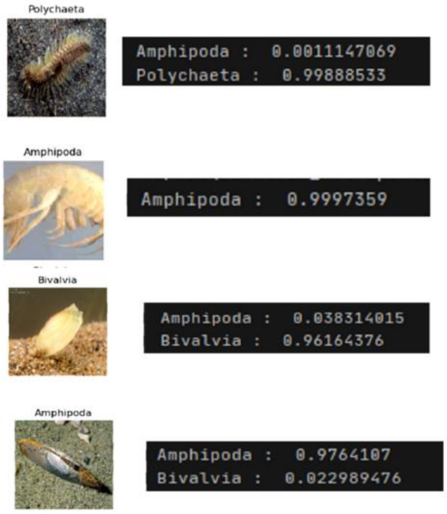


Figure 22. *Classification CNN prediction on the test images (Singh & Mumbarekar, 2022).*

6.2.2 Object detection (boxes around objects)

Object detection aims to identify the presence of a target object (e.g., a fish) within an image and pinpoint its location. This is achieved by marking the relevant area of the image with a bounding box (a box around the target object). Ortenzi et al. (2024) demonstrated the application of the YOLO[21] object detector for counting benthic species in video footage collected with a conventional visible light camera. Different fish species were noted with a bounding box (Figure 23).
Object detection models require training using annotations that include both bounding boxes and class labels for each object in the image (e.g., 'Rockfish', 'Hagfish'; Figure 23, right). This approach enables both classification and quantification of objects within images. As the dataset preparation requires bounding boxes annotations, object detection approach offers a balanced trade-off between automated image analysis performance and efforts needed for dataset preparation and training. Better results can be obtained by image segmentation at the cost of more label intensive training of the model, see section *6.2.3*.

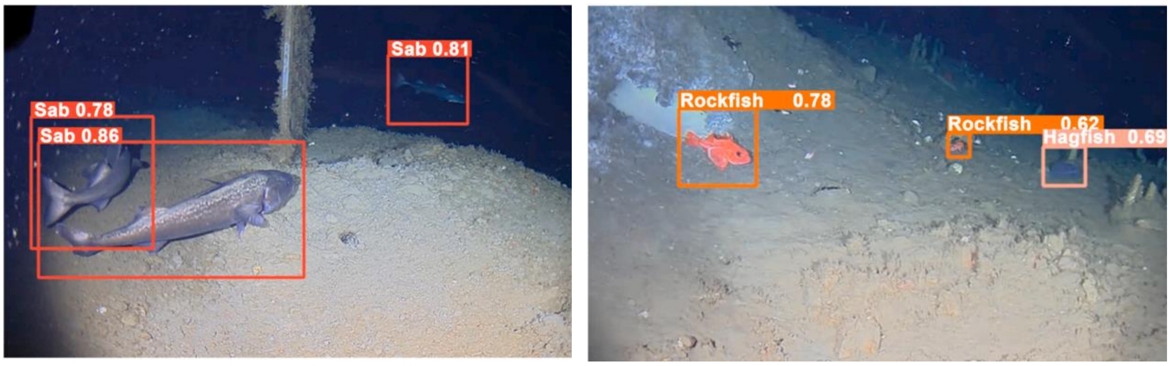


Figure 23. *Detection examples output by YOLO object detector (Ortenzi et al., 2024).*

6.2.3 Instance segmentation (polygons around objects)

Instance segmentation CV provides a more precise target object localization in the image. For this task, polygons are drawn around objects. In this way, each pixel of the target object is assigned to a class and labelled. While this method delivers the most detailed results, it is also the most labour-intensive and time-consuming of the three main CV tasks. Although automated tools exist to generate polygon annotations, significant manual effort may still be required to correct inaccuracies, particularly when images contain numerous objects that are poorly defined, overlap, or partially visible.

[21] https://www.ultralytics.com/

Despite the challenges, instance segmentation offers superior image analysis performance and provides finer detail insights into target object properties. It is particularly useful for tasks such as accurately estimating the size and biomass of benthic species (Lütjens & Sternberg, 2021) (Figure 24).

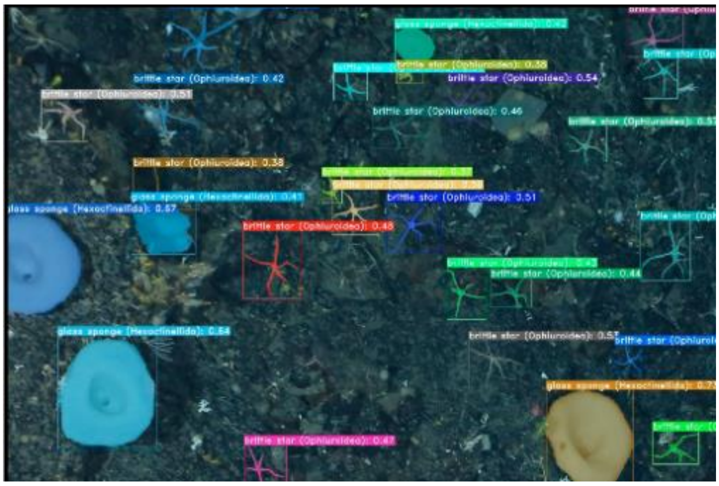


Figure 24. *Instance segmentation results of benthic species (Lütjens & Sternberg, 2021).*

6.3 Species/object identification workflow example

AI can help detect marine species and identify habitat types (e.g., sediment composition, stone coverage) in underwater video and photo footage. The typical workflow follows these steps (Figure 25):

1. Data Collection: Capture a sufficient number of high-quality images or videos to account for variations in animal phenotypes and observation conditions.
2. Data Processing: If videos are collected, extract frames to create individual images for AI training. Additional post-processing may involve filtering for informative frames containing target objects while excluding empty ones.
3. Image Annotation: Use dedicated annotation software (e.g., DarwinV7) to label the images according to the requirements of the specific CV task (*Chapter 6.2*).
4. Dataset Preparation: Once annotation is complete, export the images along with their annotations. Together, these constitute the dataset used for training and testing the AI model.
5. AI Model Selection: Select from a range of AI models tailored to specific CV tasks. For similar applications (such as identifying benthic species on scour protection structures) existing models can often be adapted or reused. The Naturalis Biodiversity Center, for example, is developing a 'living library' of AI models for biodiversity research, providing a central hub of ready-to-use resources.
6. Model Adaptation and Training: Adapt the selected AI model for the specific case study and train it using the dataset. Conduct testing and refinement to achieve optimal performance. This step may include enhancements such as object tracking to prevent double counting and scaling adjustments using laser beams from platform-mounted lasers. These lasers can also help identify the highest resolution areas within the imagery (*Chapter 5.2.1*).
7. Model Deployment: Once the model performs well, it is saved and deployed to execute the target task. For example, if the task involves determining biodiversity, the AI model can predict the number and types of species present in the test data.

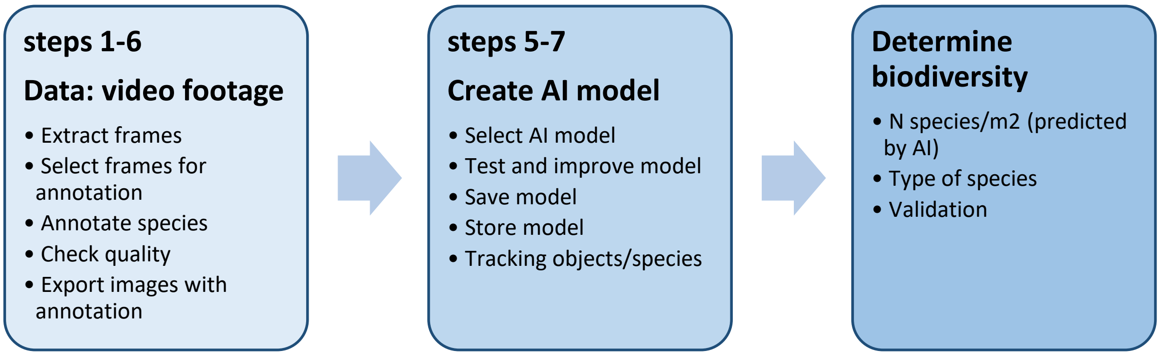


Figure 25. *Example workflow for end-to-end video data biodiversity analysis using AI models.*

Collected 2D images can be converted into a 3D model of the object using AI, which can be used for volume estimation and growth rate estimation of e.g. coral colonies (Lange & Perry, 2020). Alternatively, recent laser scanners and Sonar systems are able to output the 3D models of the scanned objects, and thus the photogrammetry step is already completed on the device and the 3D models can be directly used for automated volume and growth estimation.

Artificially generated 3D models can also be useful to increase number of examples of target objects to train AI systems. This approach is currently being developed for applications in fisheries for catch monitoring and fish handling and processing (Dyrstad & Mathiassen, 2017; Vroegop, 2024), however this method has a potential in the other areas of application, such as ecological monitoring.

6.4 AI solutions on the market

In certain marine ecological research fields, such as coral studies, a community of practitioners has already developed species identification tools, including platforms like CoralNet (Table 5). In contrast, fields such as benthic research in the North Sea still require further advancement in automated species analysis. This can be achieved by for instance expanding the availability of annotated training data to improve AI model performance.

To support the development of AI models, various software platforms are available, such as DarwinV7 (Table 5), which enable users to label species or objects within images. These annotations form the foundation for training models to automatically identify species or habitats.

Table 5. *Examples of AI solutions available for marine ecological research (characteristics taken form their respective websites).*

Name and website	For	Characteristics
Species ID tools		
CoralNet *https://coralnet.ucsd.edu/*	Coral reefs	• For tropical benthic images (corals and more) • Plots a number of random points on a photo and tells which species are below the point. • CoralNet is a resource for benthic images analysis. • The site deploys deep neural networks which allow fully and semi-automated annotation of images. • It also serves as a data repository and collaboration platform. • CoralNet is open source and free to use thanks to support from NSF and NOAA.
Observation.org *www.observations.org*	All species	• For individuals observers, groups, institutes • GBIF member • Next to storing individual records: line transect monitoring, project management tool for (large) groups of users • Focus on Europe & Caribbean • Predicts individual species on the photo (multi species prediction soon available) • Predicts the life stage / sex / etc. of species on the photo • Predicted observations are checked by specialists & validation algorithm. • Supported by Naturalis Biodiversity Centre • EU platform with servers in NL under Dutch Law • Formal cooperation between WUR, LVVN and Observation in place (Stranding.nl)
iNaturalist *https://www.inaturalist.org/places/netherlands*	All species	• For individual observers • Focus on the USA, but also on Europe • US platform with servers in USA under US law
Wageningen Marine Research	Benthos	• Several models under development for North Sea benthos species identification
Annotation software		
DarwinV7 *https://darwin.v7labs.com/*		• Used by Wageningen University and Research • AI-assisted annotation • Range of annotation types and formats available

		• Outsourcing of annotations is available • Allows for annotation of photo and video • Requires subscription
CVAT (Computer Vision Annotation Tool) *https://www.cvat.ai/*		• Range of annotation types and formats available • AI-assisted annotation • Free version is available • Depending on the plan, different storage limits and number of participants per project apply
LabelMe *https://www.labelme.io/*		• Range of annotation types and formats available • AI-assisted annotation • Free version is available • Depending on the plan, different storage limits and number of participants per project apply
Make sense *https://www.makesense.ai/*		• Free and open-source annotation tool • Range of annotation types and formats available • AI-assisted annotation (some limitations) • Only browser-based (no app)
Labelbox *https://labelbox.com/*		• Annotation of visual, acoustic data (among other) • Custom ontology (e.g. multi-class labelling) • Range of annotation types and formats available • AI-assisted annotation • Free version is available
Platforms and projects		
SUBSIM: Swedish national platform for analysis of subsea images *https://subsim.se/*	Marine images	• National Swedish platform for all kinds of marine image analysis • Mussel banks, fish
ARISE: Authoritative and Rapid Identification System for Essential biodiversity information. *https://www.naturalis.nl/en/science/arise-knowing-nature-in-the-netherlands*	Researchers	• Platform under development by Naturalis Biodiversity Centre • Aims at combining AI with eDNA
WildMe *https://www.wildme.org/platforms.html*	Wildlife	• Platform • Individuals ID • Seals ID, sharks ID, freshwater fish ID, whales and dolphins ID, and many more species
Agouti *https://www.agouti.eu/*	Wildlife camera traps	• Developed by WUR • AI platform for recognition of birds and larger mammals

7 User cases

In this chapter five user cases are described for biodiversity research that illustrate how practitioners in the field of ecological research can choose UUVs and add-on configurations for their projects. For each user case, we follow the step-by-step approach provided in *Chapter 2.1*.

7.1 Biogenic reefs and sandy seafloors

Figure 26. *Flat oyster reef in the Voordelta, Netherlands (photo: Oscar Bos, WMR).*

Biogenic reefs are structures formed primarily by living organisms. These reefs are created by the accumulation and growth of various organisms such as corals, oysters, mussels, polychaeta, and other sessile marine species. The three-dimensional structures formed by the organisms offer refuge, feeding grounds, and breeding sites for various other organisms. They can thereby play an important role in enhancing local biodiversity. Additionally, biogenic reefs contribute to ecosystem functions such as nutrient cycling, sediment stabilization, and water filtration. Their composition and structure may vary depending on factors such as substrate type, water depth, environmental conditions, and the species present, resulting in different reef types found across different marine environments. In the Netherlands, biogenic reefs such as oyster banks, mussel beds, and polychaete (*Sabellaria* and *Lanice*) aggregations can be found in the North Sea.

The use of inspection-class ROVs and small AUVs can complement/add/replace traditional monitoring methods for biogenic reefs. Some key features of ROVs and AUVs for biogenic reef monitoring:

- ROV
    - Capture high-resolution imagery and video for detailed visual assessments of reef sections.
    - Equipped with sampling tools for collecting water, sediment, or biological material.
    - Real-time observation and control for targeted inspections.
    - Suitable for precise manoeuvring around complex reef structures.
    - Ideal for close-up monitoring of specific features.
    - Etc.

- AUV
    - Perform autonomous, large-scale surveys across extensive reef areas.
    - Map reef topography and structural complexity.
    - Gather visual data to estimate species distribution and population density.
    - Collect environmental background data such as temperature, salinity, chlorophyll-a, and turbidity.
    - Enable repeatable monitoring missions for long-term monitoring campaigns.
    - Etc.

7.1.1 Case study: monitoring flat oyster reef Voordelta

Flat oyster reefs once covered around 20% of the Dutch North Sea floor but have since become rare. In 2015, a mixed reef of Japanese and flat oysters was discovered in the Voordelta, covering approximately 40 hectares (Christianen et al., 2018). Since then, several studies have focused on restoring the flat oyster population through pilot projects and protective measures against harmful fishing practices. For instance, during annual monitoring campaigns, the status of the reef, reproduction, and biodiversity are evaluated (Kamermans et al., 2024). Yearly, biodiversity is assessed by divers, who inspect species within quadrants along transects to investigate the benthic diversity. In addition to these diver inspections, a pilot was conducted in 2023, using a photogrammetry AUV to provide a direct comparison to the diver based monitoring (Kamermans et al., 2024).

In this pilot the Lobster Scout AUV by Lobster Robotics was used (Figure 27). This AUV is designed to map the seafloor independently. It follows pre-programmed transects, capturing thousands of seafloor photos while recording depth and position data. These photos are then stitched/merged into a large geo-referenced image, which can be integrated with depth data to create a 3D Digital Elevation Model (DEM) and imported into GIS programs for further analysis. The AUV was used to visualize the same transects monitored by the divers and additional 20x20 meter squares for oyster density and biodiversity inspection. While most ecological monitoring in the North Sea using UUVs is performed during neap/slack tide (when there are minimal currents). Monitoring in the Voordelta region using the Lobster Scout could be conducted all day.

Figure 27. *Lobster Scout AUV (photo: Oscar Bos, WMR).*

The survey conducted with the Lobster Scout produced quick and high-quality images. Within a few hours, all dive transects and additional squares were recorded, much faster than traditional diver monitoring. The images were processed into a large composite that can be spatially displayed in GIS (Figure 28). During the survey, the AUV also measured the seabed profile, which can be visualized in maps or line transects (Figure 29 *left*), forming a DEM for generating 3D images (Figure 29 *right*).

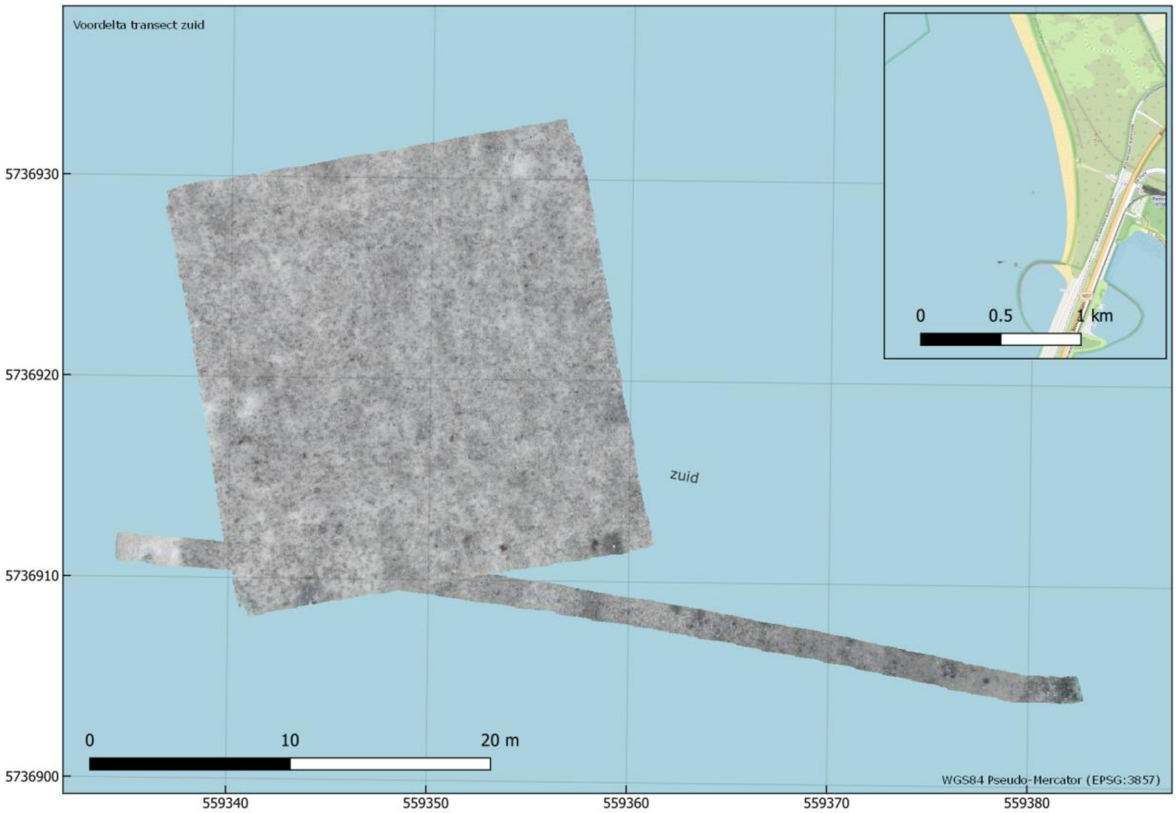


Figure 28. *An example output of the georeferenced stitched images captured by the Lobster Scout AUV, where thousands of images were combined into a single visual. The image shows a zoomed-out 20x20 m square and a transect (Kamermans et al., 2024).*

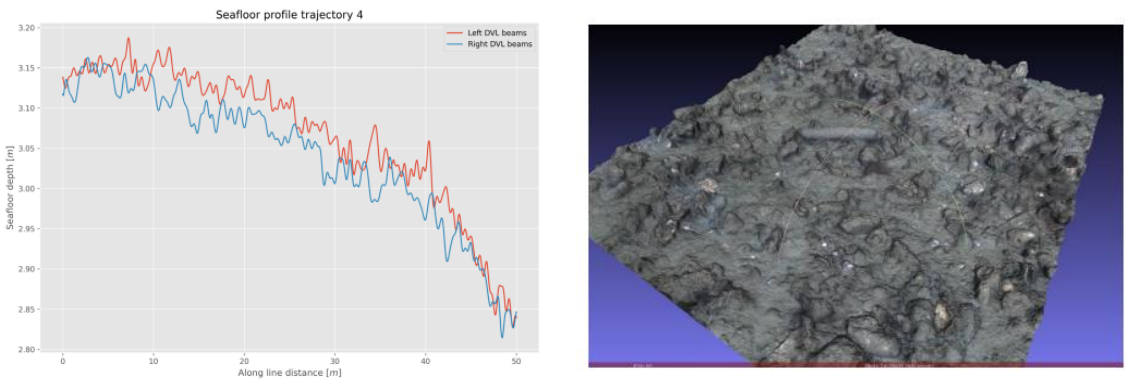


Figure 29. *Seafloor depth profile over a 50 m transect based on the depth measurements of the Lobster Scout AUV (left). 3D DEM made by combining depth and photos. Individual oysters and razor clams are visible, from which the 'reefyness' could be determined (right). (Kamermans et al., 2024).*

Image analysis revealed that the survey produced clear photos, allowing for easy identification of species such as starfish, sea anemones, mussels, and sponges (Figure 30), that can be used for biodiversity estimation. Oyster shells were also visible, but their frequent coverage with silt made it difficult to determine whether they were alive or dead, or to distinguish between Japanese and flat oysters. This uncertainty complicates AI-based annotations, making it challenging to accurately count live oysters from imagery alone. Ground truthing in the form of divers, Van Veen grab samplers, or boxcores would therefore still be necessary.

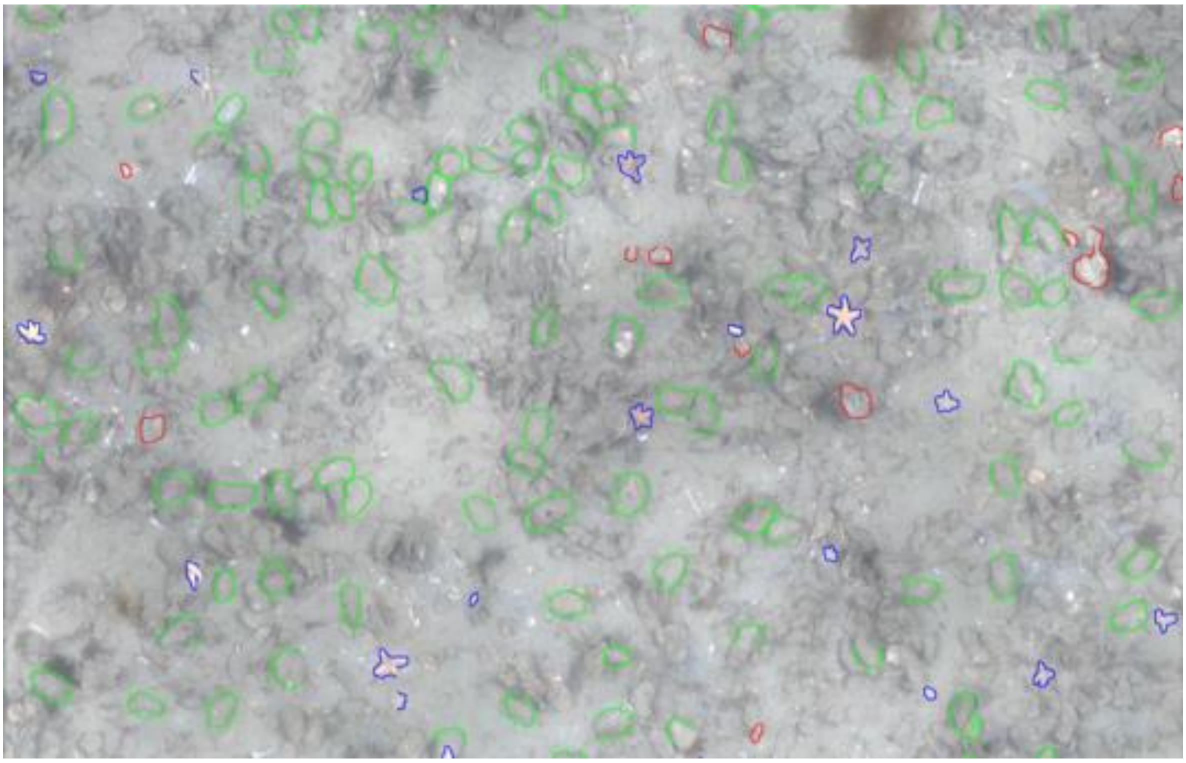


Figure 30. *Species identification using an AI-model: starfish, sea anemones, mussels, and sponges (Kamermans et al., 2024).*

The key advantage of this technique is its ability to generate detailed, surface-covering images rapidly. The resulting data is easy to view in GIS programs, providing a good overview of the oyster reef, shell coverage, and a broad assessment of biodiversity. Species as small as 1 cm are identifiable in the images, and the 3D models can be directly used to evaluate habitat complexity. However, automatic species recognition remains currently time-consuming due to the preparatory work required to fine-tune the system (but this should improve with more and more training data).

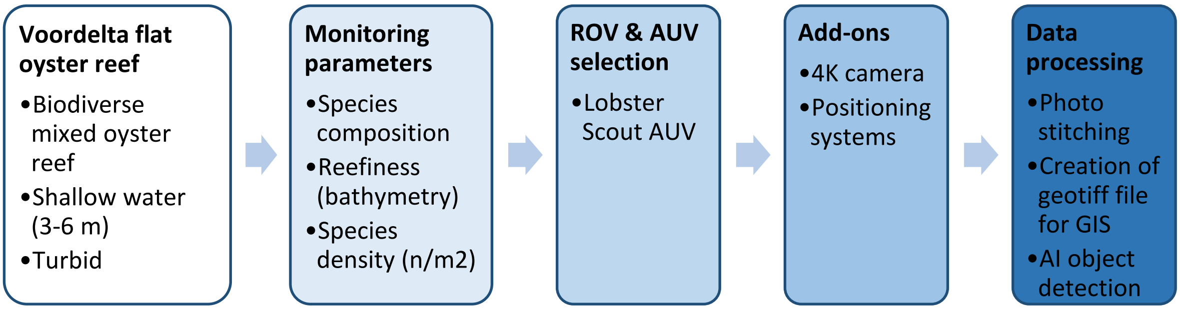


Figure 31. *Step-by-step approach for monitoring of the Voordelta flat oyster reef.*

7.2 Coral reefs

Figure 32. *Saba Bank (Caribbean) in 2015 (photo: David Stevens).*

Coral reefs, a distinctive form of biogenic reefs, form diverse underwater ecosystems primarily composed of coral polyps (marine invertebrates) and an associated diverse community. The coral reefs are characterized by their structural complexity, consisting of a calcium carbonate skeleton secreted by the coral polyps. The reef can display vibrant and colourful corals of various shapes and sizes. They thrive mainly in shallow, tropical marine environments which often have abundant sunlight. The coral reefs provide habitat, food, and protection to many organisms, thereby supporting a rich biodiversity. Moreover, they offer ecosystem services like coastal protection and tourism. The Dutch coral reefs are situated in the Caribbean Sea, particularly at Bonaire, Saba, and St. Eustatius. Assessing the health of these coral reefs involves monitoring indicators such as coral cover, species diversity, reef structure, and water quality parameters like temperature, salinity, and nutrient levels.

Inspection-class ROVs and small AUVs can enhance or even substitute more traditional monitoring techniques for coral reefs. Below some features and capabilities of ROVs and AUVs for coral reef monitoring:

- ROV
  - Capture high-resolution imagery and video for detailed inspection of coral health and reef condition.
  - Equipped with sampling tools for collecting water, sediment, or biological material.
  - Suitable for close-up documentation of coral bleaching, disease, or structural damage.
  - Can operate in high-precision for focused assessments around specific coral colonies or restoration areas.
  - Potential to assist in coral restoration activities (e.g., fragment placement or nursery inspections)
  - Etc.
- AUV
  - Perform autonomous, large-scale surveys across extensive reef areas.
  - Map reef topography and structural complexity.
  - Capture imagery and video for species identification and coral cover assessments.
  - Collect environmental parameters such as temperature, salinity, turbidity, oxygen levels, and chlorophyll-a.

- Enable repeated, standardized monitoring missions to assess temporal changes (e.g., post-bleaching events).
- Useful for surveying remote or hard-to-access reef locations with minimal human intervention.
- Etc.

7.2.1 Case study: monitoring Saba Bank, Caribbean.

Figure 33. *Reef landscape at Saba Bank in October 2015 (photo: Jean Philippe Maréchal).*

The Saba Bank (Caribbean), located within Saba's territorial waters and the Netherlands' Exclusive Economic Zone (EEZ), is a vast submarine atoll covering over 2000 km². Known for its biodiversity, it hosts diverse assemblages of fish, corals, sponges, algae, and microalgae (De Bakker et al., 2016; Toller et al., 2010; Williams et al., 2010). The ecology of the bank varies with depth and currents, coral reefs are primarily found along the southern and eastern edges (Meesters et al., 2024).

The QYSEA FIFISH Pro V6 Plus ROV (Figure 34), was deployed to monitor the Saba Bank through video transects using its forward-facing 4K camera and a GoPro mounted underneath the ROV to capture additional imagery. The primary objective using this ROV was to improve the accuracy and reliability of fish assemblage assessments and enable more frequent, detailed characterizations of the benthic communities at the Saba Bank. By using this ROV, the project shifted from previously relying on input from traditional fisherman reports to more fisheries-independent assessments of fish populations. Furthermore, the ROV facilitated regular benthic diversity monitoring, allowing for better observation of changes over time and exploring the deeper regions at the bank.

Figure 34. *QYSEA FIFISH Pro V6 Plus ROV*[22]*.*

The key monitoring parameters focused on the identification and density of commercially important fish species, such as red hind and snapper. Additionally, the study included the identification of dominant benthic groups, coral species, coral cover, and species richness. Georeferenced images were incorporated to refine and enhance the recently developed habitat map of the bank using machine learning techniques (Meesters et al., 2024). Background water quality parameters were monitored by mounting several sensors to the ROV, such as a Valeport CTD to measure conductivity, temperature, and depth.

During the processing the DarwinV7 annotation tool was used to identify fish species in the (video) images from the video transects using polygons (Figure 35). Additionally, benthic organisms were identified using CoralNet (Figure 36), which is an online ML tool designed to streamline the annotation and analysis of benthic images. The tool generates precise cover percentages of organisms, often enabling species-level identifications that surpasses the accuracy of visual estimates. However, manual verification remains necessary, particularly for challenging classifications, such as distinguishing *Lobophora* macroalgae from substrate.

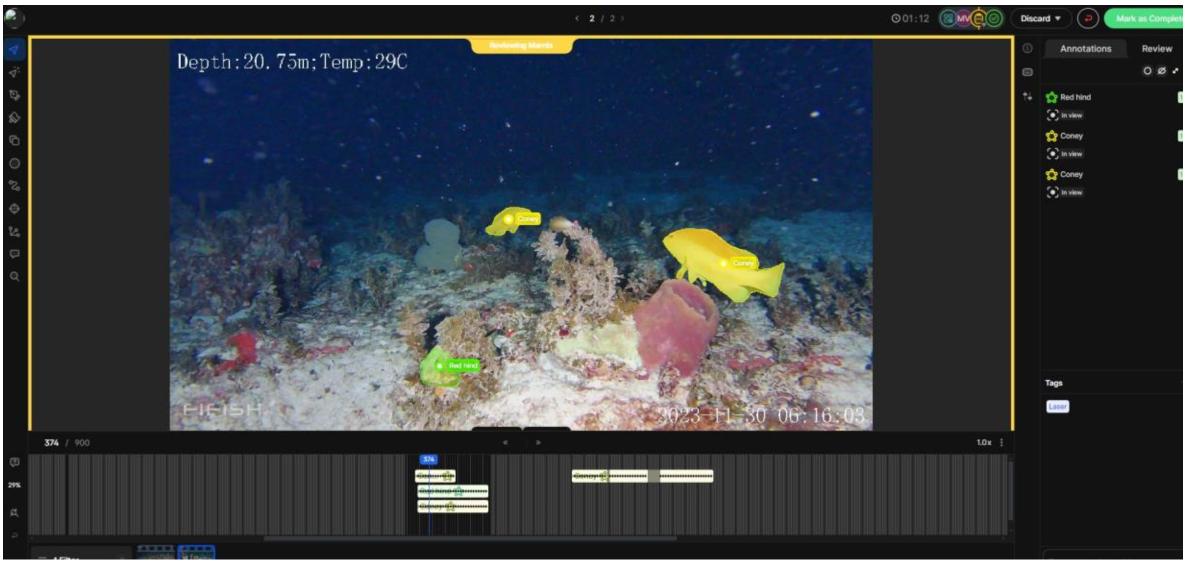


Figure 35. *Screenshot from the DarwinV7 annotation tool. Fish are annotated using instance segmentation polygons.*

[22] https://www.qysea.com/products/fifish-v6/

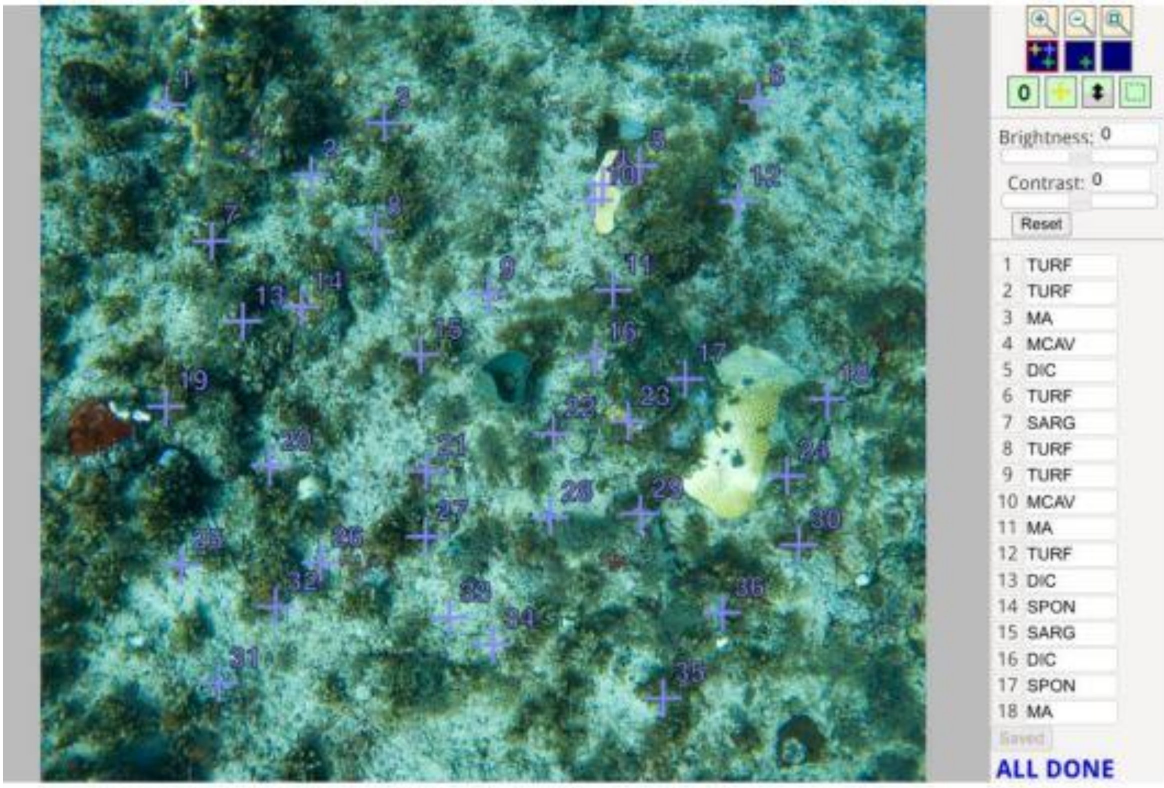


Figure 36. *CoralNet AI-based species identification.*

Using the QYSEA FIFISH inspection-class ROV for this project offered significant advantages over traditional diver-based monitoring. Unlike divers, the ROV could operate continuously in the frequent rough and unpredictable conditions of the Saba Bank, where diving was often not possible. It also allowed for the exploration of deeper areas beyond the reach of divers and covered much larger areas in a single deployment. Additionally, its compact size allows for easy transportation as carry-on luggage, making the logistics to more remote areas easier. Previously, larger ROVs were used but these were difficult and costly to transport.

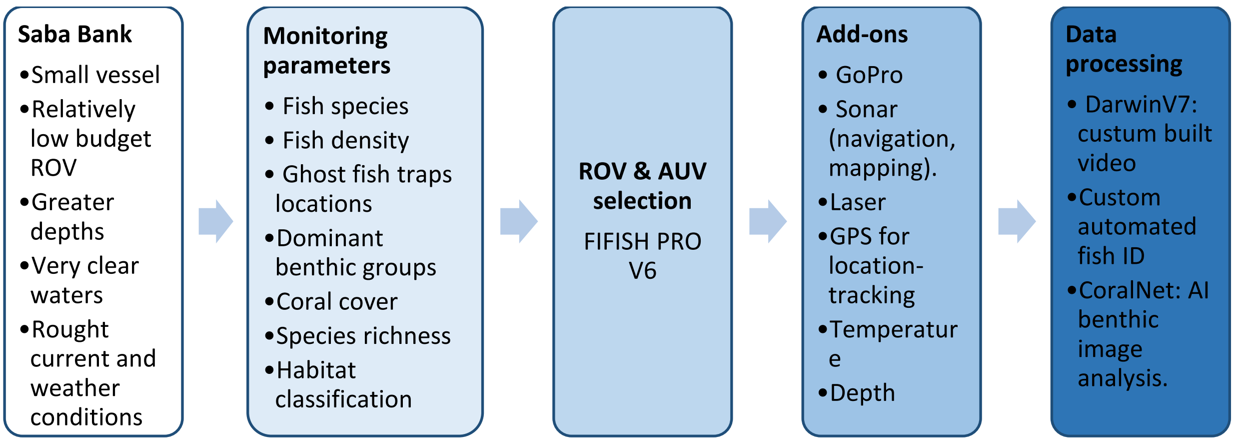


Figure 37. *Monitoring setup for Saba Bank.*

7.3 Geogenic reefs

Figure 38. *Geogenic reefs at the Borkum Reef Grounds during the MONS survey in August 2024.*

Geogenic reefs are underwater formations primarily composed of non-living materials such as rock, sand, or mud. These reefs can take various forms, including rocky outcrops, submerged cliffs, or sandbanks, depending on the underlying geological structure and local environmental conditions. Geogenic reefs often provide important habitats for marine life, serving as shelter, breeding grounds, and feeding areas for a diverse species community. They can also play a role in shaping coastal landscapes and influencing ocean currents and sediment transport patterns. Monitoring geogenic reefs involves assessing their physical characteristics, such as size, shape, and composition, as well as studying the associated marine life to understand their ecological significance.

ROVs and AUVs can provide valuable tools for assessing these geogenic reefs and add to the more traditional monitoring methods:

- ROV
  - Capture high-resolution imagery and video for detailed inspection of reef structures such as rocky outcrops, cliffs, or boulder fields.
  - Equipped with sampling tools to collect water, sediment, or biological material from specific reef locations.
  - Suitable for close-up documentation of structural integrity, sedimentation effects, or biofouling.
  - Enable real-time observation.
  - Etc.
- AUV
  - Perform autonomous and large-scale surveys to map the extent and morphology of geogenic reef features.
  - Generate 3D models and bathymetric maps to assess reef topography and spatial complexity.
  - Collect visual data for habitat classification and analysis of species distribution.
  - Collect information on environmental parameters such as temperature, salinity, turbidity, oxygen levels, and chlorophyll-a.
  - Efficiently survey remote or logistically challenging areas (such as further offshore).
  - Allow for repeatable and standardized missions.
  - Etc.

7.3.1 Case study: monitoring a stony reef - Borkum Reef Grounds, The Netherlands

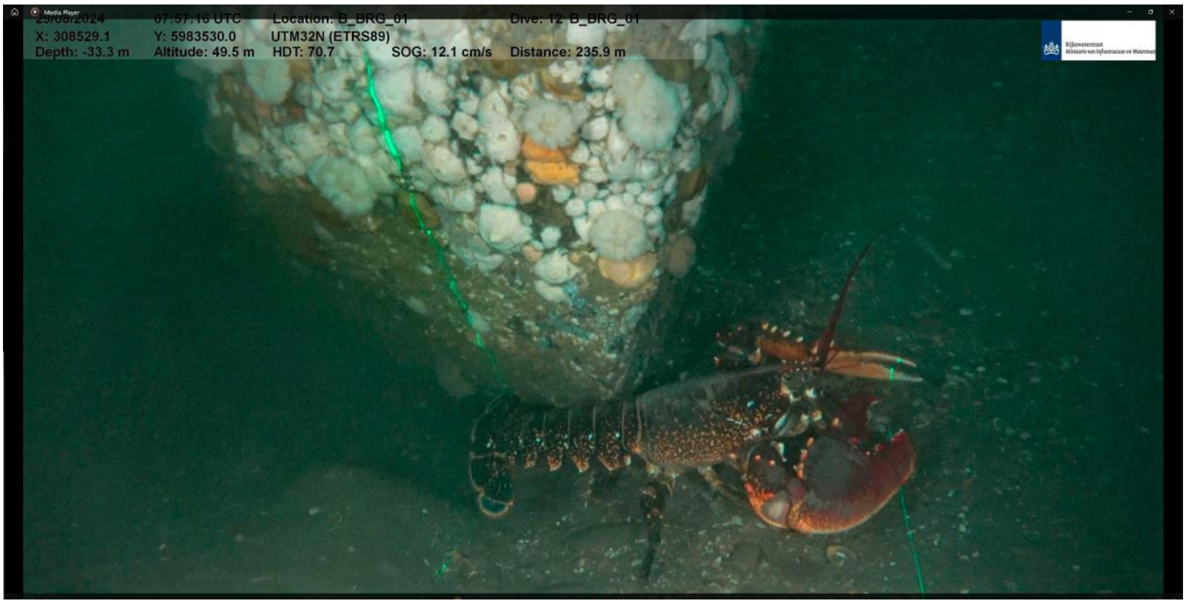


Figure 39. *Geogenic reefs at the Borkum Reef Grounds during the MONS survey in August 2024.*

For monitoring part of the Borkum Reef Grounds (Borkumse Stenen) in The Netherlands (2024) a work-class ROV was used. The advantage compared to smaller inspection-class ROVs is that it can be used under a wider range of weather and current circumstances. The area is covered with natural stony reefs. The Borkum Reef Grounds will be closed for seafloor disturbing fisheries under the European Fisheries Policy in the near future. The focus of the monitoring campaign under the MONS program was to fill in knowledge gaps on the presence and distribution of abiotic reefs (H1170) as well as biotic reefs (*Lanice conchilega*), and to describe biodiversity patterns for EUNIS habitats. This information was needed to design a 3-yearly monitoring program (MWTL) for future assessments of the quality status and development of the different benthic habitats present.

Transects were monitored using a Saab Panter ROV operated by two Rijkswaterstaat operators in close cooperation with the captain to keep the ROV at the right distance to the vessel. The typical flight speed over the seafloor was 10-15 cm/s. This allowed for obtaining a good image quality useful for subsequent species determination. Faster speeds resulted in blurry images.

The locations of the ROV transects were based on side-scan sonar and MBES images acquired during the night before. ROV transects were chosen to cover acoustically interesting features that needed ground truthing. In the stony reef areas the focus was on filming as many stones and boulders as possible, rather than flying a straight line. One ROV transect of 200-250 m takes about 1 hour of work.

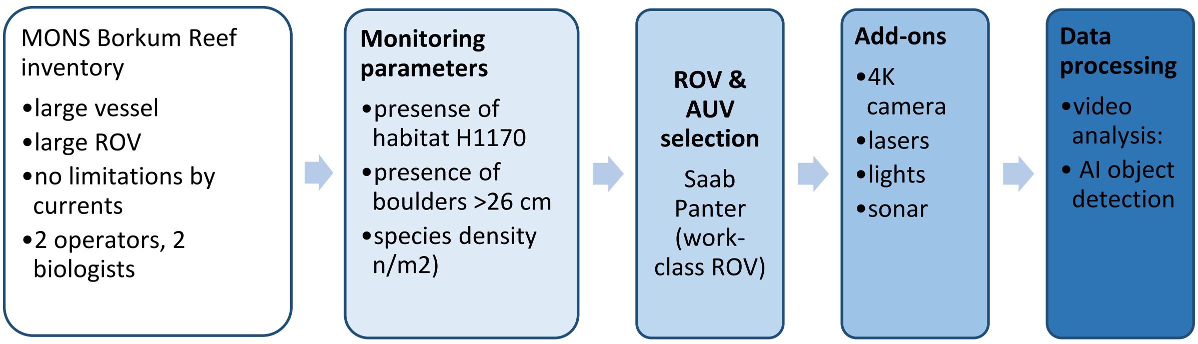


Figure 40. *Project outline for monitoring abiotic reefs in the Borkum Reef Grounds.*

7.4 Artificial reefs and NIDs

Figure 41. *Artificial reef at the Borkum Reef Grounds during the ARK Borkum Reef survey in August 2024.*

Artificial structures in the sea refer to human-made installations or constructions placed within marine environments for various purposes. These structures can range from offshore wind turbines, oil and gas platforms, and shipwrecks to scour protection and NID elements (e.g., reef cubes and fish hotels). Each type of artificial structure serves a specific function, such as energy production, transportation, or habitat enhancement. The structures also provide substrate for marine organisms to colonize, forming frequently complex ecosystems similar to natural reefs. These artificial reefs can thereby play a role in increasing local biodiversity by providing hard substrate for various marine species, creating habitat opportunities where they might not exist naturally. Monitoring artificial structures involves studying their ecological impact, biodiversity, and structural integrity over time, as well as identifying potential risks to ensure sustainable coexistence with marine ecosystems.

Mobile platforms can be used for monitoring of the artificial structures. Equipped with advanced sensors, cameras, and arms, ROVs can navigate around the artificial structures, allowing for detailed visual inspections and data collection. Video inspection with ROVs enables researchers to monitor the (epi)benthic community surrounding and on the structures. Furthermore, using artificial intelligence systems, ROV footage can be analysed to detect species and determine biodiversity, providing insights into the ecological dynamics of artificial reefs. Additionally, ROVs can be used to obtain biological scrape samples from the structures, which can be analysed in the laboratory to determine epibenthic biodiversity. By combining video inspection, artificial intelligence, and biological sampling techniques, researchers can assess the ecological status of artificial structures and inform conservation and management efforts effectively.

ROVs and AUVs can be valuable tools for monitoring artificial reefs and NIDs:

- ROV
    - Capture high-resolution imagery and video to assess colonization by marine organisms and structural condition of artificial reef elements or NID elements.
    - Close-up inspection of biofouling, habitat complexity, and ecological functionality.
    - Equipped with sampling tools to collect biological, sediment, or water samples.
    - Allow for real-time observation.
    - Etc.

- AUV
    - Conduct autonomous large-scale surveys to map the spatial distribution and spillover effect of artificial structures and NID installations.
    - Collect information on environmental parameters such as temperature, salinity, turbidity, oxygen levels, and chlorophyll-a.
    - Efficiently survey remote or logistically challenging areas (such as further offshore).
    - Allow for repeatable and standardized missions.
    - Operate efficiently in areas that are difficult to access regularly by divers or vessels.
    - Etc.

7.4.1 Case study: Monitoring Rock reefs in offshore windfarm HKZ, The Netherlands

Figure 42. *Scour protection in offshore windfarm Hollandse Kust Zuid; GoPro video frame using the BeeX ROV.*

In September 2023, the scour protection and artificial reefs surrounding wind turbines in the Duch North Sea offshore windfarm Hollandse Kust Zuid were monitored as part of the KOBINE[23] project. At two wind turbines, the regular scour protection was enriched with larger boulders (>30 cm) to enhance artificial reef formation as a NID measure. It was assessed whether these boulders improved the biodiversity compared to a regular scour protection (consisting of smaller stones) by visual inspection using the BeeX A.KANTABILIS ROV (Figure 42 & 43). The ROV followed a pre-programmed lawn mowing pattern at the scour protection at approximately 0.5 to 1 m above the seabed flying over an area of approximately 6 x 20 m. The lawn mowing pattern consisted of parallel lines, covering the study area by flying e.g. 6 meter to the East, 2m to the South, 6 m to the West, 2 m to the South, etc. A GoPro was attached to the platform to allow for 4K video recording. Additionally, at each location sonar images were captured of the rock reefs (Figure 44).

[23] https://www.wur.nl/nl/onderzoek-resultaten/kennisonline-onderzoeksprojecten-lvvn/kennisonline/kosten-en-biodiversiteit-natuurinclusieve-energie-kobine.htm

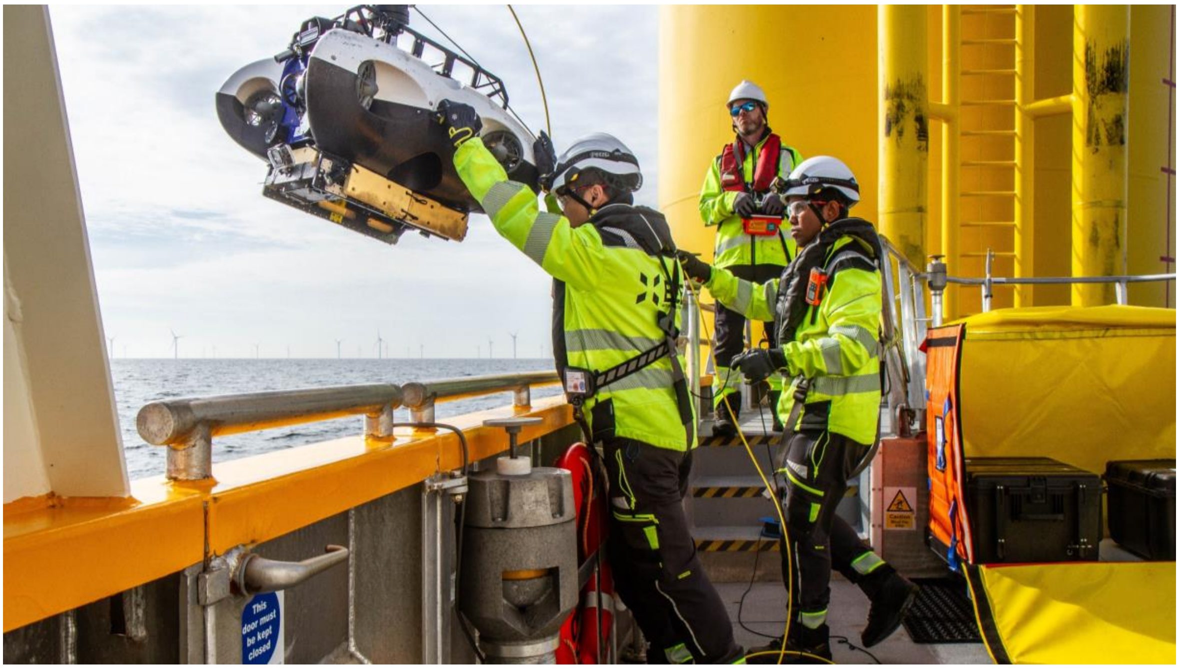


Figure 43. *Monitoring using the BeeX ROV (photo: Oscar Bos, WMR).*

During the project an AI pipeline was developed that could identify and count species present from the collected GoPro footage to determine the biodiversity pattern at the scour protection. In the first step, still images were extracted from the video. In order to prevent counting individuals twice, none overlapping stills were extracted from the video file. The interval time was kept as small as possible to obtain the largest amount of data and was determined based on the lateral speed of the ROV, camera angle relative to the seabed, and frame rate (width of view on the GoPro footage). Next, the most common species (including blue mussels, crab, starfish, several anemone species, etc.) of part of the data were annotated using boxes in annotation software (DarwinV7) to train a CV model for automatic species recognition. This obtained a datafile with x-y positions for each annotation. The model was then applied to stills that had not been analysed yet.

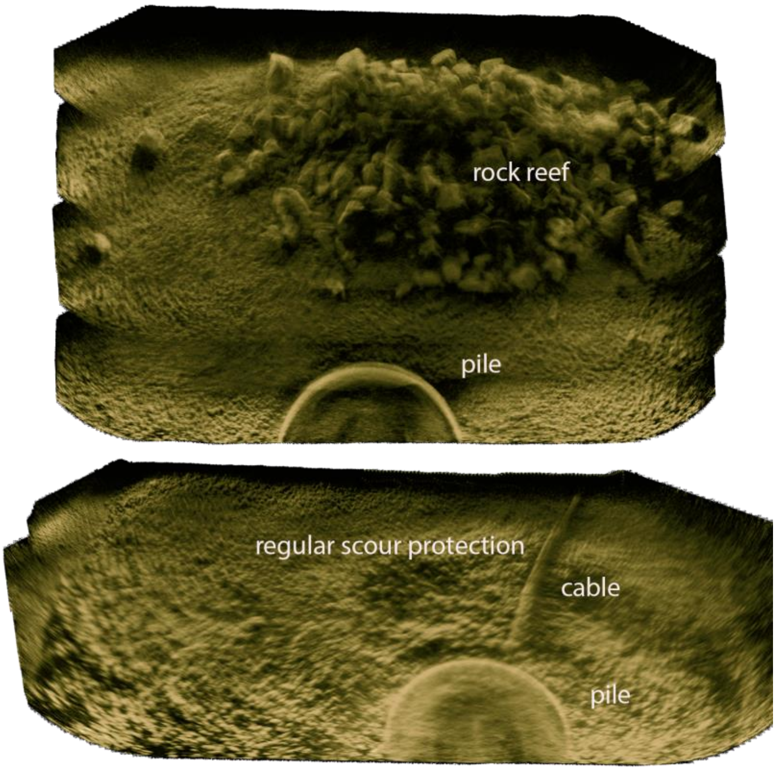


Figure 44. *Offshore windfarm Hollandse Kust Zuid (Vattenfall), June 2023. Top image: side-scan sonar of a rock reef on the scour protection of a wind turbine made with data collected by the BeeX ROV. Lower image: regular scour protection. The sizes of the areas are approximately 6 x 20 m.*

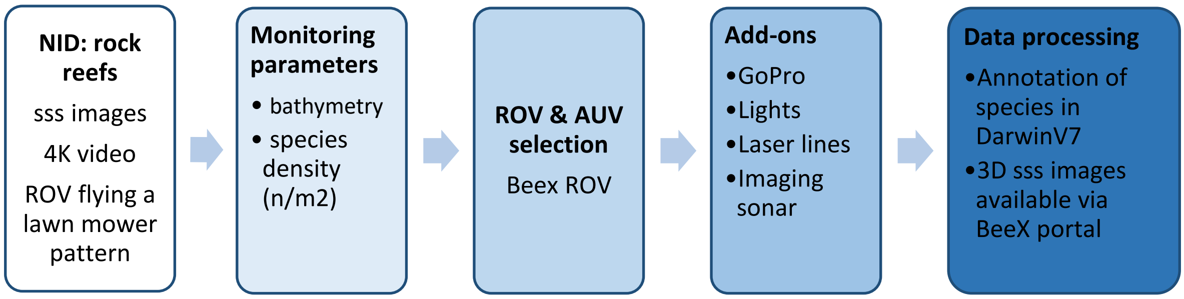


Figure 45. *Project outline for monitoring of rock reefs in offshore windfarm HKZ.*

7.5 Aquaculture

Figure 46. *Mussel farm in Bruinisse, The Netherlands (photo: Oscar Bos, WMR)*

(Offshore) Aquaculture (such as seaweed and mussel aquaculture) involves cultivation for various purposes, including food production, bioremediation, and the extraction of bioactive compounds. Seaweed cultivation in the North Sea typically uses floating or submerged structures anchored to the seabed, where seaweed species such as sugar kelp (*Saccharina latissima*) are grown (Bernard et al., 2020). Mussel aquaculture, on the other hand, often involves the suspension of mussel ropes or longlines from floating rafts or structures (Figure 46), allowing mussel spat to attach and grow in the water column. Monitoring seaweed and mussel aquaculture involves assessing species diversity, growth rates, biomass production, and environmental impacts. This process may include measuring water quality parameters, tracking growth and biomass accumulation, evaluating ecological interactions with native species, and assessing the overall sustainability of aquaculture practices.

ROVs and AUVs can help in the monitoring of (offshore) aquaculture systems, such as seaweed and mussel farms:

- ROV
    - Capture high-resolution imagery and video for visual inspection of aquaculture infrastructure (e.g. ropes, rafts, anchors) and organism health.

- Perform close-up assessments of biofouling, species colonization, and potential damage to cultivation lines.
    - Equipped with sampling tools to collect water, sediment, or biological samples.
    - Allow for real-time observation.
    - Assist in maintenance inspections.
    - Etc.
- AUV
    - Conduct autonomous surveys of large aquaculture sites, including layout mapping and structural positioning.
    - Collect information on environmental parameters such as nutrient levels, temperature, salinity, turbidity, oxygen levels, and chlorophyll-a to assess growing conditions.
    - Gather imagery and data for estimating biomass, species composition, and growth performance across different sections.
    - Etc.

7.5.1 Case study: monitoring mussel farms, The Netherlands

Figure 47. *The OOS submersible mussel farm is put into place, summer 2024 (photo: OOS International).*

In 2025, an mussel farm will be installed within the Borssele offshore windfarm as a pilot project to explore the feasibility of offshore mussel cultivation in combination with offshore wind energy production. For this pilot a depth-adjustable submerged mussel farm platform is designed by OOS International in such a way that it can withstand the strong and adverse offshore conditions in the Dutch North Sea (Figure 47). If the pilot becomes successful a larger scale mussel test farm platform is planned to be deployed in the future in windfarm Borssele III. It is intended to inspect the mussel lines using ROV monitoring to determine mussel production over time and the associated biodiversity.

A first test for biodiversity monitoring of a mussel farm using a ROV was conducted in an inshore mussel farm near Bruinisse (The Netherlands). Video footage was collected using a BlueROV2 and an attached GoPro, capturing the mussel lines and marine growth. Attached organisms and fish species could be identified and annotated to support the development of a later biodiversity assessment model (Figure 48).
This test study provided valuable insights. For example, training a model to identify individual mussels can be challenging due to overlapping colours. Additionally, seaweed growth may block large portions of the footage.

Figure 48. *Test video footage with polygon annotations in DarwinV7 of a mussel farm in Bruinisse, The Netherlands.*

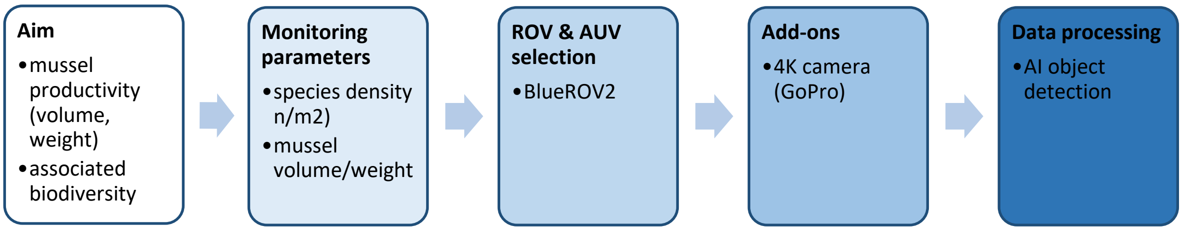


Figure 49. *Monitoring setup for the OOS mussel farm.*

8 User findings and recommendations

As part of this project a questionnaire was distributed among end-users of inspection-class ROVs and small AUVs within the field of marine ecology (research institutes and consultancies). The outcome of the survey showed that these devices are used for a variety of purposes (Table 6) including aquaculture monitoring and the visualisation of offshore artificial structures.

Different set-ups of ROV and AUV platforms were used to conduct type of imagery and acoustic monitoring, sample collection and environmental measurements. Many of the systems that were used could be equipped with various add-ons depending on the research objectives. Moreover, some platforms featured autonomous and independent monitoring capabilities, which enhanced precision and reduced environmental impact by minimizing vessel travel distances. It enabled standardized monitoring over extensive distances and periods, which surpasses the capabilities of diver-based monitoring methods. For other purposes, such as specific measurements at certain positions or surfaces, the flexibility of ROVs was listed as valuable tool. Recent developments have led to the integration of artificial intelligence software packages within the mobile platforms and now allow for automatic visual image recognition. However, the survey also indicated that reliable navigation, especially in low-light conditions and during manual operation remains challenging.

Traditional positioning systems like GPS do not function properly underwater, which makes it difficult to determine the platform position without alternative systems that require more costs and other add-ons. Moreover, the capabilities of many platforms are limited by current speed, with currents over 1.5 m/s often restricting operation or requiring higher-cost platforms such as work-class ROVS. Furthermore, manual navigation in low light environments is impossible, requiring the use of additional lights and higher-quality cameras for optimal navigation by sight and video inspection monitoring. The limited camera quality frequently integrated in ROVs often hampers effective visual inspection in projects. As a result, external high-resolution camera add-ons, such as 4K GoPros, are still necessary to obtain high-resolution imagery.

Another point raised in the survey results is the difficulty in accessing raw data for post-processing, often due to proprietary portal environments associated with the systems used. Ideally, data should be saved in standard formats (e.g., jpeg, png, (geo)tiff, mp4) to facilitate easier use and broader application. During the processing phase, a frequently listed limitation is the lack of sufficient training data, which makes the development of effective CV models for species recognition difficult. Although creating well trained models requires time and effort, this process could be boosted by establishing a public database containing raw data from ROVs/AUVs alongside annotated training datasets. Such a database does not yet exist but would enhance data accessibility for analysis. This would also require a standardized approach for the monitoring so that all data is comparable.

Table 6. *Overview outcome questionnaire: how marine ecologists use ROVs and AUVs in their work and which challenges they experience.*

1. How are ROVs/AUVs used?
Visualization of Offshore Artificial Structures: wind monopiles, scour protection, oil and gas platforms
Biogenic reefs
Seabed bathymetry
Arctic sea ice
Oil spill response
2. Functionalities
Imagery monitoring: photo and video
Sample Collection: water, sediment and biological samples
Environmental measurements: temperature, salinity, chlorophyll concentration
3. Advantages

Add-ons tailored to research objectives
Precision monitoring with minimal environmental impact (compared to diver-based methods for instance)
Reduced vessel travel distances
Standardized monitoring across extensive areas and durations
Integration with AI: automatic image recognition (e.g., species detection, habitat mapping)
Well-suited for long-term monitoring programs
4. Challenges
Navigation reliability: ineffectiveness of RTK GPS underwater and limited navigation in currents >1.5 m/s
Low light and manual navigation: requires lights and high-quality cameras for video inspection
Data processing: difficult accessing raw data from proprietary portals
Standardized data accessibility: absence of a public database for ROV/AUV data

8.1 Tips and tricks for successful monitoring

We have observed that monitoring using UUVs (ROVs and AUVs) often encounter challenges in the field that could be avoided with proper planning. To enhance the success of these platforms in marine ecological research, we outline several considerations to keep in mind:

Deployment of ROV/AUV:

1. Power requirements:
   - Ensure sufficient power to collect data for the entire task duration.
   - Account for add-ons, which increase power consumption and require more data storage capacity.
2. Propulsion capacity:
   - Verify if the device can handle strong currents; smaller devices may struggle.
   - Be aware that high current flow can shorten battery life as energy is used for stabilization.
   - Consider the risk of unstable positioning leading to data corruption (e.g., motion blur in videos/images).
3. Pre-deployment considerations (important input for the RAMS: Risk Assessment Method Statement):
   - Assess water quality for floating debris or obstacles.
   - Check for the risk of damage to exposed thrusters due to entanglement (e.g. in seaweed).
4. Tether management:
   - The tether length should be adequate for the survey depth and planned transect coverage while considering the risk of entanglement.
   - A longer tether allows for greater operational flexibility but may also lead to increased drag and handling difficulties.
   - The diameter affects buoyancy, hydrodynamics, and power transmission. Thicker tethers can carry more power and data but increase drag and manoeuvrability challenges.
   - Neutral or slightly positive buoyancy is preferred to avoid excessive tether drag, entanglement, and seabed disturbances.
   - Floats/weights can be added on the tether to maintain neutral buoyancy.
   - Strong currents can cause tether drag, affecting ROV stability and manoeuvrability.
   - Ensure the tether does not damage habitats such as biogenic structures.
5. Camera capabilities:
   - Evaluate built-in image-enhancement features, such as low light capabilities.
   - Use cameras suited for tasks where artificial illumination is not feasible.
   - Keep in mind that an artificial light source mounted on the mobile platform can cause scatter in images or videos when the light reflects off debris in the water column.

6. Navigation:
    - Depth hold using DVL may be disrupted when the mobile platform gets too close to the seabed, as sediment disturbance can interfere with the ability of the device to accurately register the distance to the sea bottom.

Visual data analysis:

1. Data quality:
    - Ensure the quality of videos/images is sufficient for the task.
    - For species detection, human annotators must be able to recognize the species in the footage.
2. AI model structure:
    - Design AI models with multiple modules if required by the task.
        - Example: For estimating species richness from video footage, include:
            - A module for detecting different species.
            - A module for counting the detected species.
3. Dataset volume and variability:
    - Collect sufficient data to capture variations in species phenotype and observation conditions.
        - Example: For species with seasonal phenotype changes, collect data throughout the year to cover this variation.
    - Minimize sources of variation in observation conditions (e.g., stabilize camera type, settings, and illumination).
4. Morphometric measurements:
    - Maintain a fixed or known distance from the camera to the object for accurate measurements if using a mono camera.
    - Use scaling lasers.
    - Use stereo cameras to capture depth (volume) information when required.
5. Acoustic sensor data:
    - Recognize that analysing output images (echograms) from acoustic sensors often requires expert knowledge.
    - Experts may need to identify and define target objects in the echograms for effective analysis.

9 Future developments

9.1 Future developments

As demonstrated in this report, UUVs can be a useful tool in ecological research with a wide range of applications. Their growing implementation within monitoring programs suggests an increasing reliance on these technologies for future research, which will likely partly replace or add to the more traditional monitoring methods such as diver-based monitoring. Beyond research, these platforms are widely used across various industries. This opens opportunities for collaboration between sectors, such as security, military, and infrastructure inspection, to support data sharing and integration into ecological studies.

9.1.1 Integration of multiple platforms

A development already emerging in some sectors and likely to become increasingly used in future research, is the integration of multiple platforms. For example, combining USVs (unmanned surface vehicles) (Figure 50) or ASVs (autonomous surface vehicles) (often powered by solar energy) with AUVs offers a more climate-neutral approach to ecological research, particularly in more remote or hard-to-access areas and reduces the reliance on crewed vessels (Figure 51). Such advancements could become relevant in industries like the offshore wind energy, where wind farms are being constructed farther from shore. The use of combined platforms allows for monitoring in these offshore environments. This is especially important given the growing emphasis in tender criteria on monitoring the impacts of construction on underwater biodiversity.

Figure 50. *Artist impression of the 12m unmanned FUGRO service vehicle that will be operational in the North Sea[24].*

[24] : https://www.fugro.com/expertise/remote-and-autonomous-solutions

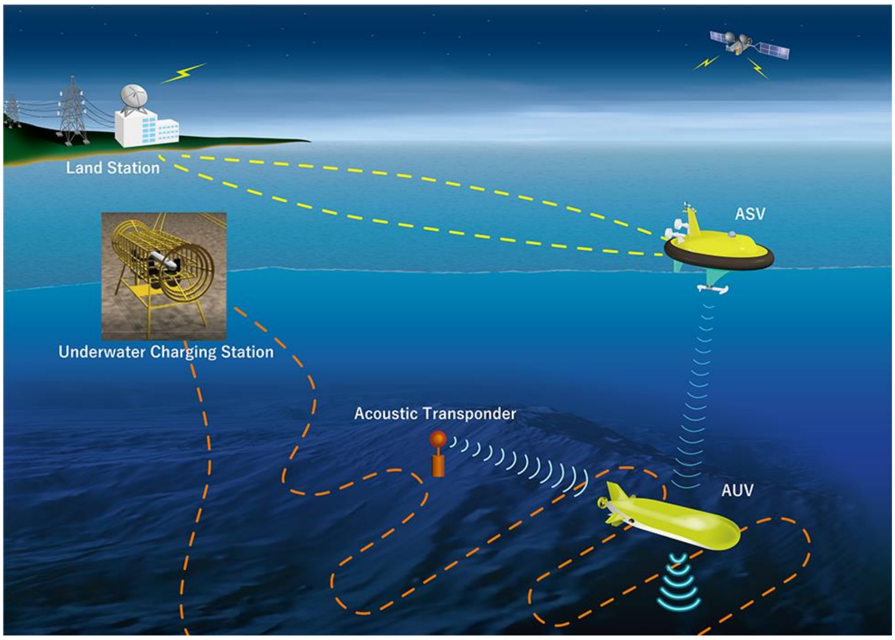


Figure 51. *Example of cooperation between different platforms[25].*

Another form of platform collaboration, already widely used in military applications such as mine detection, involves deploying multiple AUVs simultaneously to map larger areas. These AUVs can communicate and coordinate with each other, which enables efficient inspection over extensive regions.

9.1.2 Integration of multiple sensors

At Wageningen University, researchers are working on a triggering eDNA sampling device that is activated by live fish recognition using AI from camera (Yu et al., 2024). The box can be placed on the seafloor over a longer period of time and collect eDNA samples, e.g. in offshore windfarms (Figure 52). A similar combination of sensors could be developed for UUVs.

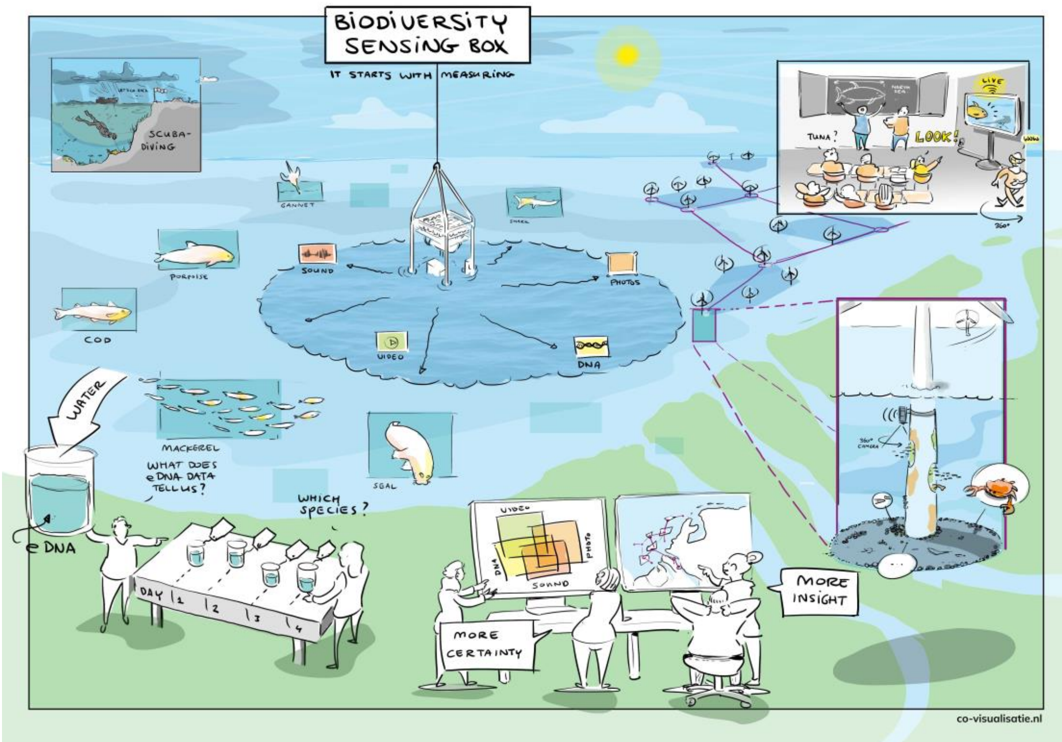


Figure 52. *The biodiversity box, developed by WUR[26]. The box combines different sensors to detect fish. More information in (Yu et al., 2024). (Figure: provided by R. Nijland, WUR).*

[25] https://www.jamstec.go.jp/engd/e/img/development/robotics/p-robotics__automatic.png

[26] https://www.wur.nl/en/project/fish-sensing-box.htm

9.2 Challenges and future perspective

One of the main challenges pointed out in the findings of the questionnaires (*Chapter 8*) is the limited use of these platforms in high current environments, where monitoring is often feasible only during slack tide. Overcoming this issue requires greater thruster capacity, which is currently constrained by battery limitations. While high performance systems already exist for such conditions, they are often associated with significantly higher costs. However, the rapid advancements in these technologies suggest that cost effective platforms capable of operating in stronger currents will likely develop in the near future.

These advancements will not only lead to better endurance battery technology but will also significantly improve the quality of data gathered by sensors. As navigation systems become more precise and sensor capabilities continue to advance, these platforms will be able to perform highly detailed monitoring that was previously impossible. For example, new technologies such as Synthetic Aperture Sonar could allow for the identification of individual organisms within complex habitats like *Sabellaria* and *Lanice* reefs. Additionally, the increasing competition among smaller players in the industry is expected to drive down operational costs, making these advanced technologies more accessible for smaller ecological research projects. Despite these advancements, it remains important to establish a sort of centralized system for storing and sharing the data collected from these platforms, to ensure that the information gathered can be easily accessed and analysed for research.

10 Conclusions

Below a list is provided with the main conclusion found during this study:

- Traditional monitoring techniques may not be fully comprehensive, and the use of UUVs can complement, add, or in some cases even replace these more conventional monitoring methods.
- There a many models of inspection-class ROVs and small AUVs available on the market nowadays (see Annex 3 & 4) and various startup companies are interested in advancing the field of ecological research.
- The various ROVs and AUVs described in this report usually can do similar tasks (e.g., film in 4k video, measure different parameters, use of grabbers for ROVs) Therefore no technical comparison was made between the systems. Furthermore, it is difficult to describe all potential limitations regarding the use of these systems in ecological monitoring settings as this would require more field tests in different areas.
- Most small platforms can be customised and equipped with various add-on configurations, to adapt them to the needs of the research project.
- Operating ROVs and AUVs from the shore or a small ship as a researcher requires training, experience and expertise and can sometimes be too difficult. However, some manufactures offer pilots and rental options.
- Inspection-class ROVs and small AUVs are not always the best tool during monitoring campaigns. For large scale monitoring in all-weather circumstances, it may be necessary to use larger ships and work-class ROVs, as is common practise in the oil- and gas industry.
- The use of AI for image analysis has advanced rapidly in recent years. This report provides a 'beginners guide' how to start analysing such data and how to use CV models.
- In the near future (and in some cases already in practice) industrial and military operations are moving towards integrated multi-platform systems. These setups combine USVs/ASVs with ROVs/AUVs to monitor the seafloor and offshore assets, all without requiring humans at sea. This shift is also driven by factors such as the rapid growth of the offshore wind sector, the need to reduce CO_2 emissions, and the shortage of skilled maritime personnel.
- In future ecological monitoring projects, inspection-class ROVs and small AUVs may be equipped with various sensors that can work together.

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12 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

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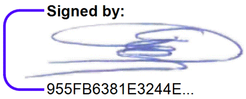
Justification

Report: C028/25
Project Number: 4318100470

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: Sander Glorius
Marine Researcher

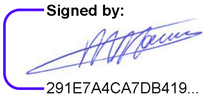
Signature:



Date: 7 May 2025

Approved: Dr. A.M. Mouissie
Business Manager Projects

Signature:



Date: 7 May 2025

Annex 1 Questions questionnaire (Manufacturers)

- What is the name of the ROV/AUV?
- What is the current application/purpose of the vehicle?
- Are you engaged in business activities within Europe?
- If your business operations do not extend to Europe, where is your primary business conducted?
- What is the Technology Readiness Level (TRL) level of the vehicle?
- Is the vehicle available for rental and purchase?
- Is it possible to rent the vehicle for a test use or demonstration?
- How can the vehicle be rented?
    - Independent use without training
    - Independent use with training
    - Rental of vehicle with company team
    - Other
- What are the approximate daily costs for rental?
- What are the approximate costs for purchase
- What is the output of the data collected by the vehicle? (select multiple answers if applicable)
    - Sonar
    - Video
    - Photo
    - Georeferenced visual footage
    - Bathymetry information
    - Logged information abiotic parameters (e.g. Temperature, Oxygen- & Nutrient levels, etc.)
    - 3D Models
    - Map
    - Other
- How is the vehicle operated?
    - Autonomous
    - Manually
- Is a crane required to lower/remove the vehicle from the water?
- What is the effective monitoring depth range of the vehicle?
- Does the vehicle come equipped with lights and lasers?
- What add-ons or accessories can come with the ROV or AUV?
- Is the vehicle capable of real-time (live) data transmission?
- In what format is the data stored?
    - Default files types (JPEG, PNG, CSV, XLSX, MP4, etc.)
    - Dedicated software environment/portal (proprietary/coded)
    - No data is stored
    - Other
- Has this vehicle been used in marine ecological monitoring activities before?
- If the vehicle has been applied in marine ecological monitoring before, which projects have implemented it?
- Has a Risk Assessment and Method Statement (RAMS) been prepared for deploying the vehicle within offshore wind farms?
- What factors may influence the application and accuracy of the vehicle?
    - Currents
    - Turbidity
    - Light conditions
    - Underwater acoustics (e.g. background noise)
    - Biological interference (e.g. presence of fish or large plankton concentrations)

- Water density and stratification
- Seabed composition
- Salinity variations
- Temperature fluctuations
- Other

- Are there any comments regarding the use of this vehicle for marine ecological monitoring purposes?

Annex 2 Questions questionnaire (End-users)

- Do you have experience using ROVs and AUVs in marine ecological monitoring activities?
- Which ROVs and/or AUVs have you used?
- Could you provide a link to the website or contact information of the devices you have used previously?
- Has the use of ROVs and AUVs successfully contributed to achieving your monitoring goals in your research program?
- How can ROVs and AUVs contribute to marine monitoring activities in your research?
    - Reach areas in places otherwise inaccessible
    - Environmental measurements
    - Collect samples
    - Video & Photo
    - Other
- What improvements do you believe can be made/what is missing in the use of ROVs and AUVs for marine ecological monitoring?

Annex 3 Overview of inspection-class ROVs

Overview of some commercial handheld ROVs available on the market for marine ecological research. List based on experience authors, Oceanology International Conference[27], and the Ocean Robotics Planet buyer's guide 2024[28]. (Product images taken from their respective websites).

Blue Robotics		
BlueROV2		
	*Depth*	100m
	Endurance	2h-6h
	Dimensions	457mm(l) × 338mm(w) × 254mm(h)
	Weight (in air)	13.4kg
	Payload	Various payloads
	Max forward speed	1.5m/s or 3kts
	Video	1080p HD
	Website	https://bluerobotics.com/store/rov/bluerov2/
Deep Trekker		
DTG3		
	*Depth*	200m
	Power	Various battery options
	Dimensions	279mm(l) × 325mm(w) × 258mm(h)
	Weight (in air)	8.5kg
	Payload	Customizable
	Max forward speed	N/A
	Video	Full HD 1080P
	Website	https://www.deeptrekker.com/products/underwater-rov/dtg3
PHOTON		
	*Depth*	120m
	Power	Various battery options
	Dimensions	481mm(l) × 332mm(w) × 228mm(h)
	Weight (in air)	11.6kg

[27] https://www.oceanologyinternational.com/london/en-gb.html

[28] https://oceanroboticsplanet.com/tportal_upload/md_buyersguide/buyersguide_2024.pdf

	Payload	Customizable
	Max forward speed	N/A
	Video	Enhanced 4K Camera
	Website	https://www.deeptrekker.com/products/underwater-rov/photon
PIVOT		
	*Depth*	305m
	Endurance	3h
	Dimensions	576mm(l) × 360mm(w) × 310mm(h)
	Weight (in air)	17kg
	Payload	Customizable
	Max forward speed	1.5m/s or 3kts
	Video	Enhanced 4K Camera
	Website	https://www.deeptrekker.com/products/underwater-rov/pivot
REVOLUTION		
	*Depth*	305m
	Endurance	3-6h
	Dimensions	717mm(l) × 440mm(w) × 235mm(h)
	Weight (in air)	26kg
	Payload	Customizable
	Max forward speed	3.5kts
	Video	Enhanced 4K Camera
	Website	https://www.deeptrekker.com/products/underwater-rov/deep-trekker-revolution
ARGUS REMOTE SYSTEMS		
ARGUS MINI/Inspector		
	*Depth*	600m
	Power	3kW
	Dimensions	900mm(l) × 650mm(w) × 500mm(h)
	Weight (in air)	100kg
	Payload	10kg
	Max forward speed	3kts
	Video	4K optional

	Website	https://www.argus-rs.no/inspector
BlueLink		
SARbot		
	*Depth*	300m
	Power	1.2kW
	Dimensions	457mm(l) × 575mm(w) × 254mm(h)
	Weight (in air)	13.5kg
	Payload	Various payloads
	Max forward speed	2kts
	Video	Full 1080p HD Video
	Website	https://blue-linked.com/sarbot
BLUEYE ROBOTICS		
BLUEYE PIONEER		
	*Depth*	150m
	Endurance	2h
	Dimensions	485mm(l) x 257mm(w) x 354mm(h)
	Weight (in air)	8.6kg
	Payload	Various payloads
	Max forward speed	1.5m/s or 3kts
	Video	FHD: 1920 x 1080 25/30 Fps, HD: 1280 x 720 25/30 Fps
	Website	https://www.blueyerobotics.com/products/pioneer
BLUEYE X1		
	*Depth*	305m
	Endurance	2-5h
	Dimensions	485mm(l) x 257mm(w) x 354mm(h)
	Weight (in air)	8.6kg
	Payload	Various payloads
	Max forward speed	1.5m/s or 3kts
	Video	FHD: 1920 x 1080 25/30 Fps, HD: 1280 x 720 25/30 Fps
	Website	https://www.blueyerobotics.com/products/x1

BLUEYE X3		
	*Depth*	305m
	Endurance	2-5h
	Dimensions	485mm(l) x 257mm(w) x 354mm(h)
	Weight (in air)	8.6kg
	Payload	Various payloads
	Max forward speed	1.5m/s or 3kts
	Video	FHD: 1920 x 1080 25/30 Fps, HD: 1280 x 720 25/30 Fps
	Website	https://www.blueyerobotics.com/products/x3
DEEPINFAR		
WHITESHARK Mini		
	*Depth*	100m
	Power/ Endurance	N/A
	Dimensions	N/A
	Weight (in air)	3.8kg
	Payload	Various payloads
	Max forward speed	2kts
	Video	1080P Full HD camera
	Website	https://www.deepinfar.com/en-product-center-rov?productType=ROV
HETUN		
	*Depth*	300m
	Power	3kW
	Dimensions	N/A
	Weight (in air)	24-34kg
	Payload	Various payloads
	Max forward speed	N/A
	Video	N/A
	Website	https://www.deepinfar.com/en-product-center-rov?productType=ROV

Deep Ocean Engineering

PHANTOM FIREFLY

Depth	46m
Power/ Endurance	N/A
Dimensions	190mm(l) × 146mm(w) × 343mm(h)
Weight (in air)	6.35kg
Payload	Various payloads
Max forward speed	N/A
Video	470 lines of TV
Website	https://www.deepocean.com/rov-phantom-firely.php

PHANTOM P-150

Depth	53.3m
Power/ Endurance	N/A
Dimensions	642.5mm(l) × 352.4mm(w) × 292.1mm(h)
Weight (in air)	18kg
Payload	Various payloads
Max forward speed	N/A
Video	HD Camera (1080p)
Website	https://www.deepocean.com/rov-phantom-p150.php

PHANTOM T-SERIES

Depth	300m (500m optional)
Power	90-250 VAC, Single phase
Dimensions	889mm(l) × 559mm(w) × 406mm(h)
Weight (in air)	39.5kg
Payload	Various payloads
Max forward speed	4kts at surface
Video	HD camera standard (1920x1080)
Website	https://www.deepocean.com/rov-phantom-t5.php

PHANTOM T5 DEFENDER

Depth	300m (500m optional)
Power	3.3kW
Dimensions	889mm(l) × 559mm(w) × 406mm(h)
Weight (in air)	65.8
Payload	Various payloads
Max forward speed	4kts at surface
Video	HD camera standard (1920x1080)
Website	https://www.deepocean.com/rov-phantom-t5-defender.php

PHANTOM L-SERIES

Depth	500m (800m optional)
Power	9kW
Dimensions	1066.8mm(l) × 800.1mm(w) × 571.5mm(h)
Weight (in air)	97.5kg
Payload	Various payloads
Max forward speed	3kts at surface
Video	HD camera standard (1920x1080)
Website	https://www.deepocean.com/rov-phantom-l6.php

OCEANBOTICS

SRV-8

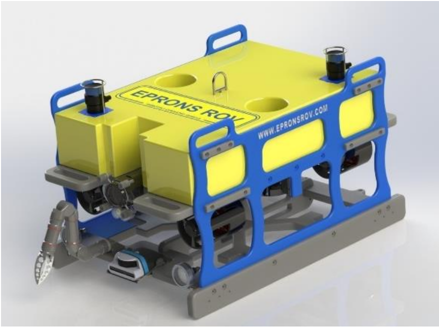
Depth	305m
Endurance	6-8h
Dimensions	500mm(l) × 430mm(w) × 330mm(h)
Weight (in air)	8.5kg
Payload	Various payloads
Max forward speed	3kts
Video	1080p (4k optional)
Website	https://oceanbotics.com/srv-8/

SRV-8X OPTIMUS

Depth	500m
Endurance	8h
Dimensions	640mm(l) × 530mm(w) ×

		510mm(h)
	Weight (in air)	25kg
	Payload	Various payloads
	Max forward speed	N/A
	Video	1080p (4k optional)
	Website	https://oceanbotics.com/srv-8x-optimus/
SRV-8 MDV		
	*Depth*	500m
	Endurance	8h
	Dimensions	640mm(l) × 510mm(w) × 430mm(h)
	Weight (in air)	25kg
	Payload	Various payloads
	Max forward speed	N/A
	Video	1080p (4k optional)
	Website	https://oceanbotics.com/the-srv-8-mdv-mine-disposal-vehicle/
DELAIR MARINE		
SEASAM		
	*Depth*	100m
	Endurance	1.5h
	Dimensions	550mm(l) × 450mm(w) × 230mm(h)
	Weight (in air)	9.6kg
	Payload	Ball mounts / 2kg payload
	Max forward speed	1.75kts
	Video	Full HD 1080p
	Website	https://www.delairmarine.com/autonomous-rov-seasam/
SEASAM HULLSCAN		
	*Depth*	100m
	Endurance	1.5h
	Dimensions	540mm(l) × 440mm(w) × 240mm(h)
	Weight (in air)	10kg
	Payload	Ball mounts / 2kg payload
	Max forward speed	1m/s or 2.1kts

	Video	Full HD 1080p
	Website	https://www.delairmarine.com/seasam-hullscan-best-rov-for-ship-hull-inspection/
EPRONS		
ALPHAROV D150		
	*Depth*	150m
	Power	0.8kW
	Dimensions	380mm(l) × 320mm(w) × 300mm(h)
	Weight (in air)	8kg
	Payload	3kg
	Max forward speed	N/A
	Video	Full HD 1080P 2MP
	Website	https://eprons.lv/en/rov-roduction/rov-products/rov-models/alpharov-d150/
ALPHAROV PROF D200		
	*Depth*	200m
	Power/Endurance	N/A
	Dimensions	N/A
	Weight (in air)	N/A
	Payload	Various payloads (such as 4K video)
	Max forward speed	N/A
	Video	Full HD 1080P 2MP
	Website	https://eprons.lv/en/rov-roduction/rov-products/rov-models/alpharov-prof-d200/
ALPHAROV PROF D300		
	*Depth*	300m
	Power/Endurance	N/A
	Dimensions	N/A
	Weight (in air)	N/A
	Payload	Various payloads (such as 4K video)
	Max forward speed	N/A
	Video	Full HD 1080P 2MP
	Website	https://eprons.lv/en/rov-roduction/rov-products/rov-models/alpharov-prof-d300/

ALPHAROV PROF D500		
	*Depth*	500m
	Power/Endurance	N/A
	Dimensions	N/A
	Weight (in air)	68kg
	Payload	15kg (such as 4K video)
	Max forward speed	N/A
	Video	Full HD 1080P 2MP
	Website	https://eprons.lv/en/rov-roduction/rov-products/rov-models/alpharov-prof-d500/
EXAIL		
H300V		
	*Depth*	300m
	Power/Endurance	N/A
	Dimensions	840mm(l) × 530mm(w) × 600mm(h
	Weight (in air)	70kg
	Payload	15kg
	Max forward speed	3.5kts
	Video	HD color zoom
	Website	https://www.ecagroup.com/en/solutions/ h300v-rov-remotely-operated-vehicle
H800		
	*Depth*	1000m
	Power/Endurance	N/A
	Dimensions	992mm(l) × 720mm(w) × 551mm(h)
	Weight (in air)	99kg
	Payload	30kg
	Max forward speed	N/A
	Video	HD color zoom
	Website	https://www.ecagroup.com/en/solutions/h800-rov-remotely-operated-vehicle
R7		
	Depth	300m

	*Power*	3kW
	Dimensions	780mm(l) × 551mm(w) × 424mm(h)
	Weight (in air)	<35kg
	Payload	Various payloads
	Max forward speed	3kts
	Video	Full HD 1080P
	Website	https://www.ecagroup.com/en/r7-rov-remotely-operated-vehicle
HYDROMEA		
EXRAY		
	*Depth*	100m
	Endurance	4h
	Dimensions	580mm(l) × 380mm(w) × 130mm(h)
	Weight (in air)	10kg
	Payload	Various payloads
	Max forward speed	N/A
	Video	4K
	Website	https://www.hydromea.com/exray-wireless-underwater-drone
JW FISHERS		
SeaLion-3		
	*Depth*	300m
	Power	600W
	Dimensions	584mm(l) × 406mm(w) × 305mm(h)
	Weight (in air)	20.4kg
	Payload	Various payloads
	Max forward speed	N/A
	Video	920 x 1080 Full HD on both sides of the ROV
	Website	https://www.jwfishers.com/product/sealion-3
L3HARRIS TECHNOLOGIES		
AGEOTEC SIRIO		
	Depth	300m
	Power	3kW
	Dimensions	590mm(l) × 560mm(w) × 450mm(h)

	*Weight (in air)*	40kg
	Payload	10kg
	Max forward speed	N/A
	Video	One high resolution PAL/NTSC videocamera
	Website	https://www.l3harris.com/all-capabilities/ageotec-rov-series

AGEOTEC ANTARES

	*Depth*	400m
	Power	3.3kW
	Dimensions	900mm(l) × 458mm(w) × 570mm(h)
	Weight (in air)	56kg
	Payload	14kg
	Max forward speed	N/A
	Video	Two HD cameras
	Website	https://www.l3harris.com/all-capabilities/ageotec-rov-series

AGEOTEC LYRA

	*Depth*	300m
	Power	3.3kW
	Dimensions	750mm(l) × 600mm(w) × 530mm(h)
	Weight (in air)	60kg
	Payload	22 kg
	Max forward speed	N/A
	Video	Three PAL/NTSC cameras
	Website	https://www.l3harris.com/all-capabilities/ageotec-rov-series

AGEOTEC PERSEO

	*Depth*	600m
	Power	6kW
	Dimensions	1100mm(l) × 710mm(w) × 857mm(h)
	Weight (in air)	120kg
	Payload	25kg
	Max forward speed	N/A
	Video	Three real-time cameras

	Website	https://www.l3harris.com/all-capabilities/ageotec-rov-series
JM Robotics		
JM HD1		
	*Depth*	300m
	Power	3kW
	Dimensions	650mm(l) × 550mm(w) × 200mm(h)
	Weight (in air)	23kg
	Payload	Various payloads
	Max forward speed	1.5 m/s or 3 kts
	Video	1080p HD
	Website	https://www.jmrobotics.no/hd-serien
JM HD3		
	*Depth*	300m
	Power	3kW
	Dimensions	740mm(l) × 660mm(w) × 240mm(h)
	Weight (in air)	38kg
	Payload	Various payloads
	Max forward speed	2 m/s or 4 kts
	Video	1080p HD
	Website	https://www.jmrobotics.no/hd-serien
MARINE IMAGING TECHNOLOGIES		
PIXEL		
	*Depth*	300m
	Power/Endurance	N/A
	Dimensions	1016mm(l) × 2438mm(w) × 838mm(h)
	Weight (in air)	127kg
	Payload	Various payloads
	Max forward speed	N/A
	Video	4k video both forward and downward
	Website	https://marineimagingtech.com/imaging-systems-home/rov/
Sea Rover		
	Depth	300m

	*Power/Endurance*	N/A
	Dimensions	813mm(l) × 660mm(w) × 686mm(h)
	Weight (in air)	63.5kg
	Payload	Various payloads
	Max forward speed	N/A
	Video	Analog color pilot camera
	Website	https://marineimagingtech.com/imaging-systems-home/rov/
MARINER UNDERWATER ELECTRONICS		
MRM 230		
	*Depth*	150m
	Power	1kW
	Dimensions	520mm(l) × 330mm(w) × 280mm(h)
	Weight (in air)	14kg
	Payload	Various payloads
	Max forward speed	N/A
	Video	Full HD 1080p
	Website	https://mariner.gr/products/r-o-v-systems/r-o-v-systems-mrm/
Ippodamus		
	*Depth*	750m
	Power	3.5kW
	Dimensions	1050mm(l) × 5800mm(w) × 570mm(h)
	Weight (in air)	75kg
	Payload	15kg
	Max forward speed	N/A
	Video	Full HD 1080p
	Website	https://mariner.gr/products/r-o-v-systems/r-o-v-systems-ippodamus/
MARISCOPE		
Peewee 100		
	Depth	100m
	Power	1kW
	Dimensions	580mm(l) × 375mm(w) × 260mm(h)
	Weight (in air)	17kg

	*Payload*	Various payloads
	Max forward speed	2.5kts
	Video	Full HD (1920 x 1080)
	Website	https://mariscope.com/product/peewee-100/
MS 2		
	*Depth*	300m
	Power	2kW
	Dimensions	510mm(l) × 400mm(w) × 340mm(h)
	Weight (in air)	23kg
	Payload	Various payloads
	Max forward speed	3kts
	Video	Full HD (1920 x 1080)
	Website	https://mariscope.com/product/ms-2/
FO III		
	*Depth*	500m
	Power	3kW
	Dimensions	800mm(l) × 600mm(w) × 360mm(h)
	Weight (in air)	35-70kg
	Payload	Various payloads
	Max forward speed	3kts
	Video	Full HD (1920 x 1080)
	Website	https://mariscope.com/product/fo-iii/
Flunder		
	*Depth*	500m
	Power	4kW
	Dimensions	1200mm(l) × 800mm(w) × 340mm(h)
	Weight (in air)	60–120kg
	Payload	Various payloads
	Max forward speed	4kts
	Video	Full HD (1920 x 1080)

	Website	https://mariscope.com/product/flunder/
DIAVOLO III		
	*Depth*	500m
	Power	3kW
	Dimensions	1000mm(l) × 600mm(w) × 360mm(h
	Weight (in air)	45–90 kg
	Payload	60kg
	Max forward speed	3kts
	Video	Full HD (1920 x 1080)
	Website	https://mariscope.com/product/diavolo-iii/
COMMANDER MK III		
	*Depth*	500m
	Power	6kW
	Dimensions	1500mm(l) × 1000mm(w) × 500mm(h
	Weight (in air)	80–150kg
	Payload	Various payloads
	Max forward speed	3-5kts
	Video	Full HD (1920 x 1080)
	Website	https://mariscope.com/product/commander-mk-iii/
CHAMELEON		
	*Depth*	500m
	Power	>15kW
	Dimensions	500mm(l) × 1000mm(w) × 800mm(h)
	Weight (in air)	100–350kg
	Payload	Various payloads
	Max forward speed	5kts
	Video	Full HD (1920 x 1080)
	Website	https://mariscope.com/product/chameleon/
OUTLAND TECHNOLOGY		
ROV-500		
	Depth	100m
	Power	1kW

	*Dimensions*	510mm(l) × 310mm(w) × 270mm(h)
	Weight (in air)	9.5kg
	Payload	1kg
	Max forward speed	N/A
	Video	1080p Video Camera
	Website	https://www.outlandtech.com/rov-home/rov500
ROV-1000		
	*Depth*	300m
	Power	4.5kW
	Dimensions	660mm(l) × 380mm(w) × 270mm(h)
	Weight (in air)	17.7kg
	Payload	2.3kg
	Max forward speed	N/A
	Video	Dual SD & HD Camera plus Rear Fixed HD Color Camera
	Website	https://www.outlandtech.com/rov-home/rov1000
ROV-1500		
	*Depth*	600m
	Power	3.5kW
	Dimensions	540mm(l)x560mm(w)x178mm(h)
	Weight (in air)	13kg
	Payload	4.5kg
	Max forward speed	N/A
	Video	Front Camera HD plus Rear Fixed HD Video Camera
	Website	https://www.outlandtech.com/rov-home/rov-1500
ROV-2000		
	*Depth*	300m
	Power	3.9kW
	Dimensions	710mm(l) × 460mm(w) × 380mm(h)
	Weight (in air)	25kg
	Payload	4.5kg
	Max forward speed	N/A

	Video	Dual SD & HD Camera plus Rear Fixed HD Color Camera
	Website	https://www.outlandtech.com/rov-home/rov2000
ROV-2500		
	*Depth*	300m
	Power	4.5kW
	Dimensions	710mm(l) × 520mm(w) × 380mm(h)
	Weight (in air)	29.5kg
	Payload	4.5kg
	Max forward speed	N/A
	Video	Dual SD & HD Camera plus Rear Fixed HD Color Camera
	Website	https://www.outlandtech.com/rov-home/rov2500
ROV-3000		
	*Depth*	600m
	Power	3.5kW
	Dimensions	723mm(l) × 622mm(w) × 325mm(h)
	Weight (in air)	32kg
	Payload	9kg
	Max forward speed	N/A
	Video	Dual SD & HD Camera plus Rear Fixed HD Color Camera
	Website	https://www.outlandtech.com/rov-home/rov3000
POSEIDON ROBOTICS		
LANAI		
	*Depth*	400m
	Power	0.6kW
	Dimensions	559mm(l) × 356mm(w) × 305mm(h)
	Weight (in air)	14kg
	Payload	2kg
	Max forward speed	2.5kts
	Video	1080 HD camera
	Website	https://poseidonrov.com/products
LANAI PRO		
	Depth	400m

	*Power*	1.5kW
	Dimensions	559mm(l) × 356mm(w) × 305mm(h)
	Weight (in air)	14.7kg
	Payload	1.5kg
	Max forward speed	3kts
	Video	1080 HD camera
	Website	https://poseidonrov.com/products
LANAI X		
	*Depth*	400m
	Power/Endurance	N/A
	Dimensions	615mm(l) x 360mm(w) x 450mm (h)
	Weight (in air)	19.0kg
	Payload	2.6kg
	Max forward speed	2.6kts
	Video	1080 HD camera
	Website	https://poseidonrov.com/products
MAUI Gen2		
	*Depth*	400m
	Power	9kW
	Dimensions	860mm(l) × 520mm(w) × 520mm(h)
	Weight (in air)	52kg
	Payload	15kg
	Max forward speed	3kts
	Video	1080 HD camera
	Website	https://poseidonrov.com/products
QYSEA		
FIFISH V-EVO		
	*Depth*	100m
	Power	97Wh
	Dimensions	383mm (l) x 331mm (w) x 143mm (h)
	Weight (in air)	3.9kg
	Payload	Various payloads
	Max forward speed	3kts (2kts flow resistance)

	Video	4K UHD
	Website	https://www.qysea.com/products/fifish-v-evo/
FIFISH V6		
	*Depth*	100m
	Power	97Wh
	Dimensions	383mm (l) x 331mm (w) x 143mm (h)
	Weight (in air)	3.9kg
	Payload	Various payloads
	Max forward speed	1.5m/s
	Video	4K UHD
	Website	https://www.qysea.com/products/fifish-v6/
FIFISH V6s		
	*Depth*	100m
	Power	156Wh
	Dimensions	383mm (l) x 331mm (w) x 143mm (h)
	Weight (in air)	4.1kg
	Payload	Various payloads
	Max forward speed	1.5m/s or 3kts
	Video	4K UHD
	Website	https://www.qysea.com/products/fifish-v6s/
FIFISH V6 EXPERT		
	*Depth*	100m
	Power/Endurance	1-4h (156Wh)
	Dimensions	383mm(l) x 331mm(w) x 143mm(h)
	Weight (in air)	4.6kg
	Payload	5kg
	Max forward speed	1.5m/s or 3kts
	Video	4K UHD
	Website	https://www.qysea.com/products/fifish-v6-expert/
FIFISH PRO V6 PLUS		
	Depth	150m
	Power/Endurance	1-4h (156Wh)

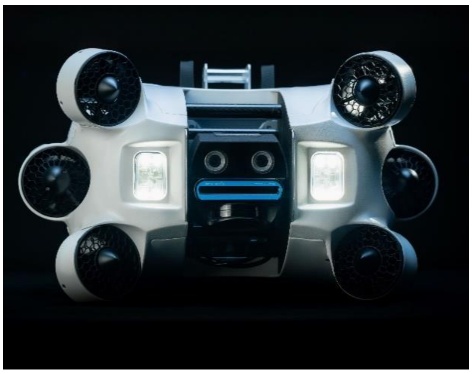
	*Dimensions*	383mm(l) x 331mm(w) x 158mm(h)
	Weight (in air)	5kg
	Payload	5kg
	Max forward speed	1.5m/s or 3kts
	Video	4K UHD
	Website	https://www.qysea.com/products/fifish-v6-plus/
FIFISH E-GO		
	*Depth*	100m/ 200m
	Power/Endurance	1-4h (69.12Wh*2)
	Dimensions	430mm(l) x 345mm(w) x 170mm(h)
	Weight (in air)	5.1kg
	Payload	5kg
	Max forward speed	>1.5m/s or >3kts
	Video	4K UHD
	Website	https://www.qysea.com/products/fifish-e-go/
FIFISH PRO W6		
	*Depth*	350m
	Power	388.8Wh
	Dimensions	700mm(l) × 469mm(w) × 297mm(h)
	Weight (in air)	23kg
	Payload	10kg
	Max forward speed	3kts ocean current resistance
	Video	Dual 4K Camera System
	Website	https://www.qysea.com/products/fifish-w6/
FIFISH PRO Zen1		
	*Depth*	100m
	Power/Endurance	N/A
	Dimensions	N/A
	Weight (in air)	N/A
	Payload	Various payloads
	Max forward speed	N/A
	Video	Cinematic underwater ROV

	Website	https://www.qysea.com/products/fifish-zen1/
SAAB		
FALCON DR		
	*Depth*	300m
	Power/Endurance	N/A
	Dimensions	1000mm (l) × 600mm (w) × 500mm (h)
	Weight (in air)	60kg
	Payload	14kg
	Max forward speed	>3kts
	Video	N/A
	Website	https://www.saabseaeye.com/solutions/underwater-vehicles/falcon-dr
FALCON DR		
	*Depth*	1000m
	Power/Endurance	N/A
	Dimensions	1055mm (l) × 600mm (w) × 555mm (h)
	Weight (in air)	100kg
	Payload	15kg
	Max forward speed	>3kts
	Video	N/A
	Website	https://www.saabseaeye.com/solutions/underwater-vehicles/falcon-dr
SEADRONE		
MINI		
	*Depth*	300m
	Power	1,200W
	Dimensions	624mm (l) × 467mm (w) × 193mm (h)
	Weight (in air)	16kg
	Payload	Various payloads
	Max forward speed	3kts
	Video	1080P
	Website	https://mini.seadronepro.com/

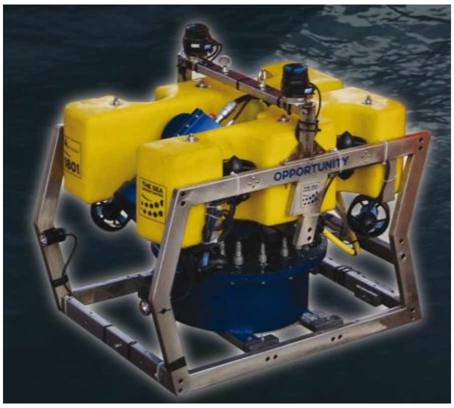
Steelhead		
	*Depth*	300m
	Power/Endurance	N/A
	Dimensions	502mm (l) x 384mm (w) x 373mm (h)
	Weight (in air)	21kg
	Payload	Various payloads
	Max forward speed	1.75kts
	Video	NTSC or PAL (full broadcast-quality)
	Website	https://seamor.com/products/seamor-steelhead/
CHINOOK		
	*Depth*	300m
	Power/Endurance	N/A
	Dimensions	686mm(l) × 384mm(w) × 406mm(h)
	Weight (in air)	33kg
	Payload	Various payloads
	Max forward speed	2kts
	Video	NTSC or PAL (full broadcast-quality)
	Website	https://seamor.com/products/seamor-chinook/
MAKO		
	*Depth*	30m
	Power/Endurance	N/A
	Dimensions	840mm(l) × 635mm(w) × 674mm(h)
	Weight (in air)	72kg
	Payload	14 kg
	Max forward speed	2kts
	Video	NTSC or PAL (full broadcast-quality), HD 1080p
	Website	https://seamor.com/products/seamor-mako/
SHARK MARINE TECHNOLOGIES		
BARRACUDA		
	Depth	300m
	Power	7.2kW

	*Dimensions*	877mm(l) × 530mm(w) × 310mm(h)
	Weight (in air)	39kg
	Payload	Various payloads
	Max forward speed	N/A
	Video	SD/HD Cameras
	Website	https://www.sharkmarine.com/products/rovs/barracuda/
Sea-Wolf 5		
	*Depth*	600m
	Power	7.2kW
	Dimensions	977mm(l) × 737mm(w) × 559mm(h)
	Weight (in air)	95kg
	Payload	18kg
	Max forward speed	N/A
	Video	SD/HD Cameras
	Website	https://www.sharkmarine.com/products/rovs/sea-wolf-5/
SRS FUSION		
FUSION		
	*Depth*	300m
	Endurance	3-4h
	Dimensions	686mm(l) × 477mm(w) × 275mm(h)
	Weight (in air)	27.5kg
	Payload	Various payloads
	Max forward speed	N/A
	Video	HD 1080p
	Website	https://www.srsfusion.com/srs-fusion
SUBSEA TECH		
Observer Mini-ROV		
	*Depth*	150m
	Endurance	4h
	Dimensions	490mm (l) x 270mm (b) x 210mm (h)
	Weight (in air)	6.4kg
	Payload	Various payloads

	Max forward speed	2kts
	Video	Full HD 1080p
	Website	https://www.subsea-tech.com/mini-rov-observer/
Mini-ROV Guardian		
	*Depth*	150m
	Power/Endurance	N/A
	Dimensions	470mm (l) x 254mm (b) x 160mm (h)
	Weight (in air)	4.5kg
	Payload	Various payloads
	Max forward speed	3kts
	Video	Colour video camera
	Website	https://www.subsea-tech.com/mini-rov-guardian/
Mini TORTUGA		
	*Depth*	300m
	Power	3kW
	Dimensions	672mm (l) x 310mm (b) x 381mm (h)
	Weight (in air)	19kg
	Payload	5kg
	Max forward speed	4kts
	Video	Full HD video camera (1920 x 1080 p)
	Website	https://www.subsea-tech.com/mini-tortuga/
Mini tortuga xp4		
	*Depth*	300m
	Power	6kW
	Dimensions	672mm (l) x 684mm (b) x 500mm (h)
	Weight (in air)	43kg
	Payload	10 kg
	Max forward speed	3kts
	Video	Full HD camera (1920 x 1080 p)
	Website	https://www.subsea-tech.com/mini-tortuga-xp4/
TORTUGA		

	*Depth*	500m
	Power	10 kVA
	Dimensions	996mm (l) x 430mm (b) x 461mm (h)
	Weight (in air)	37.5kg
	Payload	10kg
	Max forward speed	5kts
	Video	Full HD video cameras 1080p
	Website	https://www.subsea-tech.com/tortuga/
AspiROV robot		
	*Depth*	100m
	Power	220 VAC
	Dimensions	660mm (l) x 430mm (b) x 530mm (h)
	Weight (in air)	12kg
	Payload	N/A
	Max forward speed	1.5m/s, Rolling: 0.2m/s
	Video	700 TVL color cameras
	Website	https://www.subsea-tech.com/aspirov/
TETHYS ROBOTICS		
ONE		
	*Depth*	200m
	Endurance	4h
	Dimensions	N/A
	Weight (in air)	35kg
	Payload	Various payloads
	Max forward speed	3.5kts
	Video	
	Website	https://www.tethys-robotics.ch/solution/underwater-drone
VIDEORAY		
Mission Specialist Ally		
	Depth	300m
	Power	2.4kW
	Dimensions	530mm (l) x 430mm (w) x 220mm (h)

	*Weight (in air)*	13.6kg
	Payload	Various payloads
	Max forward speed	4kts
	Video	Ultra 4k Smart Camera
	Website	Various payloads
Mission Specialist Defender		
	*Depth*	1000m
	Power	1-2.4kW
	Dimensions	711mm (l) x 394mm (w) x 238mm (h)
	Weight (in air)	17.2kg
	Payload	Various payloads
	Max forward speed	N/A
	Video	1920 x 1080p
	Website	https://videoray.com/products/mission-specialist-defender/
Mission Specialist Pro 5		
	*Depth*	305m
	Power	1-2.4kW
	Dimensions	515mm (l) x 330mm (w) x 257mm (h)
	Weight (in air)	11.8kg
	Payload	Various payloads
	Max forward speed	N/A
	Video	1920 x 1080p
	Website	https://videoray.com/products/mission-specialist-pro-5/
THE SEA OPPORTUNITIES		
ROV OPPORTUNITY		
	Depth	300m
	Power	230V AC/ 3kW
	Dimensions	N/A
	Weight (in air)	N/A
	Payload	Various payloads

	*Max forward speed*	4kts
	Video	Full HD and 4K
	Website	https://www.theseaopportunities.com/rov/
BEEX		
A.IKANBILIS		
	*Depth*	300m
	Endurance	3-8h
	Dimensions	90cm (l) x 81cm (b) x 42.0cm (h)
	Weight (in air)	~70kg
	Payload	Various payloads
	Max forward speed	N/A
	Video	HD 1920 x 1080
	Website	https://beex.sg/

Annex 4 Overview of small AUVs

Overview of some light class (<100kg) commercial AUVs available on the market for marine ecological research. List based on experience authors, Oceanology International Conference[29], and the Ocean Robotics Planet buyer's guide 2024[30]. (Product images taken from their respective websites).

ADVANCED NAVIGATION

HYDRUS

Depth	300m
Endurance	2h
Dimensions	520mm(l) × 264mm(w) × 235mm(h)
Weight (in air)	6.4kg
Payload	Various payloads
Max forward speed	1.5kts
Video	4K
Website	https://www.advancednavigation.com/robotics/micro-auv/hydrus/#h-specifications

BOXFISH ROBOTICS

ARV-i

Depth	300-600m
Endurance	10h
Dimensions	520mm(l) × 264mm(w) × 235mm(h)
Weight (in air)	28kg
Payload	Various payloads
Max forward speed	N/A
Video	4K
Website	https://www.boxfishrobotics.com/products/arv-i/arv-i-technical-specifications/

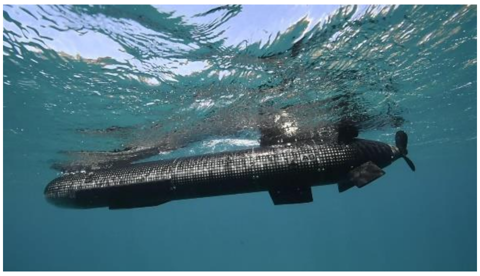
BOXFISH AUV

Depth	300-600m
Endurance	10h
Dimensions	730mm(l) × 435mm(w) × 351mm(h)

[29] https://www.oceanologyinternational.com/london/en-gb.html
[30] https://oceanroboticsplanet.com/tportal_upload/md_buyersguide/buyersguide_2024.pdf

	*Weight (in air)*	25kg
	Payload	Various payloads
	Max forward speed	N/A
	Video	4K
	Website	https://www.boxfishrobotics.com/products/boxfish-auv/boxfish-auv-technical-specifications/
ecoSUB Robotics		
ecoSUBµ5 - SVP + CT + CT-F		
	*Depth*	500m
	Endurance	12h
	Dimensions	925mm (l) x 111mm (d)
	Weight (in air)	4kg
	Payload	Various payloads
	Max forward speed	1m/s
	Video	-
	Website	https://www.ecosub.uk/ecosubu5---500-m-rated-micro-auv.html
ecoSUBm5 - CT-F+Tu+DO		
	*Depth*	500m
	Endurance	18h
	Dimensions	1000mm (l) x 146mm (d)
	Weight (in air)	12kg
	Payload	Various payloads
	Max forward speed	1m/s
	Video	-
	Website	https://www.ecosub.uk/ecosubm5---500-m-rated-small-auv.html
ecoSUBm25		
	*Depth*	2500m
	Endurance	18h
	Dimensions	1000mm (l) x 146mm (d)
	Weight (in air)	12kg
	Payload	Various payloads
	Max forward speed	1m/s

	Video	-
	Website	https://www.ecosub.uk/ecosubm25---2500-m-rated-small-auv.html
EDGELAB		
U TRACKER - III		
	*Depth*	300m
	Endurance	8h
	Dimensions	<2300mm (l) x 200mm (d)
	Weight (in air)	<25kg
	Payload	Various payloads
	Max forward speed	3-5kts
	Video	-
	Website	https://www.edgelab.eu/u_tracker/
EVOLOGICS		
QUADROIN		
	*Depth*	150m
	Endurance	10h
	Dimensions	1120mm (l) x 304mm (d)
	Weight (in air)	<25kg
	Payload	3kg
	Max forward speed	5m/s
	Video	Full HD
	Website	https://www.evologics.com/robotics
POGGY		
	*Depth*	N/A
	Power/Endurance	N/A
	Dimensions	N/A
	Weight (in air)	N/A
	Payload	N/A
	Max forward speed	N/A
	Video	N/A
	Website	https://www.evologics.com/robotics

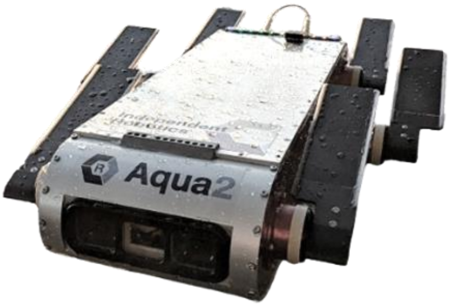
EXAIL		
A9-E		
	*Depth*	200m
	Endurance	20h
	Dimensions	2000mm-2500mm(l) × 230mm(d)
	Weight (in air)	70-100kg
	Payload	Various payloads
	Max forward speed	5kts
	Video	Customizable
	Website	https://www.ecagroup.com/en/solutions/a9-e-auv-autonomous-underwater-vehicle
A9-M		
	*Depth*	300m
	Endurance	20h
	Dimensions	N/A
	Weight (in air)	N/A
	Payload	Various payloads
	Max forward speed	N/A
	Video	N/A
	Website	https://www.ecagroup.com/en/solutions/a9-m-auv-autonomous-underwater-vehicle
GRAAL TECH		
X-300 MCM COMPACT		
	*Depth*	300m
	Endurance	8-10h
	Dimensions	< 1700mm (l) x 155mm (d)
	Weight (in air)	< 20kg
	Payload	Various payloads
	Max forward speed	4kts
	Video	N/A
	Website	https://www.graaltech.com/products/x-300-mcm-compact/
X-300		
	Depth	300m
	Endurance	14h

	*Dimensions*	2222mm(l) × 155mm(d)
	Weight (in air)	29kg
	Payload	Various payloads
	Max forward speed	5kts
	Video	N/A
	Website	https://www.graaltech.com/products/x-300-auv/
X-300 EXPLORER		
	*Depth*	300m
	Endurance	12h
	Dimensions	2100mm (l)
	Weight (in air)	25kg
	Payload	Various payloads
	Max forward speed	4kts
	Video	N/A
	Website	https://www.graaltech.com/products/x300-explorer-auv/
HII		
REMUS 100		
	*Depth*	100m
	Endurance	10h
	Dimensions	1850mm (l) × 190mm (d)
	Weight (in air)	38.6kg
	Payload	Various payloads
	Max forward speed	4.5kts
	Video	Optional 4K HD
	Website	https://hii.com/what-we-do/capabilities/unmanned-systems/remus-uuvs/
REMUS 300		
	*Depth*	305m
	Endurance	10h / 20h / 30h
	Dimensions	2030mm (l) x 190mm (d) / 2390mm (l) x 190mm (d) / 2640mm(l) × 207mm (d)
	Weight (in air)	48.5kg / 58.5kg / 70.3kg
	Payload	Various payloads

	Max forward speed	5kts
	Video	Optional 4K HD
	Website	https://hii.com/what-we-do/capabilities/unmanned-systems/remus-uuvs/

INDEPENDENT ROBOTICS

AQUA2



Depth	39m
Endurance	12h
Dimensions	600mm(l) × 240mm(w) × 130mm(h)
Weight (in air)	15kg
Payload	Various payloads
Max forward speed	N/A
Video	Multiple cameras
Website	https://www.independentrobotics.com/aqua2

IQUA ROBOTICS

SPARUS II

Depth	200m
Endurance	8-10h
Dimensions	1600mm(l) × 460mm(w) × 230mm(h)
Weight (in air)	52kg
Payload	7kg
Max forward speed	3kts
Video	N/A
Website	https://iquarobotics.com/sparus-ii-auv

JAIA ROBOTICS

JAIABOT

Depth	60m
Power/Endurance	N/A
Dimensions	960mm(l) × 70mm(d)
Weight (in air)	3kg
Payload	Various payloads
Max forward speed	> 3.5m/s
Video	N/A

	Website	https://www.jaia.tech/solutions/

L3HARRIS TECHNOLOGIES

IVER3

Depth	100m
Endurance	8-14h
Dimensions	880mm-2160mm(l) × 148mm(d)
Weight (in air)	26.8-38.6
Payload	Various payloads
Max forward speed	1-4 knots (0.5-2.0 m/s)
Video	N/A
Website	https://www.l3harris.com/all-capabilities/iver3-standard-system-auv

IVER3 EP SYSTEMS

Depth	100m
Endurance	8-14h
Dimensions	>1880mm-2160mm(l) × 148mm(d)
Weight (in air)	26.8-38.6
Payload	Various payloads
Max forward speed	1-4 knots (0.5-2.0 m/s)
Video	N/A
Website	https://www.l3harris.com/all-capabilities/iver3-ep-open-system-auv

IVER4 580

Depth	300m
Endurance	6-18h
Dimensions	208.3cm(l) x 14.7cm(d)
Weight (in air)	<45.4kg
Payload	Various payloads
Max forward speed	1-6kts
Video	N/A
Website	https://www.l3harris.com/all-capabilities/iver4-580-auv

OCEANSCAN MST

LAUV

Depth	100m
Endurance	>8h
Dimensions	1150mm-2300mm(l) × 150mm(d)
Weight (in air)	15-35kg
Payload	Various payloads
Max forward speed	5kts
Video	N/A
Website	https://www.oceanscan-mst.com/light-autonomous-underwater-vehicle/

QINETIQ

SEASCOUT

Depth	200m
Endurance	0.5-30h
Dimensions	686mm(l)
Weight (in air)	7.3kg
Payload	Various payloads
Max forward speed	3-12kts
Video	N/A
Website	https://www.qinetiq.com/en/what-we-do/services-and-products/seascout-unmanned-underwater-vehicle

RTSYS

COMET-300

Depth	300m
Endurance	12-20h
Dimensions	1900mm(l) × 150mm(d) × 332mm(h)
Weight (in air)	32kg
Payload	Various payloads
Max forward speed	12kts
Video	Camera
Website	https://rtsys.eu/comet-300-auv

NEMOSENS		
	*Depth*	300m
	Endurance	>10h
	Dimensions	895mm(l) × 124mm(d) × 183mm(h)
	Weight (in air)	8.5kg
	Payload	Various payloads
	Max forward speed	2-6kts
	Video	Camera
	Website	https://rtsys.eu/nemosens-micro-auv

SEABER		
YUCO		
	*Depth*	300m
	Endurance	6-10h
	Dimensions	1000mm(l) × 120mm(d)
	Weight (in air)	8kg
	Payload	Various payloads
	Max forward speed	2.5-6kts
	Video	N/A
	Website	https://seaber.fr/why-yuco-auv-is-unique
MARVEL		
	*Depth*	300m
	Endurance	8h
	Dimensions	N/A
	Weight (in air)	N/A
	Payload	Various payloads
	Max forward speed	2-6kts
	Video	N/A
	Website	https://seaber.fr/marvel-uuv

SUBSEA TECH		
TORPEDO		
	Depth	50m
	Power/Endurance	N/A
	Dimensions	1424mm(l) × 310mm(w) × 310mm(h)

	*Weight (in air)*	30kg
	Payload	Various payloads
	Max forward speed	0.5-0.9 kts
	Video	Full HD
	Website	https://www.subsea-tech.com/torpedo/
SUNFISH		
SUNFISH AUV		
	*Depth*	200m
	Endurance	12h
	Dimensions	1610mm(l) × 470mm(w) × 200mm(h)
	Weight (in air)	55kg
	Payload	Various payloads
	Max forward speed	1m/s
	Video	N/A
	Website	https://sunfishinc.com/
LOBSTER ROBOTICS		
LOBSTER SCOUT		
	*Depth*	300m
	Endurance	4-6h
	Dimensions	210cm(l)
	Weight (in air)	55kg
	Payload	Various payloads
	Max forward speed	N/A (Less than 0.5 m/s or 1 kts currents)
	Video	4K
	Website	https://www.lobster-robotics.com/

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