Preparing for remotely operated vehicle (ROV) seafloor surveys: a descriptive checklist for ocean scientists and managers

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PREPARING FOR REMOTELY OPERATED VEHICLE (ROV) SEAFLOOR SURVEYS: A DESCRIPTIVE CHECKLIST FOR OCEAN SCIENTISTS AND MANAGERS

by

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Neves, B.M., Auger, V., Edinger, E., Lockhart, P., and Morrissey, C. 2023. Preparing for remotely operated vehicle (ROV) seafloor surveys: a descriptive checklist for ocean scientists and managers. Can. Tech. Rep. Fish. Aquat. Sci. 3578: ix + 37 p.

Remotely Operated Vehicles (ROVs) are indispensable tools for surveying benthic environments, especially in the deep sea. Despite their efficacy, ROV surveys are intricate, costly, and demand meticulous planning and coordination. Each ROV survey's uniqueness underscores the need to consider key factors ensuring efficiency and data quality. Neglecting these may lead to losing valuable ROV and ship time, diminished survey quality, or data collection inconsistencies, impeding subsequent analysis. This guide aims to enhance the preparation and execution of ROV surveys by providing comprehensive advice on dive plan elements, sample collection preparation, and early discussions about deliverables and expectations with the ROV team. Before the expedition, discussions should define deliverables like high-definition (HD) video and digital still camera (DSC) photos, including file name conventions. Dive plans must intricately detail dive objectives, transect lengths, depths, and available study site information. Maps displaying survey designs and bathymetry also prove invaluable to pilots and the ship's crew. Pre-expedition discussions should encompass specialized sampling needs like sediment push-cores,use of instruments, and sample storage. A well-defined dive plan, effective communication, and comprehensive pre-dive discussions ensure preparedness at the survey location, optimizing both ROV and ship time thereby enhancing overall survey quality.

RÉSUMÉ

Neves, B.M., Auger, V., Edinger, E., Lockhart, P., and Morrissey, C. 2023. Preparing for remotely operated vehicle (ROV) seafloor surveys: a descriptive checklist for ocean scientists and managers. Can. Tech. Rep. Fish. Aquat. Sci. 3578: ix + 37 p.

Les véhicules sous-marins télécommandés (ROVs) sont des outils essentiels pour l'étude des environnements benthiques, en particulier en haute mer. Cependant, leur efficacité dépend d'une planification minutieuse et d'une coordination entre scientifiques et pilotes de ROV. Plusieurs facteurs doivent être considérés pour garantir l'efficacité et la qualité des données, évitant la perte de temps précieux et les complications dans l'analyse ultérieure. Ce guide facilite la préparation et l'exécution des enquêtes par ROV en fournissant des conseils détaillés sur les éléments d'un plan de plongée, la préparation de la collecte d'échantillons, et les discussions sur les livrables. Les discussions pré-expédition doivent inclure les besoins d'échantillonnage, des instruments spécialisés, et les arrangements de stockage des échantillons. Les plans de plongée doivent spécifier les objectifs, les longueurs et les profondeurs des transects, ainsi que des informations sur le site d'étude. Les cartes montrant la conception de l'enquête et les informations bathymétriques sont utiles, ainsi que la définition des livrables tels que la vidéo HD et les photos, et des conventions de nom de fichier. Un plan de plongée bien défini, une communication efficace et une préparation approfondie garantissent une optimisation du temps du ROV et du navire, améliorant ainsi la qualité de l'enquête.

1 Introduction

Remotely operated vehicles (ROVs) are one of the most complete tools for the survey of benthic environments, particularly in the deep sea, as many of these systems have depth operational capabilities of thousands of meters (Jamieson et al. 2013). Work-class and mid-size ROVs (also known as observation/inspection ROVs), generally have the potential to be equipped with a full range of instruments and tools (Christ and Wernli 2014a). The most complete vehicles for use in science have powerful high-definition (HD) or 4K cameras, scaling lasers, dexterous manipulators, space for sample storage, and tools such as CTDs, Niskin bottles, suction samplers, and multibeam sonar. Some ROVs may be relatively simple in their basic configuration, but can be improved to attain specific goals.

For instance, the Canadian Coast Guard Ship (CCGS) *Amundsen*, a research icebreaker, had an inspection class ROV (Super Mohawk - SuMo, SubAtlantic) for 15 years. However, most of the scientific activities using this ROV were conducted between 2013 and 2018, during which years the ROV went through multiple iterations to improve its scientific capabilities. In 2013, the ROV only had a standard definition (SD) camera, no lasers, and no space for sample storage. That year, a dive at Disko Fan (Baffin Bay, Eastern Canadian Arctic) took place using a mesh bag to store coral samples, and a ruler to estimate sizes *in situ* (Neves et al. 2015). In 2014, an HD camera and a pair of lasers were added to the ROV, and in 2016 a sampling skid was built and installed under the ROV to store samples. While the ROV was more scientifically capable by 2018, it was also older and a decision was made to retire it. The progress of SuMo represents an example of how scientists can work with pilots to improve the quality of ROV surveys, despite potential limitations.

While some scientists might often work with ROVs, there are often individuals with varied levels of experience on both science and ROV teams. ROV surveys are generally complex, logistically demanding, and require a high level of preparation ahead of the expedition. Having information outlining the basic considerations required as part of an ROV survey is crucial to ensure that data collection is efficient, consistent, and scientifically sound. Failure to consider these elements could result in loss of valuable ship time, decreased survey quality, data/sample loss, and/or inconsistencies in data collection. The successful planning, direction, and outcomes of ROV surveys therefore largely benefit from the combined exchange of experiences between scientists and ROV pilots.

This guide is the result of several years of collaborative work between scientists and ROV pilots and it aims to assist scientists to better prepare for ROV surveys. While other ROV guides exist (e.g., Tillin et al. 2018; Monk et al. 2020), published guidance on the development of detailed ROV dive plans to be shared between scientists, ROV pilots, and ship's crew is usually lacking. Here we provide guidance on important items to be considered before an expedition, before/during/after the ROV surveys, and before the end of the expedition. In addition, we describe the components of an ROV dive plan and provide four appendices that exemplify pre-dive summaries, expected data product (deliverable) check-lists, and a post-dive check-list. This guide does not focus on video transect design or types of ROV applications in detail, or data/sample post-processing, which can be found elsewhere. Although it focuses on inspection/mid-size class ROVs, we believe that it contains information that can be useful for other seafloor video-surveys, including those performed using mini-ROVs and tow/drop cameras.

2 ROV capabilities

Many different types of ROVs can be used to conduct scientific surveys, but these have been described elsewhere (Capocci et al. 2017; Tillin et al. 2018). Overall, vehicles that can perform high-quality visual surveys, sample collections, deploy and recover equipment and/or experiments are often best suited for scientific work (Figure **1**). Although the often interdisciplinary nature of ROV surveys means that they often require all of these qualities, not all surveys do. Some surveys might focus on imagery data collection (videos/photographs), while others might focus on sample collection and deployment/recovery of experiments/instruments. Advanced ROV capabilities are often associated with high costs, and trade-offs between these two elements often need to be considered. Either way, elements associated with imagery quality, specific visual survey needs, and sampling/storage capabilities must be considered.

This guide does not provide a prescriptive list of technical information such as lights or camera/recording parameters, as these can be variable and depend on survey objectives. In the lack of such lists, and given the complexity of ROV systems, scientists will often rely on technical expertise provided by the ROV operators, and should not assume that different ROVs and operators will deliver comparable results. Therefore, many of the items discussed in the next sections should be used to raise discussions with operators, who might require additional guidance tailored to more specific scenarios. Often, specifying scientific objectives in great detail is enough to allow operators to assist with an appropriate level of technical support and delivery.

2.1 Imagery needs

Visual surveys (e.g., transect lines) are one of the most common uses of ROVs in science. Visual surveys that aim at investigating megabenthic diversity patterns, for example, generally require relatively high camera quality (HD or higher). Surveys performed using Standard Definition (SD) cameras can still yield useful data, but resolution of taxa identification will often be compromised. Scientists should be aware that in some cases, even though video is being recorded as HD (or higher), the video being fed to the surface is at a lower resolution (e.g., SD), which might or not be enough for their needs. A minimum live imagery quality standard is often needed to allow scientists to make informed decisions during the dive. The opposite might also occur, where quality of live video is better than that of the recorded video, which might not be ideal depending on dive objectives. Not all ROV operators have the same standards of video recording, imagery quality, and storage. To ensure that scientific needs are met, these parameters must be discussed with the ROV team ahead of the expedition. See also **Screen display** section for additional information on video quality.

While video cameras are the default with ROVs, digital still cameras (DSC) are not always available. Having access to high-quality still photos in addition to video data is a common request in scientific surveys. When DSCs are not available, very high video resolution can often generate high quality image snapshots. Choosing a specific camera (s) is often not possible, but in some cases scientists with specific needs might be able to have their own camera added to the system, although this might be a special case scenario. Stereo cameras can also be a useful tool in scientific surveys, as they capture images that can yield three dimensional data (Shortis et al. 2008).

Position of the camera is another important consideration. Many science ROVs have a downward-looking camera in addition to the main forward-looking camera. In some studies this might be advantageous, as it provides different spatial scales at which the data can be analyzed. Downward-looking cameras survey a more precise but also more restricted area, while forward-looking cameras have a much broader field of view. Some cameras might be on a pan and tilt unit (left-right, up-down movements), and zoom capabilities are also variable across cameras. Scientists should ask pilots for more information if these parameters are important for their surveys.

2.2 Lasers

Parallel scaling lasers are one of the most basic tools in underwater visual surveys. In the simplest cases, the lasers are used to determine the size of objects and to calculate field of view (FOV) area. In these cases, having two laser beams is the standard practice, although for some studies having an extra pair might be required (Istenič et al. 2020). Not all ROVs have scaling lasers and this should always be verified with the ROV team. Distance between lasers should also always be confirmed, as they can vary. However, a distance of < 10 cm is recommended. Lasers that are built-in, integrated with the cameras, are generally the best option for benthic surveys, as they follow the camera's movements and are therefore more reliable. In our experience, green lasers tend to be easier to visualize than red ones (Figure **2 A-B**), but this might not be the case for all. In addition, dots often provide a cleaner view of the seafloor than lines (Figure **2 C)**. Being able to turn lasers on and off during a dive can also be advantageous, depending on objectives. For instance, turning lasers off might be of interest when taking photos for outreach purposes, or when their reflection in high turbidity environments further hinders visibility. Finally, it is important to ensure that lasers target the seafloor, not the water column.

2.3 Lights

ROVs that work in deep-water environments are often well equipped in terms of lights. However, adequate illumination makes a significant difference in the quality of a video survey and it should not be underestimated. In addition, if the ROV is flying at sub optimal altitudes (i.e., too high), seafloor illumination will become an issue, independently of how good and well positioned the lights are (see section **ROV altitude**) Lights might also play a role under high turbidity conditions, and pilots might need to reduce light intensity as an attempt to improve visibility (Christ and Wernli 2014b).

When light is particularly important for a specific project or in cases where the ROV is equipped with a wide-angle camera, for example, scientists should make sure that they are satisfied with the video quality before the survey. They should also ask pilots to let them know about any changes in the number or location/position of lights between dives. In addition, when working with new ROVs or new cameras, it might be prudent to ask to see a sample video clip, in order to better set expectations. Sea trials might provide a good opportunity for pre-expedition adjustments.

2.4 Navigation capabilities

Having access to and understanding the accuracy, precision, and frequency of the ROV altitude and geographic position is often crucial in the survey design and subsequent data analysis. These ROV capabilities should be discussed with the ROV team to assess potential limitations. In some cases, additional sensors (e.g., Inertial Navigation Systems - INS) might be added to the ROV for more precise navigation, and scientists should inquire with the ROV team if they have particular needs (e.g., repeat surveys of a very specific and small area). ROV positioning precision will also depend on the ship's position keeping capabilities. For instance, ships with dynamic positioning (DP) systems can keep stations much more easily, consequently allowing for a more precise survey. While ROV surveys can still be conducted without DP, the feasibility and quality of the surveys will depend on ship's crew experience. In addition, scientists should inquire whether real-time data is accurate or whether data post-processing is required.

2.5 Manipulators

There are different types of manipulators, including grippers, grabbers (5-function) and dexterous 7-function arms (Christ and Wernli 2014c), and they will define what kind of movements and actions can be expected, such as the kind and size of samples that can be successfully collected. Grippers and grabbers are the simplest types, and are not capable of intricate movements. For instance, while collecting biological samples and rocks has been successful using SuMo's grabber, push-coring was not possible as a 7-function manipulator would be needed. However, there are also distinctions within the 7-function family, and it is crucial that scientists consult with the ROV pilots to make sure that arm capabilities and limitations are understood. Experienced pilots will be able to tell scientists what they are able to do with the arms available on their ROV. In addition to sampling, manipulators are often used to trigger and/or deploy instruments and tools (see section **Instruments and tools**).

2.6 Sampling capabilities

One of the key advantages of many ROVs is their ability to collect samples. Samples can include biological specimens, rocks and other objects, seawater, and sediment.

- *Specimens/rocks/objects*: sampling that directly depends on the manipulators will depend on their dexterity (as described above), and on sample storage capabilities (described below). In some cases, manipulators are fitted with cutters to facilitate breaking specimens if only fragments are desired, as opposed to the whole organism. It should be mentioned that adding cutters to the manipulator(s) might preclude other activities that involve the arms, such as push-coring.

  Some ROVs (e.g., ROPOS - Canadian Scientific Submersible Facility) are equipped with suction samplers (Kahn et al. 2018) and tools to avoid crushing specimens (Vogt et al. 2018), but these are not always part of the regular pool of tools on a science ROV. Breaking off pieces of rocks (e.g., when sampling hydrothermal vent chimneys) can be a more challenging sampling experience. But often pilots can improve and adapt tools that can assist with different types of sampling (e.g., scoops).

- *Seawater*: scientific ROVs often have oceanographic sampling bottles (e.g., Niskin) for the collection of seawater. These bottles can be triggered closer to the seafloor than rosette samplers, which are usually deployed at a maximum depth ~10 m off the bottom. They can also be triggered at very precise locations during a dive, often in combination with other sampling. This can be of interest when seawater is required from a very specific location for a range of objectives such as the collection of environmental DNA (eDNA).

- *Sediment*: sediment samples are often desired and ROVs can be equipped with push-cores (also called push-corers). ROV push-cores can be variable in their mechanisms and sizes. The ROVs ASTRID (Amundsen Science) and ROPOS, for example, host sediment push-cores with liners 6.6 cm in internal diameter and ~35 cm tall (Figure **3**, but smaller or larger corer diameters exist (Bennett and Desiage 2022; Forum SubSea Technologies 2023). While in some cases these push-cores can be fabricated upon request for specific projects or even rented, in other cases they become part of the ROV's pool of equipment (e.g., ASTRID, ROPOS). Having the appropriate ROV manipulator that can complete this task is also important. While many 7-function arms might be capable of collecting a core, the movement of less dexterous manipulators might cause the sediment to fall when transporting it back to the holsters, if a core-catcher is not available. Core-catchers are accessories that can be added to the bottom of a corer to better retain the sediment, especially if the sediment is sandy, as opposed to cohesive mud. Some scientists prefer to not use core catchers because they can smear the sample. Small sediment grabs (e.g., Ekman) can sometimes also be deployed using an ROV. But it is important to discuss with ROV pilots regarding expectations, as they can assess whether their equipment is or not capable of conducting the task, and what limitations might be expected.

2.7 Storage capabilities

While some ROVs have built-in containers/boxes for sample storage (Figure **2 D**), many ROVs do not have native storage capabilities, which can limit sampling, even if the ROV has a capable manipulator. The mesh bag used with SuMo (Neves et al. 2015) was useful, but it can represent a hazard to the ROV, and its deployment is relatively time-consuming. Serious consideration must be taken before opting for using this type of accessory. The addition of a retractable sampling skid such as the ones developed for SuMo, ASTRID, and others (Figure **2 E-F)** can solve storage issues, but they might not always be an option due to space or weight constraints, for example.

A storage system that can be deployed independently from the ROV is also an option. Storage systems such as an "elevator" can be a frame with floats and storage boxes that can be deployed independently from the ROV near the target dive site, and recovered using an acoustic release system (Figure **2 G-H)**. They can also simply be a storage basket/cage which can be deployed separately from the ROV (Figure **2 I-J)** or carried using the ROV manipulator. The ROV will collect samples and move them to the elevator for storage, but the vehicle is required to stay near the elevator area, limiting the spatial extent of where sampling can be conducted. Elevator systems are better used if dive activities are concentrated in a small area. In some cases, if the ROV has its own Launch and Recovery System (LARS) and the ship has a DP system, it is possible that an elevator can be simultaneously deployed using the ship's crane (Bennett and Desiage 2022). In other cases, the two will be deployed separately, which increases the complexity of operations and consumes additional ship time.

Other more portable storage solutions have also been developed, which can be brought to the seafloor directly by the ROV using one of the arms. These are often limited in the size of specimens that can be stored, but are nevertheless an option. Another important consideration is whether there is a need for sampling containers to be sealed. In high-latitudes, differences between bottom and surface temperature might be small, but in cases where changes in temperature or other parameters are large, considering insulated containers that can retain bottom seawater all the way to the deck might be important (e.g., if animals will be used for live experiments) (Kellogg et al. 2009).

Storage units can often be adjusted to fit the scientists' objectives. For instance, storage boxes can have dividers which can be added or removed depending on space needs (e.g., Figure **2 E-F**). See more details in the **Before the dives** section. Samples can sometimes be brought back using alternative storage methods such as bringing the sample on the ROV arm itself (at the end of a dive) or using empty push-core core quivers. In addition to being used to store samples, containers are often used to carry tools, equipment, or experiments, which will often reduce available space for samples if these need to be brought back with the ROV. Some ROVs, such as ROPOS and MBARI's Ventana, might have swing arms, which can be fitted with baskets, core tubes, or custom payload. Finally, ROV pilots are also creative and often can suggest solutions to storage needs.

2.8 Instruments and sensors

While it is not within the scope of this document to list the different types of instruments and sensors that can be deployed using an ROV, a wide range of possibilities exist. Certain instruments, tools, and/or sensors can be mounted to the ROV or brought during a dive if discussing ahead of time with pilots. Examples include CTDs, multibeam sonar (Lim et al. 2018; Lecours et al. 2020), temperature probes, and chemical sensors (Sarrazin et al. 1997; Leys et al. 2011; Du Preez and Fisher 2018).

2.9 Reliability and spares

The technical aspects of back-up (spare parts) needs for ROVs are not in the scope of this document, but it should be a consideration for scientists when discussing their needs with pilots (and likely as part of contract discussions). ROVs operate in a challenging environment and a comprehensive complement of spare parts and the tools needed to fix nearly everything offshore is essential. In practice, the inclusion of certain spare parts might incur additional cost to scientists, particularly in situations where overall ROV functionality does not depend on these parts. For instance, lasers are crucial for most scientific surveys, but not essential for ROV functionality. If not discussed ahead of time, scientists might be surprised to learn that lasers broke during a dive and that no spares were available for the rest of the expedition. This scenario would compromise the quality of a video survey and reduce trust in ROV reliability. Therefore, discussions regarding the availability of spare parts should also be considered before the expedition. Furthermore, certain spare parts might not be readily available, which is another reason for early discussions. Many of these types of spares or specializing sensors can be rented.

2.10 ROV control location

The set-up for the ROV control room might differ depending on the ROV and ship. In some cases, the ship might have room to accommodate the ROV control set-up (e.g., a laboratory), and in other cases the ROV might need its own container, which will take deck space. Having these discussions early will help to better plan (e.g., if a lab needs to be turned into control room).

Figure 1. Examples of ROVs used in science. A) Super Mohawk (SuMo) ROV used aboard CCGS *Amundsen* until 2018 (photo taken in 2014 before adding sampling skid), B) ASTRID, a Comanche ROV currently used aboard CCGS *Amundsen*, C) ROPOS ROV in 2017 aboard CCGS *Martha L. Black*, but used internationally, and D) Magnum ROV aboard MV *Atlantic Condor* in 2022, showing its Launch and Recovery System (LARS).

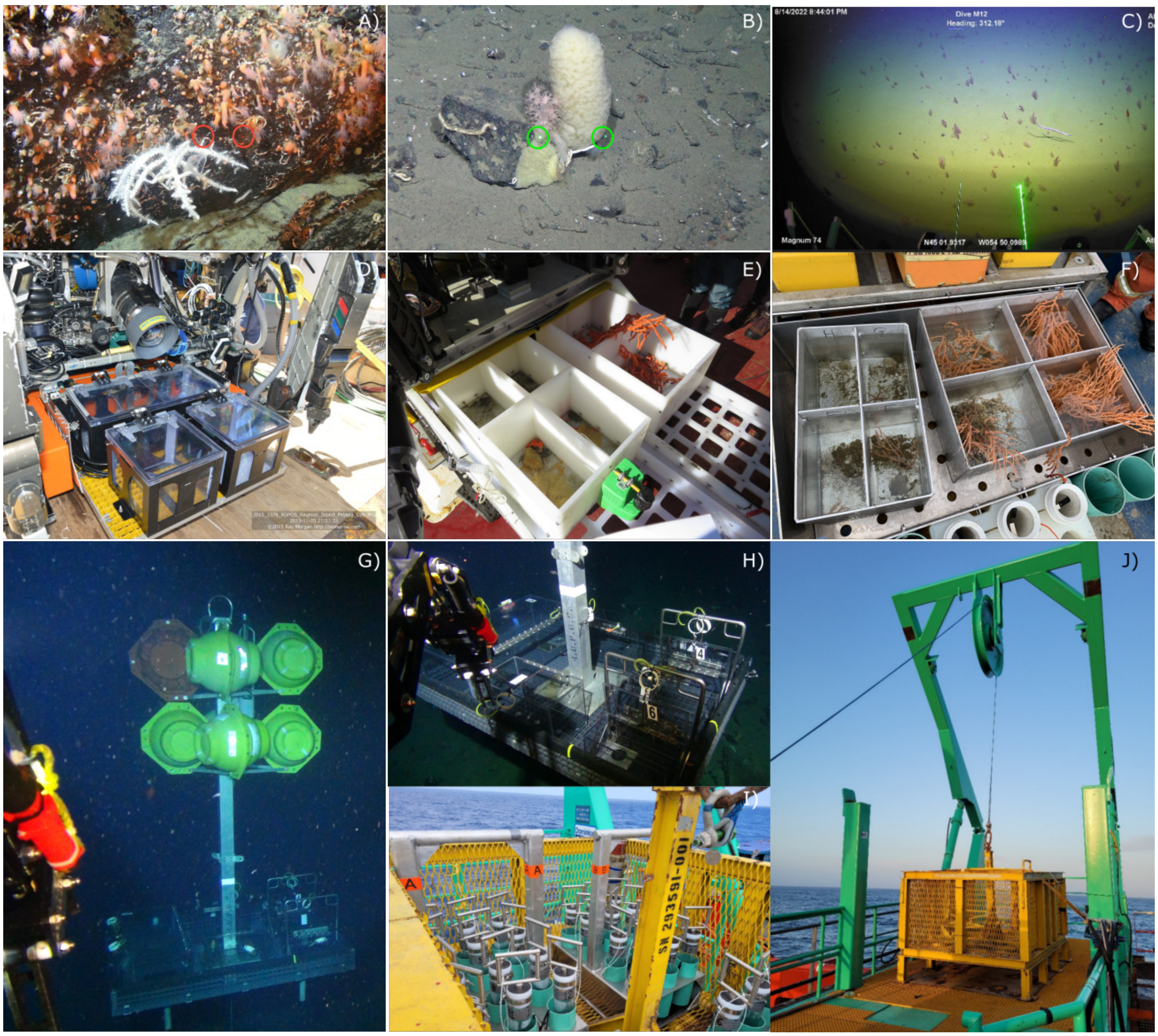


Figure 2. Examples of lasers and ROV sample storage devices. A-B) images showing red and green laser points, respectively (circles added for emphasis), C) green laser lines, D) ROPOS bio-boxes, E) sampling skid on ASTRID, F) sampling skid on the Magnum ROV, G-H) example of elevator used aboard CCGS *Amundsen* in 2015, I-J) example of sampling basket used aboard the MV *Atlantic Condor*. Underwater images A, B, and G) by ArcticNet-CSSF-DFO, C) MV *Atlantic Condor* expedition 2022, D) Ray Morgan, I-J) from Bennett and Desiage (2022).

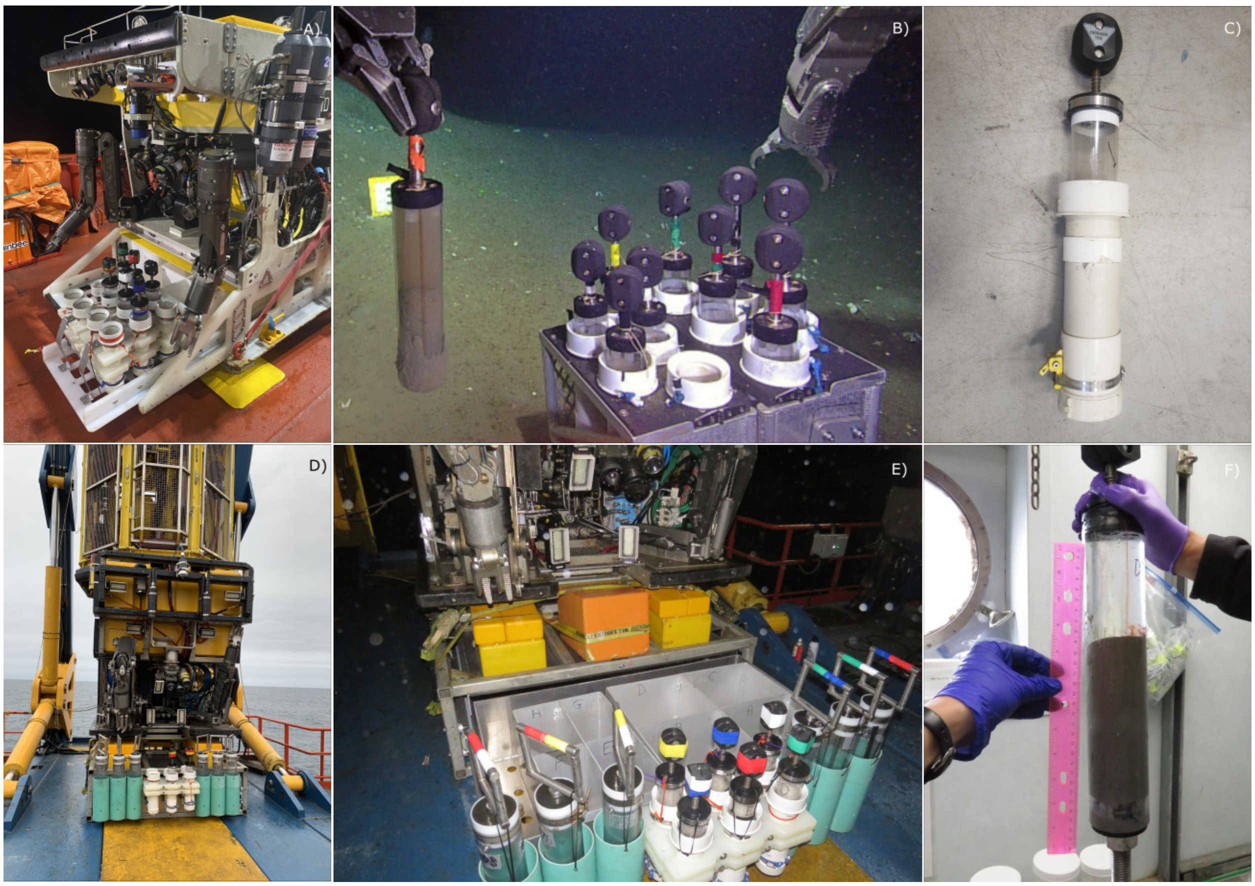


Figure 3. Examples of ROV push-cores. A) ASTRID ROV with a set of 11 push-cores, B) ROPOS ROV *in situ* transferring core back to holster tube, C) ASTRID/ROPOS individual push -cores with holster, D-E) push-cores mounted on Magnum ROV (note two different sizes), F) core liner filled with sediment, after being removed from holster tube.

3 Survey guide

Considerations regarding ROV dives during scientific expeditions are described in this section in four parts: before the expedition, before the dive, during the dive, and after the dive.

3.1 Before the expedition

Setting clear priorities before any expedition will increase its chances of success. ROV-related expeditions have an additional degree of complexity and often demand extra dedication during the planning phase. Furthermore, ROV surveys often take place as part of multidisciplinary expeditions, which demands a balance between research goals, tools, and study sites. Surveys should be designed considering the ROV's capabilities and limitations in order to avoid unrealistic expectations and unnecessary frustration. If available, participating in sea trials represents an opportunity to become more familiarized with the ROV, its tools, and team, and likely solve potential issues before the first dive.

The amount of time allocated to ROV surveys during an expedition will depend on several factors, including whether the expedition is ROV-dedicated/focused or not. In some cases, ROV operations can run for 24 hours, while in other cases 12 hours or less. See subsection Dive duration/time on bottom in **Dive plans** and Table **1**. Also, there might be a learning curve for both ROV pilots working on new vessels or with new ROVs, as well as new ship crews working with ROVs or on new vessels. These factors need to be taken into consideration when defining expectations of what can be accomplished during a mission.

3.1.1 Instruments and tools

As soon as the need for specific ROV instruments and/or sensors is known to scientists, these should be discussed with the ROV team to assess feasibility and logistics, well ahead of the expedition. Scientists should not assume availability of tools based on previous experiences, as every survey (and ROV) is different. Integration of instruments and sensors is often possible, but might require significant advanced planning and often additional funds. Careful planning at this stage will maximize the use of ROV capabilities and increase chances of survey success. In addition to discussions on ROV physical capabilities, options regarding the availability of navigation (position) data and their formats should be discussed and defined ahead of time.

Defining the use of a system to log ROV real-time operations and observations during a dive should also be considered ahead of the expedition (see section **Logging**). Logging is an important component of ROV operations. Scientists can log observations about the biota, physical characteristics of the habitat, but also the status of the survey (e.g., the start/end of a transect line, ROV reached bottom, ROV waiting for ship, etc.). These types of information can be extremely useful post-survey, particularly if the videos will be analyzed by someone that was not present during the survey. In some cases, logging by shore-based participants is also possible (e.g., ONC's SeaTube), which can increase scientists participation. If a logging system is unavailable as part of the ROV's tool set, having early discussions will give time for scientists to explore alternatives.

3.1.2 Dive plans

Having a detailed dive plan written by the science team which contains all relevant information about each proposed ROV dive and priority of activities can greatly assist with survey success. Copies of the dive plan should made available to the bridge, ROV and science teams, preferably ahead of the expedition. Some of the elements of a dive plan include dive objectives, priorities, ROV configuration, geographic/planar coordinates and maps, depth and slope range for the dives (if available), transect design, and estimated dive duration.

Dive objectives and priorities

Clearly explain dive objectives and identify the focus of the dive (e.g., video transects, biological, sediment sampling), etc. Prioritizing dive activities and locations ahead of time will facilitate decision-making offshore if plans need to be changed due to unforeseen events (e.g., equipment failure or rough seas). Priorities for the different activities per dive should be identified and discussed with pilots, as they can assess feasibility and assist with time management during the dive. With careful planning, there might be time for extra activities at the end of a dive. Planning for back-up dives at locations of interest can also prove useful if the opportunity for an unexpected dive arises.

ROV configuration

Detail all ROV configuration needs in the dive plan. For example, identify whether push-cores will be used (how many, and their specifics), the number of box dividers in storage containers, if applicable (e.g., sample skid or bio-boxes), if additional storage solutions might be needed (with discussion before dive plan is finalized), whether Niskin bottles will be used, and whether other tools will be needed for a particular dive (e.g., sample scoop, suction sampler, and cutter on manipulator).

Geographic data

Tables containing geographic data (e.g., latitude, longitude, and depth) should be included in the dive plan. Start and end positions for a transect line may or may not suffice, depending on the desired level of precision. In some cases, adding several points along a line might be necessary to keep a straighter transect. In fact, if attempting to repeat a previously surveyed transect line, providing precise positioning (e.g., by the second) can yield better results. Since detailed positioning might entail large amounts of data, sharing GIS files or spreadsheets might be more appropriate than having the data tabulated on a dive plan. Scientists should consult with the ROV team and ship's officers on preferred format for coordinates (e.g., type of files, decimal degrees *vs* degrees decimal minutes).

Maps

Maps showing the general location of the dive, close-up of dive site, transect design, direction (start and end positions clearly labelled), depth contours, and basic map elements (e.g. coordinates, scale bar, north arrow) are useful (e.g., Figure **4**). If available, specific map layers such as multibeam bathymetry (in addition to depth contours), slope, bottom types, and other layers of interest (e.g., position of nearby mooring) should also be displayed.

Depth and slope

If available, depth and slope for the expected start, end, and any other relevant positions should also be listed along with the geographic information. The origin of depth values should also be indicated (i.e., multibeam bathymetry, GEBCO, or Google Earth), and any uncertainties should be noted. For instance, we have identified GEBCO-Google Earth discrepancies of >200 m, which were only corrected after multibeam data collection (e.g., Cote et al. 2023). In fact, if multibeam data are not available during the planning stage, collecting these before an ROV dive should be considered, particularly in areas where complex topography might be expected. In some cases, the ROV team can integrate multibeam data into their navigation software, to view the ROV transect overlayed on the multibeam in real time. If planning a dive in known steep areas, displaying depth and/or slope profiles for the transect can help the ROV team to better assess the planned survey (Figure **5**). *Transect design and direction*

Transects might follow a single line or varied patterns (e.g., zigzag) and should be discussed with the pilots beforehand to assess feasibility. With an ROV, up-slope transects are more efficient and generate better quality videos. Therefore, video transects should move from deeper towards shallower locations of the study area. However, down slope surveys are also possible, depending on steepness of the seafloor and dive objectives (Figure **5**). A different ROV configuration might be required in such cases. Transect direction will therefore depend on slope, but should be discussed with the ship's captain and ROV team for weather conditions that might limit some directions more than others. A change in direction that requires a significant ship turn can significantly increase the time necessary to complete a survey. Ship's capabilities, crew experience, depth, currents, wind, and sea state are all part of the balancing act. If there is flexibility on which direction to follow, ROV pilots and the ship's captain/officers might offer the best scenarios for an effective dive.

Transect length

Surveyed distance will depend on dive objectives, and available bottom time. Realistic transect lengths (and therefore dive duration) will depend on ROV speed and whether sampling and/or exploring (e.g., stopping for photographs) is also occurring. Transects can be variable in length, but several kilometers of the seafloor might be surveyed during a single dive, if time is available. Bottom time should be optimized when possible given that for every new dive, time is allocated to non-scientific activities (e.g., ascent, descent, ROV checks). In this sense, there will be situations where transiting to a new location with the ROV underwater might be preferable to recovering and redeploying it (e.g., <2 km distances). However, assessing which scenario is more advantageous will be a function of depth and ROV turn-around time *versus* the transit distance and the average speed the ROV can maintain at that depth.

Dive duration/time on bottom

In addition to planned survey duration, estimating available time on bottom should consider time for ROV pre-dive and post-dive checks, including potential changes to ROV configuration (conducted by the ROV team), dynamic positioning calibrations (if applicable), as well as ROV descent and ascent duration, which will depend on depth. If ROV pilots are available on a 12-

hour shift and there are no issues with the system, time on bottom might be as long as eight hours or more. When 24-hour ROV operations are possible, time on bottom could be >24 hours. For instance, ROPOS conducted a 96-hour uninterrupted dive in 2016 (without sampling). While pilots and ROV scientists might be well aware of the time required for each operation, having those listed as a table in the dive plan can be useful to other scientists and ship crew, and facilitate scheduling operations. For instance, diving to a 700 m depth might take 35 minutes to descend, plus time for deployment (lift off deck, drive away from ship, etc), ascent and recovery (Table **1**). Therefore, allocating three hours for this dive could mean spending one hour on the seafloor, which likely will not be enough.

Table 1. Example of estimated duration of ROV dive operations (actual durations may vary). Transect speed assumed to be 0.25 knots, and ROV ascent/descent at 20 m/min. Deployment and recovery durations can vary, depending on multiple factors such as weather or crew experience. The table does not include time for ROV pre and post-dive checks, which needs to be considered as part of ROV pilot time.

Dive info	Site 1	Site 2	Site 3
Start depth (m)	300	1500	696
End depth (m)	250	1500	457
Transect length (m)	1000	2000	1000
Deployment (min)	30	30	30
Descent (min)	20	75	35
Ascent (min)	12.5	75	23
Transect duration (min)	130	260	130
Other activities (e.g., sampling) (min)	60	60	120
Recovery (min)	30	30	30
Total (min)	282.5	530	368
Total (hours)	4 h 43 min	8 h 50 min	6 h 58 min

Knowledge about the location

Having general knowledge about the area to be surveyed is important, and can have an impact on the success of an ROV survey. This includes knowledge about physical characteristics of the site and human-made obstacles.

Physical characteristics

- *Bottom-type*: diving in areas of high topographic relief will increase dive complexity. It is important to discuss best dive scenarios with both ROV and ship teams. As mentioned above, if multibeam data are not available for the study area, efforts should be made to collect these ahead of the dive. Meanwhile, soft bottom areas might be less complex from the point of view of physical hazards, but have decreased visibility due to sediment turbidity in the water column. High sediment turbidity can be natural (e.g., due to biological activity) but also caused by the ROV. Therefore, when planning for activities on soft bottom areas (e.g., landing the ROV for sampling or photos), scientists should expect potential decreased visibility and delays. In some cases, visibility might not improve within a reasonable time frame, and scientists might need to make a decision to end the dive earlier than planned and reassess next steps. Scientists should also take advantage of any other data that might be available for the study area, such as data from previously collected sediment samples that can inform about bottom type, particularly if sediment push-coring is expected during the dive.

- *Currents*: high current speeds can create limitations and should be seriously considered in order to avoid preparing for a dive that might be deemed to be unsuccessful. At locations with strong tidal currents, diving might need to be timed to avoid the period of highest current strength, but not all currents are tidally-mediated. In addition, even when timing a dive, seafloor duration might be limited to only a few hours. If available, current models for the specific location and expected diving dates should be included in the dive plan and be reassessed before diving. Examining currents data collected at or near the station just before the dive (e.g., from ADCP) can also give a snapshot of the currents in the area. Surface and bottom currents are both important, as ship handling is a critical component of an ROV survey. The pilots and ship's captain can determine whether the site is diveable and the scientists should help accessing the available information. While some models might not be very precise at a local scale, they can still be useful to identify areas under the influence of tidal currents, and allow to adjust the dive site location to increase the chances of success.

- *Biological/geological/archaeological features*: in areas where Vulnerable Marine Ecosystems (VME) or other sensitive habitats might be expected to be found (e.g., cold seeps, hydrothermal vents), as well as areas of archeological/cultural importance, scientists should advise ROV pilots about what to expect, as to avoid unwanted physical contact with fragile organisms/structures. These areas might require special permits. In addition, including photos of specimens/features of interest (e.g., certain species) in the dive plan can also help pilots to better understand the scientist's needs.

- *Human-made obstacles*: The presence of shipwrecks, moorings, or other underwater equipment near a dive site should be considered. Diving in areas where ghost fishing gear is expected should also be noted.

Experiments/instruments

If there are plans to inspect or recover experiments, instruments or any other item that needs to be searched on the seafloor (i.e., from a previous deployment), photos and detailed information about such items should also be included in the dive plan. Precise positioning of where these items should be located is also crucial.

Other dive plan considerations

Turnover time of scientific samples and data recovery by the ROV team should also be considered at the planning stage, particularly if back-to-back dives are expected. This includes time for downloading data from instruments, the amount of internal storage available on instruments (whether cameras can record more than one dive worth of data), or the availability of extra equipment such as push-core tubes. Dive plans might be adjusted during the expedition, but setting expectations about the type of dives before the start of the expedition helps pilots to better prepare.

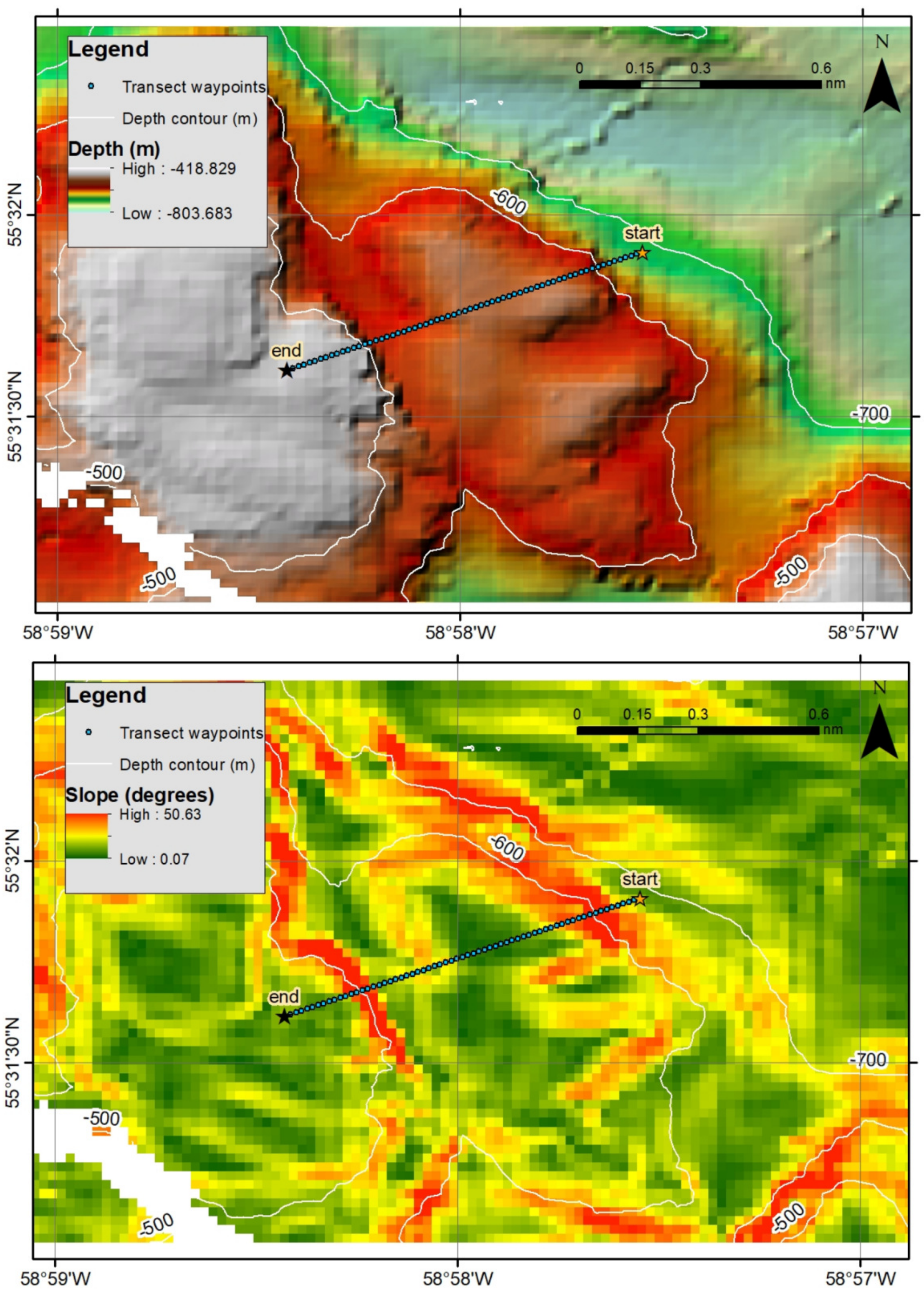
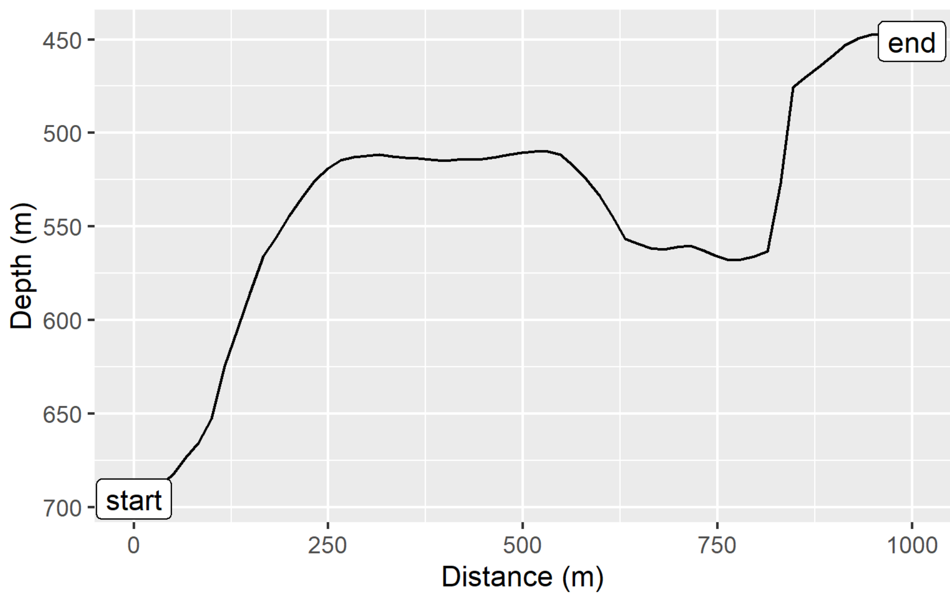


Figure 4. Example of a remotely operated vehicle (ROV) dive plan map. Top: ship-borne multibeam bathymetry, bottom: slope derived from bathymetry. The maps should display start and end positions, basic map elements (e.g., scale bar), depth contours, and other relevant information (e.g., location of a nearby mooring).



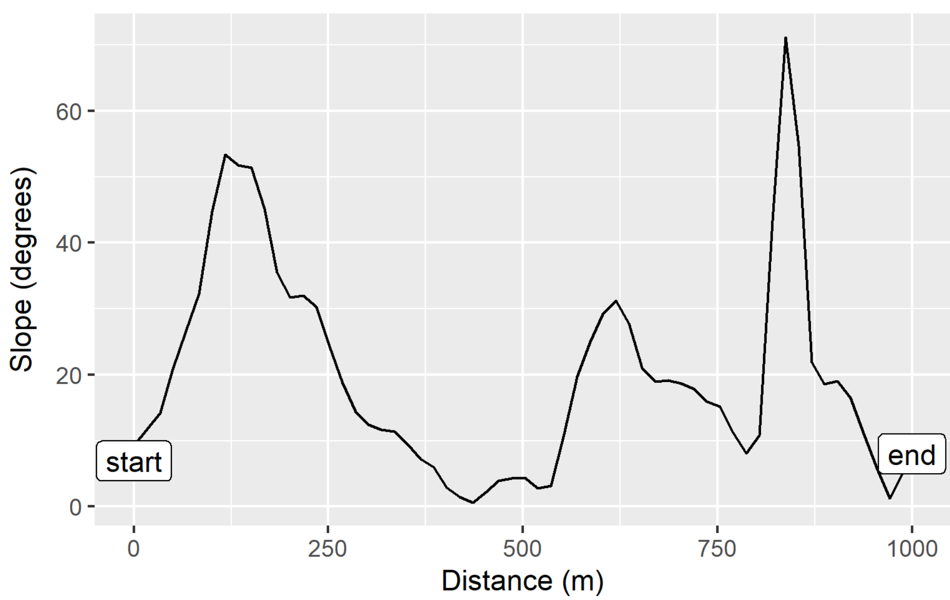


Figure 5. Example of bathymetric (top) and slope (bottom) profiles for a transect line. Note that this dive has steep walls and both up and down-slope directions (but see text for discussion on transect direction).

3.1.3 Digital storage needs

External hard drives are often used to store ROV data at sea, and a general knowledge of the amount of data generated per dive (i.e., in GB or TB) is important to ensure that enough hard drive space is available. File sizes differ depending on the camera and mode (e.g., 4K or HD video, photos), so scientists should make sure to discuss/confirm storage needs with the ROV team ahead of the expedition. For example, for the MiniZeus camera used with the ASTRID ROV, we estimate a data collection rate of 0.14 GB per minute of video, compared to 0.12 GB for the 1CamAlpha. In 2021, for a full 8-hour dive with this ROV, the files (i.e., videos, photos, logging, and navigation) totaled ~200 GB per dive. As another example, for a full 10-hour dive with ROPOS in 2017, the maximum amount of data per dive summed ~600 GB. With the development of new cameras at higher resolutions, the size of files is expected to significantly increase, and the choice of HD versus 4K (or higher) should consider storage and the time needed for file transfers. Hard drives should be provided to the ROV team by the scientists (usually pilots make one copy which will be further copied afterwards) and should not have restrictions on them (e.g., BitLocker). In addition, there should be a discussion regarding timing of data availability, i.e., whether the data will be available in real-time, post-dive (s), or at the end of the expedition. Creating hard drive back-ups while still at sea is also recommended, as ROV operators might not have access to files after the expedition. Scientists should also ensure that hard drives have complete copies of the files before sharing them.

3.1.4 Screen display

ROV and survey information such as heading, depth, altitude, date/time, and position can be superimposed on video inputs using a video overlay system. However, overlay video is generally of lower quality, and in some cases video overlay modules will only support SD cameras. There are cases where overlay video might be the only video input delivered to clients, which might not reach desired scientific standards. Therefore, in addition to having access to basic overlay video, scientists might also require high quality video with metadata information that can be added as a subtitle add-on (e.g., closed-captioning system), as opposed to overlayed. In addition, the location of this information on the screen should avoid covering important parts of the field of view (e.g., avoid adding information to the bottom of the screen). This should be discussed ahead of the expedition.

3.1.5 Imagery permissions and crediting

A large number of images and videos can be collected during an ROV expedition, therefore clearly defining permissions to use the imagery and crediting should be defined ahead of the expedition. For instance, scientists might be interested in doing outreach through social media and other platforms during and/or after the expedition. In addition, images might be used in publications and/or presentations. Ensuring that proper use of data and credits are defined ahead of time is therefore essential to avoid images being used inadvertently and/or without proper recognition.

3.1.6 Live streaming

In some cases, ROV footage can be live streamed from the ship to shore. Live streaming can be open to a fixed number of people (e.g., a few other scientists) or to the general public. Available funds and logistics (e.g., offshore internet speed/reliability) will often determine whether live streaming is possible, so conversations should start early in the expedition planning. In addition to facilitating expert participation, live streaming is also a great general public outreach tool (Hoeberechts et al. 2016; Fundis et al. 2018), and it should be considered whenever possible. Ocean Networks Canada (ONC) SeaTube is a great example of live ROV video streaming in Canada and elsewhere (`https://data.oceannetworks.ca/SeaTube`).

Nevertheless, live streaming requires its own planning and dedication at sea. Having a scientist who is assigned and dedicated to the live streaming work is therefore important, and sometimes this might be challenging (e.g., not enough personnel or space in the ROV room). Another consideration is that live streaming events should be well advertised, and therefore work best for ROV-dedicated expeditions, where the ROV is expected to be in the water most of the time. In expeditions where the timing of the ROV dives is not confirmed well ahead of time, it will take enhanced communication between offshore and onshore scientists (and other groups benefiting from the streaming) in order to increase participation and public outreach.

3.2 Before the dives

3.2.1 Communication

There should be clear communication between the scientist in charge of the dives and the ROV team to ensure that the ROV will be ready for its deployment and that last-minute requests are avoided. In addition to the thorough dive plan document described in the previous section, a one-page pre-dive summary sheet can also be of help to pilots (e.g., Appendix **A**). The scientist in charge should ensure that loggers and their roles are defined before the dives. If the dive is being streamed live and audio of the room is being recorded, the scientist in charge should make sure to inform everyone in the ROV room. Confirming that the ship is at the correct launch position is also recommended before ROV deployment starts.

3.2.2 Data products

A list of data products often required as part of an ROV mission can be found in Appendix **B**. This list should be discussed with the ROV team to set the expectations regarding data products and other details (e.g., file naming convention, Dive ID, and information displayed on screens) ahead of the first dive. It is critical that imagery and ancillary files can be linked (e.g., to know when and where a specific DSC was taken), and scientists should ensure that they understand how this can be accomplished. For instance, having a time stamp displayed on the video, which can be linked to the navigation data, might be the solution proposed by the ROV operator (but see **Screen display** section). File formats should also be discussed if specific formats are preferred (e.g., M4V vs. MP4) and whether changing the format can affect quality. File names and formats are more difficult to modify after collection, so having this discussion is a critical step. Geographic data can be generated as latitude/longitude or northing/easting, and scientists should identify their preferred format beforehand, as different ROV operators might use different coordinate systems. Depth can be obtained from different sources, such as the ROV sensor and the ship's tracking system. Therefore, it is important to know the source being used in navigation, logging, and video overlay. These data should not differ by much, and any large discrepancies should be fixed or explained. The time zone being displayed on the imagery should also be noted (e.g., expedition report), as it might differ from that of the ship - although efforts should be made to ensure synchronicity. In some surveys, the ROV and navigation teams (the latter also called surveyors) might not be the same (even different companies), and scientists must ensure that there are no inconsistencies between the formats used by both teams.

3.2.3 ROV room and roles

Scientists should identify participants in the science crew that will be in the ROV room during the dives and each of their roles. If the ROV room is small, the number of scientists that can be in the room might be limited. However, in some vessels ROV dives can be channeled through the CCTV system, so anyone aboard can watch the surveys in real-time from other locations of the ship. In ships where the number of scientists having access to the dives is more limited, an audio system can be discussed to allow better communication. Video/audio streaming and shore-based participation can increase involvement by scientists that cannot participate in person and provide an excellent opportunity for public outreach. Although streaming and shore-based participation will incur additional logistics and costs, their benefit is significant, and should be considered when possible (see section **Live streaming**).

3.2.4 Specimen sampling (e.g., biological/geological)

If the configuration of the storage containers is adjustable, the desired configuration should be defined well ahead of the dive, to allow time for any modifications to be made (e.g. plan to collect larger or smaller samples). Labeling the containers (e.g., skid drawers and bio-boxes) where labels can be visible during a dive can help to avoid confusion regarding where each specimen was placed (e.g., A, B, C, D).

3.2.5 Push-core sampling

Push-cores can be used for different purposes, and their configuration on the ROV should also be determined ahead of the dive. For instance, some scientists use different types of liners (e.g., with sensors), and these should be prepared in advance. Markers that can distinguish the corers should be placed on the corer handles or sleeves ahead of the dives. It is also useful to add a mark on the liner to indicate how deep the pilot should push the corer into the sediment. Scientists new to push-coring can benefit from practicing assembling and disassembling the corers ahead of the dive. In addition, some ROV pilots might not be experienced at push-coring, and providing an opportunity for them to practice before collecting a sample can be beneficial.

Push-core users should also bring basic tools to remove the liners from the holsters and access the sediment. Push-core processing aboard generally requires more than one scientist.

3.2.6 Deploying instruments/experiments

If any instruments or experiments are to be deployed using the ROV, these should also be discussed with the ROV team, and scientists should ensure that they are ready for deployment ahead of the dive.

3.2.7 Photos of ROV configuration

Taking photographs of ROV configuration before the dive can be be useful for post-data processing and future ROV survey planning. This is particularly important if instruments or experiments are loaded on the ROV, but also for camera/light positions.

3.2.8 Pre-dive check-lists

Scientists can benefit from having a check-list when deploying instruments, push-cores, or any other device, to make sure that they are ready for deployment before the dive. For instance, ensure that the number and types of push-cores are correct, or that jaw cutter is present if requested, etc. Scientists should double check with pilots on the status of specific devices/instruments (e.g., loaded, turned on, etc).

3.2.9 Camera settings

While camera settings can be adjusted during the dive (see section **Camera parameters and settings**), scientists should discuss with the ROV team if they have special needs ahead of the dive.

3.3 During the dives

3.3.1 Roles

During a dive, scientists are generally expected to direct, log, and take DSC photographs/short clips. Directing might be alternated between the scientist in charge of the dive, and other scientists that might have specific requests, but this should be clearly established with the ROV team. The pilots should be aware of the general dive plan, but scientists need to direct them on the order and timing of activities. It is important to be loud and clear, as pilots are focused on the screen ahead of them.

3.3.2 Logging

Logging real time dive activities is an essential part of an ROV survey, and ensuring that an appropriate logging system is set-up before the mission is strongly recommended (discussed in section **3.1**). Logging consists on annotating information about dive events (e.g., sampling, transiting, problems with the ROV/ship) and observations of interest (e.g., species A, high densities of something, change in bottom type/fauna). While logging can be performed using basic spreadsheets, more robust logging systems have been developed (Gomes-Pereira et al. 2016) and are preferred. For instance, IRLS (Integrated Real-Time Logging System, Canadian Scientific Submersible Facility/ROPOS) is used with the ROV ROPOS and it has been used with the CCGS *Amundsen* ROVs (SuMo and ASTRID) since 2015. In addition to logging observations, IRLS allows information about samples to be entered and it integrates observations with navigational data (and optional photos) (Figure **6**). It is useful for video post-processing and quick finding of events of interest. Another useful logging system is ONC's SeaTube mentioned earlier in this guide, which can allow at-sea users and on-shore participants to log in real time through live video streaming.

A list of pre-determined terms can be used to make sure consistency is kept on naming conventions when logging. For example, in IRLS sample IDs are generated automatically (e.g., Dive 12-1), but their qualifiers (e.g., type of sample) are inserted manually by the scientist logging sample entries. Scientists should make sure that they reach a consensus on templates for how to name their qualifiers, because even small differences in terms can create additional work during post-processing (e.g., coral vs. Coral). Other logging systems might offer the possibility of selecting pre-determined terms from drop-down menus or forms. We suggest keeping names simple, for example all low-case, with or without hyphens, such as below:

- *Identifier*: coral, sponge, sediment, rock, sea star
- *Method*: manipulator, niskin, scoop, push core
- *Location*: box A, box B, niskin aft, niskin for, blue red blue (for cores), red yellow blue (for cores)
- *Event*: ROV launched, descending, on the bottom, off bottom, sampling, push coring, inspecting, transiting, start of line, end of line, end of dive, ascending, ROV on deck

If a logging system is not available during a dive, scientists should make sure that if they use a spreadsheet option (e.g., Microsoft Excel), that they can record the time of each observation by the second (in the correct time zone used by the ROV). Keeping a list of species names (i.e., for biological surveys) handy during a dive can also be useful to ensure consistency among loggers.

3.3.3 Video transect

A video transect might not start exactly where the ROV lands. It is important that scientists ask pilots to let them know once they have reached the start position. Pilots might be concentrated on other tasks and not mention that the ROV is still moving towards the start position, and therefore not yet on transect mode. Once this position is reached, it should be logged as the start of the line (and same if multiple lines are expected during a dive). Considering the purpose of the transect is crucial to define transect parameters. For instance, straight lines at approximately constant altitude and speed are required for obtaining fish data (Sward et al. 2019). Transects aiming to survey sessile/sedentary fauna might have more flexibility.

3.3.4 Taking photos/video clips

One scientist is often assigned to be in charge of taking ROV still photos or video clips during the dive. This task gives this scientist control of zoom and other camera parameters. However, scientists should always ask for permission before zooming-in or out, and familiarizing themselves with the control buttons ahead of the dive. High-quality photos generally require the ROV to be stopped. See Christ and Wernli (2014b) for tips regarding video recording during a dive.

3.3.5 Sampling

If planning on stopping for collections, scientists should let the pilots know with as much notice as possible, since stopping the ROV requires coordination with the ship's bridge, and it is not easy to completely stop the ROV on short notice. For instance, consider whether samples should be taken opportunistically, before, or after a transect, keeping in mind that for long dives specimens might stay in the sampling container for hours. In cases where this might be problematic, sampling at the end of a dive might be an option. Before sampling, ensuring high-quality video footage and zoom of the specimen can facilitate species identification afterwards and observation of other elements of interest, such as species associations. During sampling, scientists must give clear directions to pilots on how they need their samples to be collected (e.g., piece or whole specimen, push-core angle, depth, and location).

It is useful to immediately take notes of which samples are located where in the ROV, because this will facilitate identifying, labeling, and retrieving them when the ROV is back on deck. In fact, sampling of multiple specimens that might share the same storage container during a dive requires taking detailed notes about the specimens to ensure their distinction once on deck. Mixing similar taxa or specimen fragments in the same container might lead to considerable issues distinguishing them afterwards. Similarly, taking notes of push-core IDs and their colors during the dive can also be helpful once on deck. This information (sample locations on ROV) should also be entered in the dive log to provide a clear and synthesized list of samples collected per dive and their location.

Sampling can take between a few minutes and more than 10 min per target, depending on the level of sample complexity and other factors. In some cases, such as in soft bottom areas, sampling operations may hinder video quality by obscuring the field of view or making the ROV negatively buoyant, forcing a slight upthrust to keep altitude. This can greatly impact visibility and temporarily restrict or preclude ROV movement until visibility improves. Another challenging scenario involves sampling along a vertical wall, since the ROV cannot land. In many cases, ROV sampling or water movement caused by the thrusters can also influence organism behavior (e.g., contraction, make organisms to move). Therefore, sampling can take more time than expected, making it crucial to evaluate how it fits in the dive priorities and available dive time to ensure that all objectives can be achieved.

Some items to pay particular attention during the dive include the following:

3.3.6 ROV altitude

For most surveys that aim to investigate seafloor benthic diversity patterns, camera height off bottom (i.e., altitude) should be around 1 m or less. If altitude is not optimal for the survey objectives, the seafloor will not be visualized well enough despite good cameras and lights. The video should provide a nearly complete illumination of the seafloor given the camera's FOV. In these conditions, the survey will generally provide suitable imagery data. Large areas of black/dark video at the top usually indicate that the ROV camera is tilted up too much, while large areas on the left and right of the monitor indicate that the altitude is too high. Pilots can use an altimeter or comparable device to control for altitude (also useful in imagery post-processing), but often the illumination of the seafloor provides a much faster feedback to experienced pilots, and it helps ensure the best imagery data throughout.

The scientists should be aware that the ROV's altitude being displayed on the screen reflects the location of the instruments on the ROV, not that of the cameras. In soft bottom areas, if the instrument is located too low on the ROV, it might accumulate sediment, which will interfere with the altitude data being recorded. Keeping an eye on altitude and logging potential issues is important for data post-processing. Scientists should take note of where these instruments are located on the ROV and should make sure that pilots are following the desired altitude. Consistency is key to allow a better comparison between transects and dives. If precise altitude information is unavailable, distance between laser points in pixels can be used as a proxy for variation in the FOV during post-processing, and therefore altitude during a dive.

3.3.7 ROV speed

ROV transect speed should be ~0.25 knots (~0.5 km/hour). Faster surveys will often yield lower video quality. Scientists should pay attention to survey speed and communicate with pilots if speed does not go as expected, so pilots can adjust, where possible.

3.3.8 Lasers

Lasers can be turned on and off during a dive (i.e., photos without lasers might be more appealing for outreach purposes or lasers might be required for photo/video-mosaicing work; also discussed in section 2.2). Make sure to communicate with the pilots on desired lasers status (i.e., on or off) at the beginning of the dive. Scientists should also make sure that they know the distance between laser points, as they can vary across cameras and ROVs, and make sure that pilots know that any changes should be immediately communicated to them.

OBSERVATIONS

Time*	Description	Latitude	Longitude
2021-07-20 13:26:25	preparing to launch.	-	-
2021-07-20 13:28:57	Clear to launch	N55° 31.845′	W58° 57.81′
2021-07-20 13:31:18	Power off, depth not changing, sensor still problematic	N55° 31.845′	W58° 57.81′
2021-07-20 13:34:00	Trying again	N55° 31.845′	W58° 57.81′
2021-07-20 13:34:34	Launching ROV	N55° 31.845′	W58° 57.81′
2021-07-20 13:36:27	ROV in the water	N55° 31.845′	W58° 57.81′
2021-07-20 13:38:48	Depth sensor is working for this dive	N55° 31.0368′	W58° 56.541′
2021-07-20 13:42:49	ROV heading to dive location	N55° 31.0452′	W58° 56.5476′
2021-07-20 13:43:36	ROV going down	N55° 31.0476′	W58° 56.5572′
2021-07-20 13:45:21	65 m	N55° 31.0062′	W58° 56.6166′

Figure 6. Example of log using the Integrated Real-Time Logging System (IRLS). Observations are entered during the dive and are associated with the time and position where the observation was taken.

3.3.9 Camera parameters and settings

Camera orientation/angle depend on the scientist's preferred field of view and objectives. It is often important to keep a consistent camera orientation, and scientists need to communicate if camera orientation or zoom should not be changed during the transect or between dives. This is particularly important if some of these parameters cannot be changed to fixed values. For example, if it is not possible to know the precise amount of zoom given, this might interfere with consistency of data collection. In the case of ROVs that have push-cores or other devices partially showing in front of the camera, scientists or pilots might be tempted to zoom-in to "remove" them from the camera's field of view. However, caution should be taken because this can limit comparability between dives if the same zoom is not used elsewhere. If a transect is being performed in "zoomed-in mode", this should be clearly stated and detailed in the dive's log.

While other camera parameters and settings should ideally be discussed/adjusted before the beginning of the dive (or transect), some parameters can still be changed during the dive. Camera settings such as shutter speed and ISO can be adjusted and improve imagery quality. Using auto settings such as auto-exposure allows the camera to automatically adjust for these parameters. The use of auto or manual focus can also be adjusted during the dive, and their choice will depend on factors such as water turbidity. Using auto-focus in high turbidity environments might lead to focusing on particles in the water. White balance can also be important. Since appropriate camera settings are so crucial for collecting high-quality imagery data, the team should take the time to ensure that imagery is optimal for their needs early in the dive.

3.4 After the dives

At the end of a dive, if samples were collected, scientists should be ready to retrieve them when the ROV pilots deem that it is safe to do so. Before moving or removing the samples, taking photos with a scale and label indicating the dive number is recommended. As explained above, in the case of push-cores, scientists should bring their own tools to remove the push-cores from their holsters. After done collecting their samples from the ROV, scientists should let pilots know that they have finished (i.e., pilots might want to work on the ROV).

In soft bottom areas, sampling of specimens might be accompanied by associated sediment, which will tend to accumulate in the sampling containers. In some cases, scientists can ask pilots to open the containers during descent of the next dive, in order to wash them, but this might not always efficiently remove the sediment and it might not always be possible. If contamination between samples and sites is a concern, it might be an option to use a wet vacuum cleaner in order to remove remaining sediment and water from previous sites between dives.

At the end of a dive, the ROV team will begin to work on preparing the data products, whose details should have been discussed beforehand, and setting up for the next dive. Scientists and ROV team should also have discussed the timing of data products delivery (e.g., after each dive or at the end of the expedition).

3.4.1 Data products checks

Appendices **C** and **D** show examples of post-dive check-lists that scientists can use to quality control the data products, which would have been discussed ahead of the dives (e.g., appendix **B**). Ensuring that the data set is complete, and that there are no corrupt or empty files is an important step. As a general rule, but specifically if using IRLS or other logging systems generated by the ROV team, check for spelling mistakes, duplicated entries, and communicate any potential issues to the technical team as soon as possible.

3.5 Before the end of the expedition

Scientists should be familiar with ROV settings and features before and during dives (especially if any dive activities depend on these settings), but should not leave the ship without confirming a few basic items, summarized below.

3.5.1 Camera specifications and field of view

Camera field of view can be challenging to precisely calculate for forward-looking cameras, even if laser pointers are present (Dias et al. 2015). Depending on the scientific objectives of the dive/expedition, knowing parameters such as camera aperture angles (from manufacturer) and height on the ROV (Long et al. 2020) might be important, and should be checked with the ROV team before the end of the expedition.

3.5.2 Distance between laser points

Scientists need to ensure that the distance between laser points for each camera is known.

3.5.3 Confirm imagery permissions and crediting

The team should define permissions and credits for all imagery resulting from the dives. This information can be included by the scientist in charge as part of the data products package produced by the ROV team. This will be more effective if defined before the expedition begins, to ensure appropriate social media and imagery sharing during the expedition.

3.5.4 Summary of deliverables

Scientists should understand the data products shared by the ROV team. A summary of deliverables provided by the ROV team, such as a README file containing general information about the data and metadata, can assist with this. This should include basic information such as units (e.g., depth in meters) and distance between laser points, for example. This summary can be particularly important if any data require calibration and/or post-processing before being used.

3.5.5 Expedition report

Cruise reports are generally produced at the end of an expedition. Briefly describing ROV dives, successes, and challenges can help during data analysis and can be useful for future planning. A detailed material and methods section can be particularly useful. The expedition report is also a good place to detail some of the items described above such as camera specifications, field of view, and distance between lasers. In addition, reports should include photos of the ROV and samples, *in situ* highlights, maps showing completed transects and location of samples. Generating spreadsheets and summary tables listing samples, their preservation methods, location (institution), and contact person is also important.

4 Final considerations

While this document provided information on several items worthy of consideration when preparing for and conducting ROV scientific surveys (see Figure **7**), general advice is summarized below:

- Establish early and open communications with the ROV team to define available capabilities and those that could be developed. Including the ROV team on preliminary dive/expedition plans is the best way to get this started and make the most of an ROV expedition.
- ROV operators are usually commercial entities. Planning for a “consulting” budget for anything that falls outside a system’s “regular” capabilities is recommended. When possible, work these capabilities and integration in the contracts or grant requests.
- Invest on a detailed dive plan and expedition report. These can be extremely useful after the expedition.
- Establish priorities and back-ups at all levels to adapt to unexpected events.
- Ensure that enough science personnel is available. The several tasks during and between dives can be better accomplished if enough scientists are present to share these and avoid rushing.
- ROV expeditions can represent a great opportunity for outreach and communication. Taking advantage of high-quality images and videos to educate and/or inspire should not be underestimated.
- ROV time is expensive and somewhat of a fair-weather endeavor; it is often better used when the expedition focuses exclusively on objectives requiring that tool. Nonetheless, this may vary among expedition types and often is impossible.
- Every minute of a dive could be the last for that day, and every dive could be the last dive of the expedition; plan accordingly.

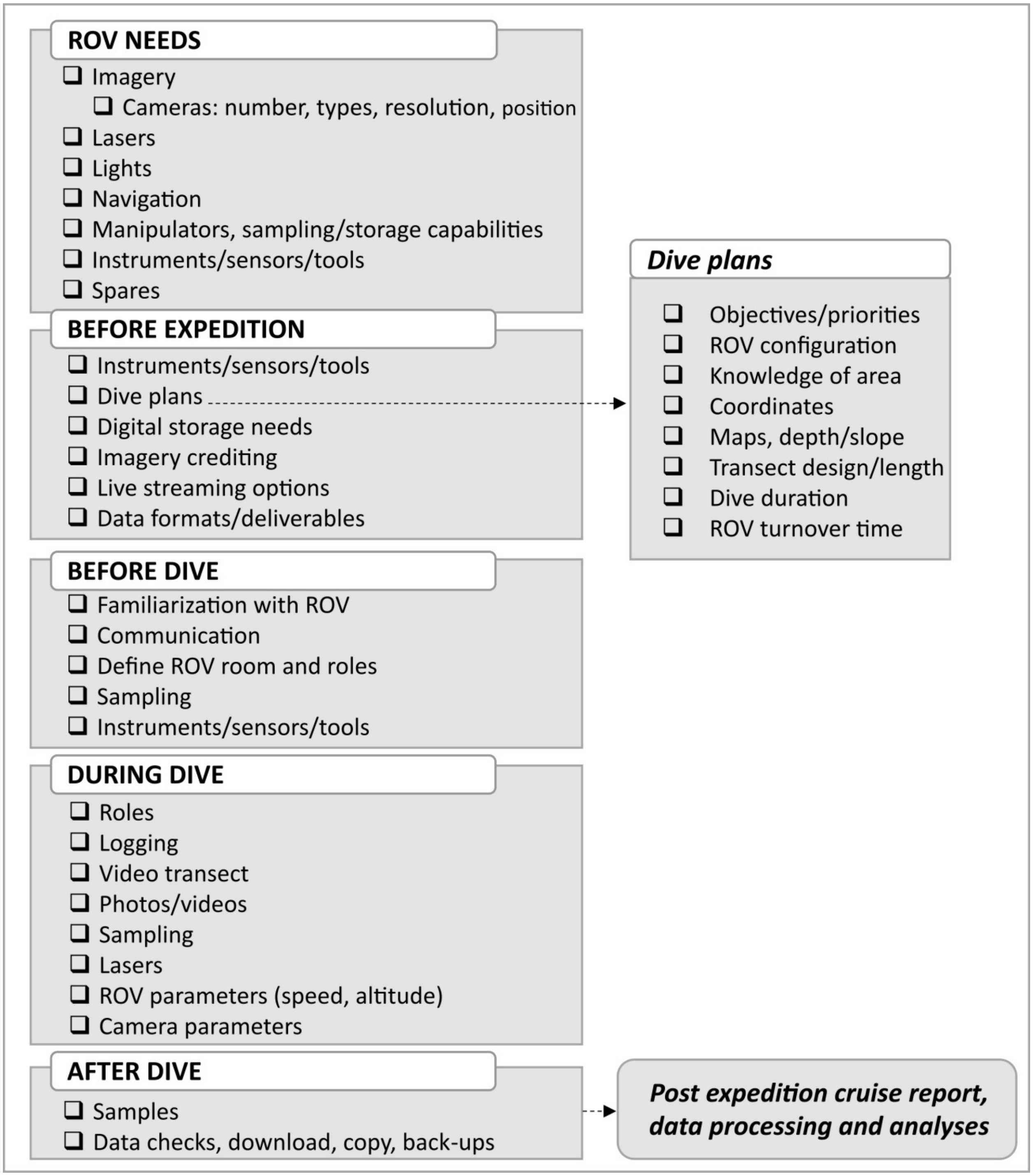


Figure 7. Summary of items for consideration as part of remotely operated vehicle (ROV) scientific surveys.

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APPENDIX A Examples of pre-dive summaries

Site 1. Name of site (Dive 1)

Launch target: 55° 31.9077N, -58° 57.5466W, 696 m (Table A.1).

ROV setup:

- ROV with sampling skid: box 1 divided in 4, box 2 divided in 2 (longer horizontally)
- 2 Niskin bottles
- Sampling scoop
- No push-cores
- Manipulator cutter

Summary of dive plan

- Planned transect line is ~1 km in length, starting at a depth of 696 m and ending at 451 m.
- The first 200 m of the transect move up a slope reaching a maximum of 50° towards the end.
- From there the transect continues over a plateau, including a slight descent, until a new steep slope of ~70° is reached near the end of the dive.
- Biological sampling expected *after* transects (e.g. fragments of gorgonian *Primnoa resedaeformis*, for genetics and skeletons, examples of most common sponge taxa).
- Maps and additional dive plan details and background can be found in the main dive plan document.

Table A.1. Start and end positions and depths for ROV transect at Site X, dive 1.

Waypoint	Lat_dd (N)	Long_dd (W)	Lat_DDM	Long_DDM	Depth (m)
T1-Start	55.5318	-58.9591	55 31.9077	058 57.5466	-696
T1-End	55.5269	-58.9738	55 31.6143	058 58.4292	-451

Site 2. Name of site (Dive 2)

Launch target: 55° 31.0152N, -58° 56.5482W, 685 m (Table A.2).

ROV setup:

- ROV with sampling skid: box 1 divided in 4, box 2 divided in 2 (longer horizontally)
- 2 Niskin bottles
- Sampling scoop
- 11 push-cores:
  - 6 regular corers for macrofauna
  - 1 corer for oxygen microsensors
  - 4 corers for biogeochemistry:
    * 3 optode corers (before deployment corers must be covered with a black bag, which should be removed immediately before launch).
    * 1 porewater corer (liners with holes covered with tape)

Summary of dive plan

- Dive will focus on push-coring.
- The dive will start at a depth of 685 m and once on the seafloor we will identify desired locations for push-coring.
- The ROV will land on the seafloor and we wait until sediment has settled before starting coring.
- Pilots will be asked to push the corer ~20 cm deep into the sediment, leaving ~10 cm filled with seawater.
- Corers will be collected over a small area and scientists will indicate when to move the ROV for further coring.
- Maps and additional dive plan details and background can be found in the main dive plan document.

Table A.2. Start and end positions and depths for ROV transect at Site X, dive 2.

Waypoint	Lat_dd (N)	Long_dd (W)	Lat_DDM	Long_DDM	Depth (m)
T2-Start	55.5169	-58.9425	55 31.0152	058 56.5482	-685
T2-End	55.5163	-58.9497	55 30.9785	058 56.9832	-457

APPENDIX B Expected data products check-list

The following data products are generally expected during an ROV mission:

- Imagery
  - ☐ Videos (varied formats: HD, 4K, SD, etc - for all cameras)
  - ☐ Digital Still Camera (DSC) photos
  - ☐ Frame grabs
  - ☐ Video clips

☐ Navigation files

☐ CTD data

☐ Logging files

☐ Audio recordings (if available)

- Imagery and ancillary files can be linked, for instance:
  - ☐ Time stamp/date on imagery (overlay and/or close-captioning, where applicable)

☐ File naming convention in the desired/expected format

☐ Files in expected format (e.g., JPEG, MP4, etc)

☐ Summary of data products (i.e., README file)

☐ Time zones known and synchronized between ROV, navigation, and logs **(before diving)**

APPENDIX C Expected data products check-list (specific example)

The following data products are more specific examples to current ASTRID ROV missions as of 2023 and might change:

- Imagery
  - ☐ MiniZeus: HD video, overlay video, strobes, frame grabs
  - ☐ Alpha1Cam: HD video, DSCs
  - ☐ RayFin: 4K/HD video, DSCs
- Navigation files
  - ☐ Output file containing: dive ID, date, time, geographic data (e.g., latitude, longitude), depth, heading, pitch, roll, altitude.

☐ CTD data

☐ IRLS files (or other logging files, if not using IRLS)

  - ☐ csv
  - ☐ headers: Dive#, Date (UTC), Observation, Latitude, Longitude, Depth (m), Heading, Pitch (deg), Roll (deg), Altitude (m), Speed (knots), File (DSC file name: /files/dscs/DSC00001_C0025_2021-08-05 13-34-14.JPG)
  - ☐ html_zip
  - ☐ static_html
  - ☐ kmz
  - ☐ DSCs are listed in IRLS csv

- Imagery and ancillary files can be linked, for instance:
  - ☐ Time stamp/date on imagery (overlay and/or close-captioning, where applicable)
- Video file names somehow as follows:
  - ☐ CameravideoID_divenumber_yyyy-mm-dd-hh-mm-ss.fileextension
  - ☐ Example: Mini0001_C0016_20210724133640052.m4v
- DSC names as follows:
  - ☐ DSCID_divenumber_yyyy-mm-dd-hh-mm-ss
  - ☐ Example: DSC00001_C0020_2021-07-27-14-39-38

☐ Time zones known and synchronized between ROV, navigation, and logs **(before diving)**

☐ Summary of data products (i.e., README file)

APPENDIX D Post-dive check-list (Science)

After video and auxiliary data are provided by the ROV team to the scientist in charge, and before the end of the expedition, the following check-list should be considered[1]:

- ☐ Folders with files for all dives are present
- ☐ For each dive, the following files are present:
  - ☐ Videos for all cameras
  - ☐ DSCs for all cameras
  - ☐ Other applicable imagery
  - ☐ Navigation files
  - ☐ Logging files
  - ☐ Audio recording files
  - ☐ CTD files (and/or other sensors)
  - ☐ README file (s)
- ☐ There are no empty folders or files with 0 KB
- ☐ Files open without issues
- ☐ Files are not corrupted
- ☐ Dive IDs make sense
- Imagery and ancillary files can be linked, for instance:
  - ☐ Time stamp/date on imagery (overlay and/or close-captioning, where applicable)
- ☐ Start of one video corresponds to the end of the previous video (i.e. no video was lost). Check at least for a few random videos.
- ☐ Utilized time zones are known and synchronized between ROV, navigation, and logs.
- ☐ Files are saved in more than one hard drive (back-ups).

[1] ROV pilots have their own check-lists to consider

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