Technical report

Dive medicine capability at Rothera Research Station (British Antarctic Survey), Adelaide Island, Antarctica

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Abstract

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Rothera is a British Antarctic Survey research station located on Adelaide Island adjacent to the Antarctic Peninsula. Diving is vital to support a long-standing marine science programme but poses challenges due to the extreme and remote environment in which it is undertaken. We summarise the diving undertaken and describe the medical measures in place to mitigate the risk to divers. These include pre-deployment training in the management of emergency presentations and assessing fitness to dive, an on-site hyperbaric chamber and communication links to contact experts in the United Kingdom for remote advice. The organisation also has experience of evacuating patients, should this be required. These measures, as well as the significant infrastructure and logistical efforts to support them, enable high standards of medical care to be maintained to divers undertaking research on this most remote continent.

Introduction

The first recorded dive under Antarctic ice was in 1902 to carry out ship repairs and, for the last six decades, diving has been integral to facilitating scientific study in the region.[1] The British Antarctic Survey (BAS) has undertaken scientific diving since the early 1960s.[2] In the mid-1990s, a marine science facility was completed at Rothera Research Station (RRS), where the BAS diving programme is currently located. Some of the environmental and technical considerations related to diving in Antarctica have previously been reported[3–6] and, in 1994, Milne and Thomson briefly summarised the medical care available to divers at Signy Research Station, where the majority of BAS diving was undertaken at the time.[7] While many of the issues encountered and risk mitigation measures are similar, our aim is to provide a comprehensive account of the current dive medicine capability at RRS.

Primarily the diving at RRS is for scientific research but other activities (e.g., hull inspections) are occasionally necessary. The hostile environment and remote location of RRS create challenges which must be met to ensure that the risk to divers is minimised as far as possible. Part of mitigating this risk includes the medical response to a dive incident and access to an on-site hyperbaric chamber.

Rothera Research Station

The station is located in the British Antarctic Territory on the Antarctic Peninsula at 67°34’8” S, 68°07’29” W (Figure 1). It is the largest BAS station and has been continuously occupied since 1975. Over recent years, construction workers have boosted the summer population to approximately 150 and over the winter this falls to about 25. The station serves as a key hub to deploy fieldwork projects across a large part of the continent, as well as hosting its own science programmes.

Diving at RRS

We examined the dive logs submitted to the BAS database for five years up to 1 June 2024. These recorded 651 dives. As the team do not dive alone, the number of person-dives is at least 1,302. This risk is not distributed evenly across the year, with more dives occurring during the austral summer (Figure 2).

Figure 1

Location of Rothera Research Station relative to potential evacuation routes. Figure produced by the Mapping and Geographic Information Centre, with data from the SCAR Antarctic Digital Database, 2024

Figure 2

Monthly dives over a five-year period

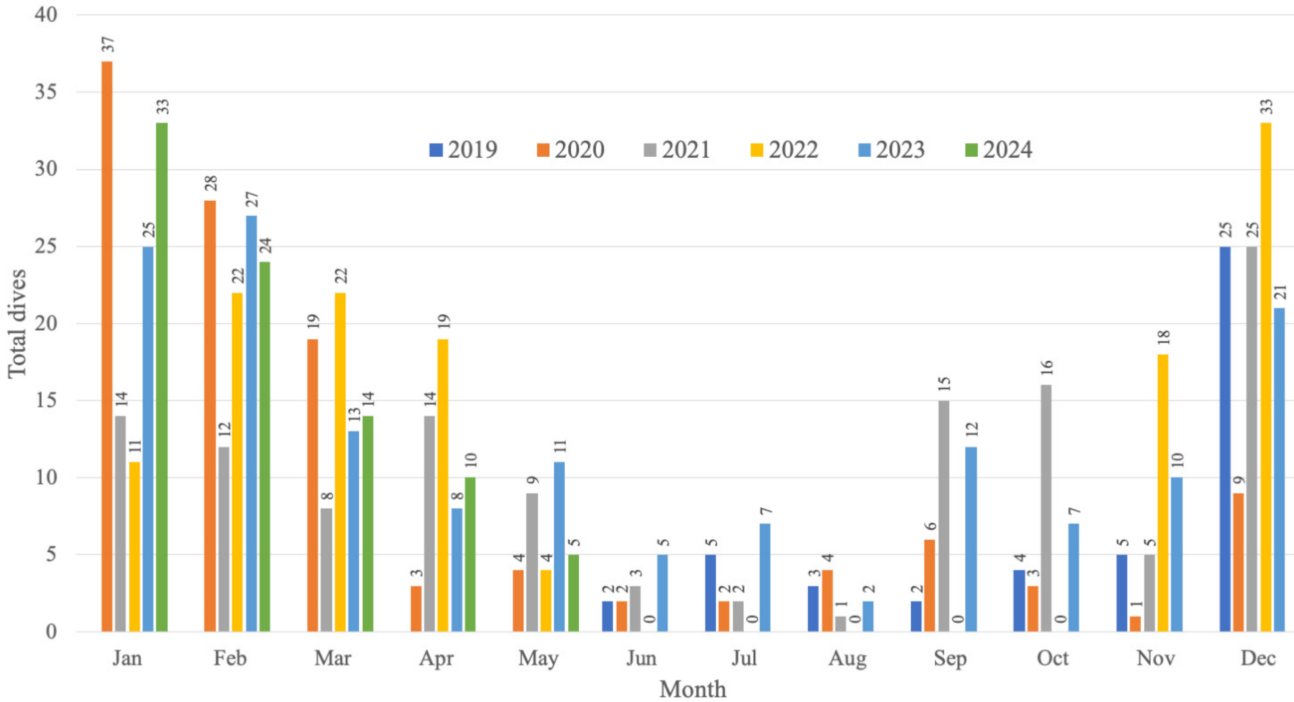
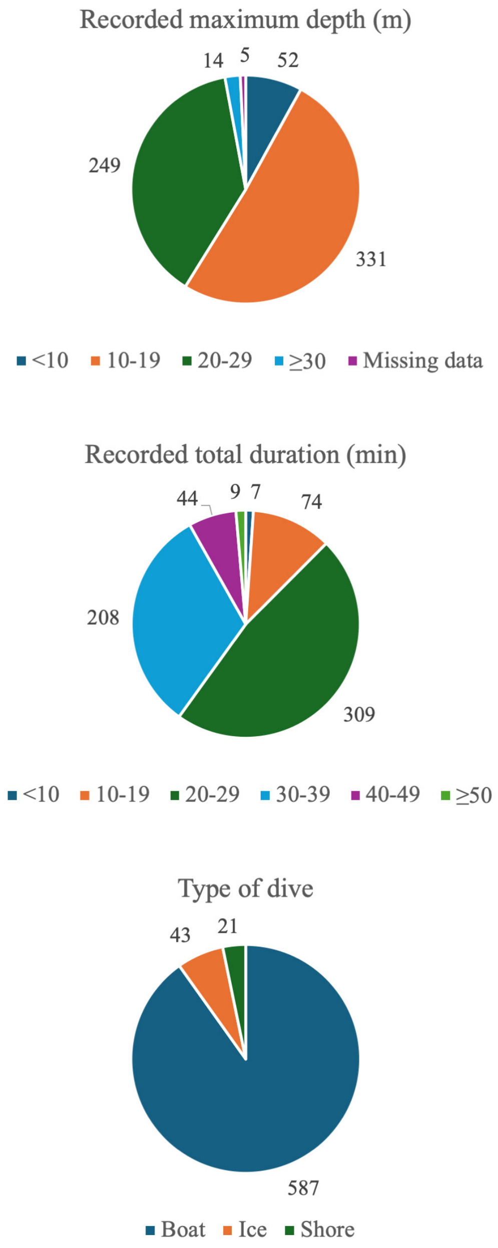


Figure 3
Characteristics of the 651 recorded dives from May 2019–May 2024



The collated dive characteristics are shown in Figure 3. The majority of dives were < 40 min and only 14 had a documented maximum depth of 30 m or more.

While most (> 90%) diving was from rigid inflatable boat, 43 ice dives are recorded. These were distributed as follows:

- 6 July – 11 October 2019: 14 dives.
- 27 July – 8 October 2020: 13 dives.
- 3 September – 17 September 2021: 4 dives.
- 12 September – 22 September 2023: 12 dives.

(From June–October 2022, there were insufficient staff to dive safely, so the programme was paused.)

The value of the scientific diving undertaken at RRS is enhanced by the long-standing nature of the programme. Many projects are part of a multi-year programme of work that allows year-on-year comparison and contributes to BAS's monitoring of long-term trends. Under-ice diving further enhances this value, allowing seasonal variation to be captured.

As an illustrative example, during the 2022–3 season, scientific diving projects at RRS included:

- Sampling of soft sediment assemblages from benthos at 6, 12 and 20 m using an air lift bag and corers; two to five dives each week, all year round.
- Sediment traps deployed at 10, 28 and 33 m; left for one season then retrieved; total of approximately 10 dives over the season. Since the deeper traps are below the usual diving limits, special permissions are required with simple deployment procedures and conservative dive times.
- Annual assessments of anemone growth, 18–24 m, a few dives every quarter.
- Organism sampling. Any depth up to 18 m; up to five dives monthly.
- Fish collection; up to 18 m with multiple dives until all collected.
- Monthly survey of wall life at 24 m.
- Photography and maintenance of IceBergs Impact Study[8] grids at 5, 10 and 25 m. Multiple dives in early summer.

In recent years, divers have also been called upon to survey the new wharf (maximum depth 12 m) and perform survey work on the Sir David Attenborough research ship.

Undertaking the work outlined above, the dive team at RRS usually consists of four people. Each has relevant qualifications for occupational diving and experience from scientific diving or other relevant fields.

All diving is on scuba, with 12 L compressed air tanks and a 3 L bailout. Full face masks reduce the amount of skin exposed to cold water and allow divers to communicate with each other and with the surface. Drysuits are worn. Currently, divers wear wet gloves and, anecdotally, cold hands are felt to be a limiting factor for dive duration. The dive team are part way through the process of procuring dry gloves as a potential alternative. Divers use a bottom timer which shows depth, time, maximum depth and temperature.

Defence and Civil Institute of Environmental Medicine (DCIEM) tables[9] are used to plan dives. A safety stop at 6 m for three minutes is standard practice for all dives deeper than 9 m. This may be a dedicated safety stop or incorporated into the dive plan if there is work to do in the 5–6 m depth range, after deeper work has been completed. The average sea-level atmospheric pressures at RRS are lower than much of the rest of the world. Atmospheric pressures ≤ 980 hPa require adjustments to bottom times, equivalent to diving at 300 m altitude. As such, corrections are made for dives > 18 m in this circumstance.

In good weather, it may be expected to have one pair diving twice in a day (with an appropriate interval to warm and recover). The second pair may also be expected to dive once, so all four divers on station may have been diving in a single day. This is important when considering who may be able to act as internal tenders in the event of an emergency.

The majority of diving is undertaken from rigid inflatable boat. A dive may only be undertaken if the time taken to reach the dive site is less than 20 min. However, depending on conditions (wind, brash ice, etc.) the return journey may take considerably longer and this is not always predictable.

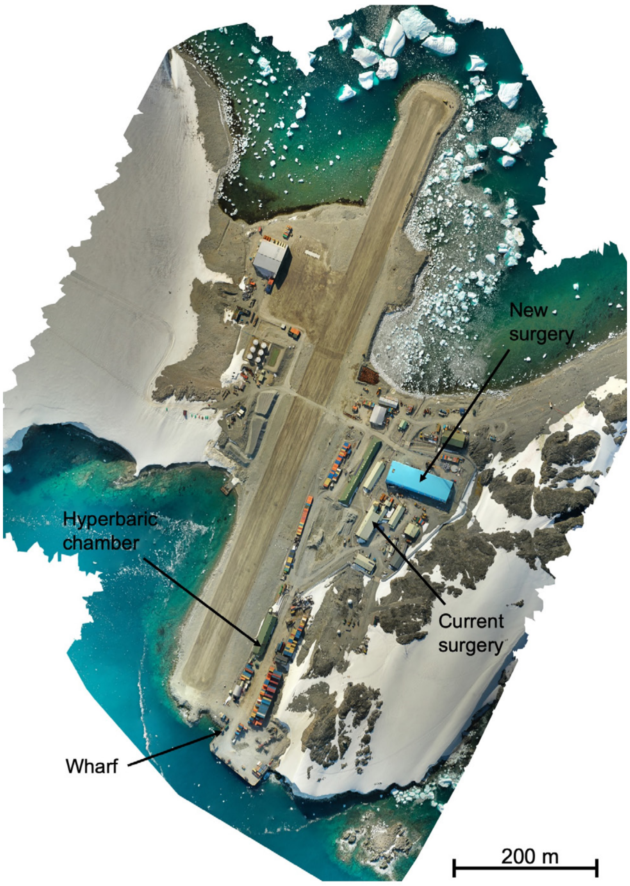
If there is sea ice cover during the winter, then diving may be undertaken if certain conditions are met to ensure the ice is safe to transit across and work on. Ice diving involves the cutting of a primary and a backup hole 30 m apart. Communication lines act as a surface tether for each diver. Each line has a dedicated attendant on the surface and is anchored to the body to be used as a safety line, which can help pull a diver back to the entry point, if required. If verbal communications fail, it can also be used for line signals. Under ice, divers aren't directly tethered as it adds another potential source of entanglement. However, the nature of under ice diving means generally good visibility (> 20 m) so divers can readily remain in visual contact.

Specific hazards and mitigations

The water temperature in which RRS divers operate may be as low as -1.5°C but relatively short dive times, drysuits and surface rewarming are effective at preventing hypothermia.[4] The risk of non-freezing cold injury when diving in these conditions is unknown. A condition of significance in its own right, non-freezing cold injury also has the potential to be mistaken for decompression sickness. It has been proposed that dry gloves may offer better protection than wet gloves during longer dives.[10]

Only no decompression diving is planned using DCIEM tables[9] and a safety stop is incorporated into dives deeper than 9 m. Pooled data has previously been published from Australian, New Zealand, United States and British programmes (1985–2007). From 17,647 person-dives, there were five reported cases of 'mild decompression sickness', five cases of minor barotrauma and no serious diving incidents.[11] This gives an estimated incidence of decompression sickness during Antarctic scientific diving of 2.8/10,000 person-dives. This is higher than other scientific

Figure 4
An aerial view of Rothera Research Station



diving.[12] It has been proposed this difference may be due to an increased risk of diving in the cold or to a cautious approach that favours treating equivocal cases early due to the remote setting.[11]

In July 2003, marine biologist Kirsty Brown, was attacked and drowned by a leopard seal while snorkelling at RRS. While leopard seals are known to display curiosity towards divers, aggression is very rare.[13] Following this tragic incident, snorkelling is no longer undertaken. It is felt to engender greater risk than diving given that leopard seals normally hunt prey on the surface. Orca also pose a potential risk to divers. Diving does not commence or is aborted if either of these species is seen in the water. Additionally, divers carry a seal prod to deter advances, if required.

Medical facilities at RRS

Given the remote and hostile setting, provision of medical care is important for all at RRS. The station is served by a single medical facility which can be configured to give two resuscitation bays. Equipment is available to provide essential lifesaving interventions (e.g., chest drains) and basic diagnostics (e.g., X-rays but not ultrasound). Figure 4 is an aerial view of the site. The location of the current surgery is shown with its anticipated new location in a nearby building, currently under construction. These locations are approximately 300 m from the hyperbaric chamber, which is in the marine laboratory near the wharf.

A medical kit is also available in the marine laboratory and oxygen, as well as basic first aid supplies, are available on the dive boat.

Medical personnel and training

Medical provision on station is the domain of the British Antarctic Survey Medical Unit (BASMU). Their permanent staff are based in Plymouth, United Kingdom (UK), and each year they employ doctors for the upcoming season to cover the BAS stations and the royal research ship Sir David Attenborough. The main doctor at RRS will usually deploy for about 18 months to cover most of a summer season then over winter, returning part-way through the next summer season. Successful candidates will typically have several years post-qualification experience including emergency medicine and some expedition experience. There is a package of pre-deployment training to develop primary and emergency care skills as well as, for example, basic dentistry and radiography. During the peak summer season, there will usually be a British military emergency medicine registrar to support the station doctor.

The doctors typically run a morning and afternoon clinic with pre-arranged and open access appointments. The majority of consultations are primary care or minor injury complaints but the pre-deployment training is crucial to prepare for less common presentations. A significant amount of time is spent training and preparing for less common emergency scenarios (including diving-related emergencies) and when these do occur they require a significant amount of resource to manage the clinical, logistical and myriad other aspects. The medical team must also manage all other aspects of running the surgery (e.g., dispensing medications, stock resupply, equipment checks and basic maintenance) that would likely not be part of their core role in the UK. Lastly, the doctors carry out a number of other duties contributing to station life but not related to medical matters.

Since experience in dive medicine is not a pre-requisite for employment, this is also covered in the pre-deployment training. Preparation for the 2022–3 season included:

1. Twenty-minute session on the background to dive medicine.
2. One hour shadowing dive medicals.
3. Five-day chamber operators' course.
4. One hour discussing deployed process for Health and Safety Executive (HSE) medicals.

This training package is currently under review to ensure it provides the best preparation for the deploying doctor in the time available.

In addition to the core medical staffing, a number of station personnel are trained, prior to and during deployment, in advanced first aid techniques so they can act as medical assistants. Lastly, the dive team includes at least two people trained as International Marine Contractors Association Diver Medical Technicians.

Hyperbaric chamber

A hyperbaric chamber is located in the marine laboratory, which is the base for most dive related activity at RRS. It is a Hytech 60 (Hytech-Pommec, Raamsdonksveer, The Netherlands) with space for three people inside (two stretchered with one sitting). It is serviced by visiting technicians, as required to ensure reliability and regulatory compliance. The chamber must be left ready to use when diving is undertaken. It is used periodically for training, which also serves to check that it is in working order.

A decision to utilise hyperbaric treatment in a given set of circumstances must consider the potential risk to the patient and attendants as well as the intended benefit. If the chamber was unusable (e.g., due to technical failure) or felt to be unsuitable, then other management options should be considered (e.g., surface oxygen and supportive care).[14]

Provision of oxygen

Oxygen in the RRS medical facility may be provided via an oxygen concentrator at 10 L·min^{-1}. Apart from this all oxygen is shipped to RRS in cylinders via annual resupply as necessary.

The medical facility plan to start the winter season with a supply of approximately 15,000 L of oxygen mainly in 340 L and F 1,360 L cylinders.

Two cylinders are carried on the dive boat (3 L at 140 bar giving circa 50 min of O_2 at 15 L·min^{-1} via a non-rebreather mask), which is deemed sufficient for the anticipated 20 min journey to shore.

The oxygen stored at the marine laboratory at the start of winter is 12 x 50 L cylinders at 140 bar. This is calculated to be sufficient to complete a series of all of the following tables:

- 1 x fully extended United States Navy Treatment Table 6.
- 1 x United States Navy Treatment Table 6 without extension.
- 6 x Royal Navy Table 66.

This is the maximum treatment likely to be required by one diver. If a second diver (e.g., the buddy required treatment, it is felt that there is still sufficient oxygen for adequate treatment in most likely scenarios). Approximately one 50 L cylinder is used for training and refills annually. If

Figure 5
Diver transported on boat and trailer during training exercise

Figure 6
Piston Bully Antarctic transport vehicle

the oxygen stores were to be significantly depleted (e.g., following treatment of a diver) then urgent resupply may be possible in the summer months but would be unlikely during winter. An impaired ability to provide emergency hyperbaric oxygen therapy, may necessitate curtailing the dive programme prior to resupply.

Oxygen ready for emergency use is stored in the marine laboratory and surgery with the remainder in lockers outside to reduce fire risk.

Transport around RRS

During summer when there is minimal ground snow cover, in the event of a stretchered casualty on the boat, there is the ability to crane the boat from the water onto t he trailer which is then towed by tractor to the marine laboratory (Figure 5).

If required, stretchered casualties may otherwise be transported around station by a variety of vehicles. For much of the year, the roads around the site are covered in snow and ice. In adverse conditions, the most appropriate vehicle is likely to be the Piston Bully (Figure 6) or a skidoo and Nansen sledge. These are used for a variety of roles around station and, in the event of a medical emergency, a vehicle would likely have to be re-tasked to undertake patient transport.

Evacuation

In the event that medical evacuation was required, this would most likely be by air in the summer months. This would typically involve flying to Punta Arenas, Chile, or to the Falkland Islands. Depending on wind conditions and aircraft type, this could entail a flight time of seven hours or more. Additionally, there may be further substantial delays due to factors such as:

- Aircraft / aircrew location and availability.
- Runway snow clearing.
- Weather.

Evacuation by sea is also an option but this would require a suitable vessel in the vicinity and even a direct passage to the destinations above would take several days.

During the winter, evacuation is likely to be substantially delayed. As an example, in recent years a patient (not a diver) was evacuated from Halley Research Station during the winter season. This involved flying two Twin Otter aircraft from Canada to RRS, which was used as a staging post for the rescue effort. The journey to RRS took almost a week, even with favourable weather.

The expectation would be that a casualty with decompression sickness would complete a course of hyperbaric oxygen therapy prior to flying unless there was another pressing reason for evacuation. Any decision to evacuate must balance the potential risks to the patient and crew with the intended benefit.

Communication

Communication among personnel at RRS is primarily via free net VHF radio. Communication outside the immediate area is via a satellite link that enables email, WhatsApp and telephone traffic to the UK. Until recently, it would not be possible to rely on video calls due to bandwidth limitations. Recent improvements to connectivity mean that video calling could now be considered. A back up option is to call the UK via Iridium satellite phone (Iridium Communications, McLean, Virginia, United States) but this may be time-consuming depending on connectivity.

Remote advice

Remote advice is available as necessary via DDRC Healthcare, Plymouth, UK, (who are contracted to provide advice in the event of a dive emergency and are co-located with BASMU) or by BASMU directly. The communication cascade is published internally to ensure the appropriate response. If it is not possible to contact senior support but the doctor and dive supervisor agree that treatment is in the patient's best interests then this should be commenced and contact made when possible.

Relevant personnel at RRS in the event of a dive emergency

While diving is ongoing, a station doctor must be within the local travel area and their presence physically on station is preferred.

The dive team and boating officer (five people in total) all undertake the chamber operator course in the UK prior to deploying. They have varying levels of previous chamber experience, though this is not a pre-requisite to employment. The team is augmented by non-diving personnel who are trained on station in the roles of chamber operator and internal tender, having had diving medicals prior to deployment. This redundancy is vital to enable the prompt treatment of a diving casualty as the dive team may have other roles following an incident or have been diving themselves. Chamber training and medical scenarios are run periodically to ensure that personnel are familiar with their allocated roles and each day the dive plan is emailed with a nominated person for every role.

Medicals

Occupational diving in the UK is regulated by the Health and Safety Executive (HSE). They specify that divers must have an annual medical performed by an approved medical examiner of divers (AMED). Divers and potential internal tenders have an HSE medical in the UK prior to deploying. If someone is deployed for more than one year, as is frequently the case, their HSE medical will expire. However, the station doctor is not an AMED. The deployed doctor will undertake a history and examination (in-line with their pre-deployment training above) and any tests required (as specified below). They will then discuss their findings with the medical director at DDRC Healthcare. Assuming the medical and fitness standards specified by the HSE[15] are met, the medical director can then issue a temporary re-certification for deployed diving only. Divers should be aware that this does not constitute an HSE medical for diving when back in the UK.

All divers undertake the first three of these tests annually, with the remaining only performed if indicated following history and examination.

Cases

To our knowledge, two divers have been treated for decompression sickness at RRS in the last two decades. The decisions to treat were largely precautionary based on mild symptoms potentially consistent with decompression sickness. The first case was a diver who developed tingling in one leg while showering 30 min after exiting the water. The second case was a diver who felt nauseous soon after surfacing, which was unusual for them. On examination, they were felt to have unilateral lower limb hyperreflexia. In both cases, the symptoms were fully resolved following a single treatment with hyperbaric oxygen therapy.

Conclusions

Diving is important to facilitate the marine scientific programme at Rothera Research Station. We have described the medical measures in place to mitigate the risk to those diving in this extreme environment. In the event of severe decompression illness, prompt hyperbaric oxygen therapy and remote guidance regarding initial and ongoing management are available with the intent to minimise lasting morbidity. Supporting these measures in such a remote setting requires a significant effort in terms of training, equipment, logistics and UK-based on-call expertise.

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