SCIENCE CASE FOR A REPLACEMENT POLAR RESEARCH SHIP

1. Executive summary

1.1 The polar regions, and the Arctic and Southern oceans in particular, play a pivotal role in the functioning of the Earth system, impacting upon the UK and global climate and sea-level. They also support unique ecosystems and natural resources of importance to a range of UK stakeholders. To maintain the UK's strong international leadership in producing high quality research in this area, NERC must retain both the capability to field internationally competitive scientific programmes at sea using a state-of-the-art ice-strengthened research ship and the capability to resupply the UK research operations in Antarctica.

1.2 The British Antarctic Survey (BAS) currently operates two dedicated ice-strengthened ships for NERC. RRS James Clark Ross is a purpose-built ice-strengthened research/logistic ship and is the platform for the majority of UK scientific programmes conducted at sea in the Arctic, sub-Arctic and Southern oceans, whereas RRS Ernest Shackleton is used primarily for polar logistic support and is operated by BAS on a long-term charter.

1.3 NERC recognises the need to maintain polar ship operations in support of its science priorities and goals, and has secured government funding to replace the aging RRS James Clark Ross with a larger, single, state-of-the-art polar ship that will also perform most of the logistic resupply functions presently carried out by RRS Ernest Shackleton. The renewal of ice-strengthened ship capability for polar research has also been identified as a priority in the Research Councils UK (RCUK) Strategic Framework for Capital Investment. The total cost of the replacement of the two current polar vessels by a larger, single polar ship with the required specification will be £225M.

1.4 The single polar ship will have to take on most of the logistic support work undertaken by both the RRS James Clark Ross and RRS Ernest Shackleton in support of land-based polar science, as well deliver a large proportion of the sea days for polar marine science that are presently provided by RRS James Clark Ross. As such it will require significantly greater cargo-carrying capacity, longer endurance, and the capacity to work over a longer season near Antarctica, which will therefore require it to have a better capability in ice than the existing UK polar ships. The enhanced ice capability will reduce risk to research in areas that previously had been marginal for ship operations and will present opportunities for research in areas of the Arctic and Antarctic that have been inaccessible to UK research ships hitherto. The new ship will also need highly flexible deck and laboratory spaces to enable continued cost-effective delivery of large elements of offshore polar NERC science.

1.5 The replacement of both the RRS James Clark Ross and RRS Ernest Shackleton with a single vessel will lead to a reduction in the annual number of science days available at sea on BAS-operated ships from 180 to ≥137. This reduction in capacity can be mitigated, in part, by efficiencies gained from the enhanced endurance, navigation, cargo-carrying and cargo-handling capabilities of the new vessel, and potentially in part by bartering or chartering time on other polar vessels.

1.6 It is essential that the capability and capacity of the new ship meet the science requirements of the UK Earth system science community in terms of both provision of a polar seagoing science platform and provision of logistical support for land-based polar science. NERC will therefore undertake wide consultation with its science community to refine the specification of the science capabilities and facilities required on the new polar research vessel.

1.7 The new ship will deliver world-class polar and Earth system science in support of UK government and NERC strategies, contribute to the international positioning of UK science and science strategy, help train the next generation of environmental scientists, and enable knowledge, technology transfer and innovation to public and private stakeholders.

2. Introduction

2.1 This document sets out the science case for a new UK ice-strengthened research ship to replace RRS James Clark Ross and RRS Ernest Shackleton. NERC believes that their timely replacement is required to avoid major adverse impact on UK polar and marine science research, to meet its strategy of delivering Earth-system science, and to ensure that international research vessel barter partnerships remain strong. A new ice-strengthened research ship will also ensure continuing visible UK presence in British Antarctic Territory and around the Falkland Islands, South Georgia and the South Sandwich Islands.

3. Background

3.1 The polar regions, and the Arctic and Southern oceans in particular, play a pivotal role in the functioning of the Earth system. For example: interactions between the oceans and the margins of the Antarctic and Greenland ice sheets are expected to result in increasing contributions to sea-level rise in the current century; cold, dense water masses produced in the polar oceans are primary drivers of global thermohaline circulation; sea ice formation initiates the production of such dense water masses; changes in sea ice extent affect weather patterns over a much wider area; uptake of carbon dioxide in the high latitude oceans plays an important role in buffering rising emissions and drives ocean acidification; potential release of methane resulting from melting of permafrost and destabilisation of gas hydrates in polar marine sediments is a major source of uncertainty in predicting future climate; the polar oceans have played an important role in shaping global biodiversity, but marine communities in the polar regions today are highly vulnerable to climate change.

3.2 The study of the polar regions is an essential element of NERC's new strategy "*The Business of the Environment*". To implement this strategy, and to maintain the UK's strong international leadership in producing cutting edge polar research, NERC must retain the capability to field internationally competitive scientific programmes at sea in the polar oceans, in the air, and on ice-covered and ice-free land areas. Scientific programmes at sea in the polar oceans require a state-of-the-art ice-strengthened research ship, while airborne and land-based scientific programmes in Antarctica depend on ice-strengthened ships to resupply research stations and coastal depots, and to deploy field parties.

3.3 The British Antarctic Survey (BAS) currently operates two dedicated ice-strengthened ships for NERC. RRS James Clark Ross is a purpose-built ice-strengthened research/logistic ship that provides the platform for the majority of UK scientific programmes conducted at sea in the polar oceans, whereas RRS Ernest Shackleton is used primarily for polar logistic support and is operated by BAS on a long-term charter from GC Rieber Shipping AS. Continued investment

in polar ship operations is required to ensure that the UK maintains its position as one of the leading polar and Earth systems science nations.

3.4 RRS James Clark Ross (99m length, 6.4 m draught, gross tonnage 5732) was built in 1991 at a cost then of £50M and has a range of systems and facilities that have been progressively updated through the lifetime of the ship so it remains capable of much modern multidisciplinary research. The ship can carry up to 46 scientific personnel for up to 57 days at sea, although the maximum scientific personnel capacity requires multiple occupancy of every cabin and is normally only used for short periods when transporting people to and from stations. She provides NERC with a high specification ice-strengthened research ship with specific lifting and positioning facilities to deploy and recover remotely operated vehicles (ROVs) and heavy overside loads, a low level of underwater radiated noise that is required for some acoustic measurement techniques, and a hull that allows navigation through most first-year sea ice conditions, albeit at a low speed and increased fuel consumption. By January 2014 she had completed more than 300 science cruises.

3.5 RRS Ernest Shackleton (80 m length, 6.85 m draught, gross tonnage 4028) has been operated by BAS on a long-term bare boat charter from GC Rieber Shipping AS since 1999, having been built in 1995, and is used primarily for polar logistic support. The ship is made available for commercial charter during the northern hemisphere summer, generating income that offsets operating costs.

3.6 Research ships are typically designed for an operating life of 25 to 30 years after which they are at the end of their scientifically useful lives. RRS James Clark Ross is currently approaching 23 years in service and although the vessel hull is in excellent condition for its age the deck machinery and superstructure are in need of major refurbishment and replacement. Independent engineering and technical assessments have concluded that by 2019, when RRS James Clark Ross will be 28 years old, the upkeep and repair of the vessel will have a significant cost implication. The ship, whilst still in demand from the scientific community, is also in need of a significant upgrade to its scientific facilities and laboratories to bring it in line with current scientific expectations and demands. Consequently a feasibility project was started in April 2013 to investigate the option of building a new multi-purpose polar vessel to come into service in 2019. The current plan for RRS James Clark Ross, outlined in the BAS Business Plan and the NERC National Executive Board Risk Register, is to extend the life of the vessel until that time but to only complete work that is absolutely necessary for continued safe operation of the vessel. In line with this, the charter of RRS Ernest Shackleton, which is used predominantly for cargo and logistics, will also be extended to coincide with the delivery of the new polar ship. By that time RRS Ernest Shackleton will also be approaching 25 years old and will require significant work year on year to meet its Class requirements.

3.7 There has been an increase over the past few years in the cost of refits and upgrades to obsolete systems on both ships and as they get older these costs will

increase further. Machinery has a finite life and regardless of a rigid adherence to planned maintenance programmes it is inevitable that equipment will start to fail in service. The cruise planning for these vessels is already tight with little time in the programme set aside for maintenance (ca. 21 days each per year). The vessels are also required to operate in some of the most hostile environments in the world, remote from support infrastructure, with the consequence that repairs are costly and have significant potential to impact on an already tight schedule. For example, in the event of an equipment failure in Antarctica, even to complete the most basic repairs would result in the loss of weeks of research time and could also prevent the relief of an Antarctic station for that season.

3.8 Renewal of ice-strengthened ship capability for polar research was identified as a priority in the Research Councils UK (RCUK) Strategic Framework for Capital Investment (2012). NERC has now secured government funding for a larger ice-strengthened ship to be procured to replace both RRS James Clark Ross and RRS Ernest Shackleton. This will provide NERC with a single research/logistic ship that could take on most of the logistic support work undertaken by both existing ships, as well delivering a large proportion of the sea days for polar marine science that are presently provided by RRS James Clark Ross. The investment in the replacement polar research ship will enable the UK to maintain both its ability to deliver multidisciplinary polar sciences that have global relevance and impact and its contribution to major international programmes. The investment in the replacement polar research ship could also have significant implications for attracting and retaining leading polar scientists and engineers in UK universities and research institutes.

4. Importance of science delivered

4.1 Contribution to the Government's and NERC's strategies

4.1.1 The replacement of RRS James Clark Ross and RRS Ernest Shackleton with a single new state-of-the art ice-strengthened ship will ensure that the UK can continue to mount the large marine, terrestrial and atmospheric polar science programmes that are required to improve our understanding of the inter-relationships between biological, chemical, physical and geological processes, many of which are on a scale that will continue to require strong international collaboration.

4.1.2 Such programmes are required to inform a wide range of Government policies, including the Department of Energy and Climate Change's policies of '*Using evidence and analysis to inform energy and climate change policies*' and '*Supporting international action on climate change'*, and the Department of the Environment, Food and Rural Affairs's policies on '*Adapting to climate change*', '*Protecting and sustainably using the marine environment*', *'Protecting biodiversity and ecosystems at home and abroad'* and *'Reforming and managing*

marine fisheries for a prosperous fishing industry and a healthy marine environment'. Given that concerns over sustainability and the effects of climate change have continued to increase over the past decade, as highlighted by the recent publication of the Intergovernmental Panel on Climate Change Fifth Assessment Report, similar polar science programmes will undoubtedly be required in the future to reduce uncertainties in predicting environmental change.

4.1.3 The science knowledge provided by polar research conducted both at sea and onshore is critical to delivering against a number of NERC's strategy and delivery plan science priorities. Research work conducted on RRS James Clark Ross, and the onshore polar research for which she and RRS Ernest Shackleton have provided logistic support, has been essential for improving our understanding and prediction of the Earth's environment and such work will continue to underpin the UK's approach to Earth system science. This is driven by NERC's current science strategy, '*The Business of the Environment'*, in which polar research makes a major contribution to three of NERC's four strategic science priority areas (i.e. 'benefitting from natural resources', 'resilience to environmental hazards' and 'discovery science'). The increasing political and commercial focus on natural resources and trade routes in the Arctic means there is an urgent need for scientific research to establish environmental baselines. Furthermore, there will be an ongoing need to conduct studies to identify environmental and economic opportunities and threats, and to underpin responsible environmental stewardship. The high rates of warming and changes in sea ice extent occurring in the polar regions may be driving changes in weather systems and extreme events at lower latitudes, including in the UK. Such changes have impacts on agriculture and industrial infrastructure and could also increase secondary hazards such as landslides and coastal erosion. Therefore, there is a pressing need for further research to improve understanding of the linkages between changes in the polar regions and the global climate system. Longer term changes such as glacial isostatic adjustment ("glacial rebound") stemming from removal of ice load at the end of the last glacial period may affect the stability of continental margins leading to increased tsunami and submarine landslide hazards. Therefore, research is needed to improve understanding of factors resulting in submarine slope instability to quantify the risks. A particular focus of the 'discovery science' theme is 'understanding polar ice melt'. Recent studies have shown that the West Antarctic and Greenland ice sheets are particularly sensitive to warm ocean currents impinging on their margins, making it particularly important to improve understanding of interactions between the oceans and the ice sheets in order to make accurate predictions of ice sheet contributions to sea-level rise.

4.1.4 Processes operating in polar regions are critical in a range of environmental changes that could have significant societal and economic impacts, including: the further contribution ice sheets will make to sea-level rise; changes in sea ice extent, which affect deep water production and also impact on Arctic resource exploitation and marine transportation; the interactions of changing sea ice extent and deep water production with global ocean circulation and climate; the extent to

which carbon emissions will be taken up by the oceans; the rates of ocean acidification, temperature rise and circulation changes and their consequences for the sustainability of marine ecosystem goods and services; change in the stability of polar continental margins and the resulting hazards affecting coastal infrastructure and sea-floor installations and cables; the quantities of methane that will be released from permafrost and polar marine sediments. Research studies based on polar research ships are critical to improving understanding and quantification of processes involved in all of these changes, and in order for UK scientists to maintain leadership roles in such studies it is essential that the UK continues to operate an ice-strengthened research vessel.

4.2 Delivery of world-class multidisciplinary science

4.2.1 Further measures of the importance of the science knowledge are the quality, multidisciplinarity and international collaboration that are delivered. The UK has world-leading strengths in polar and ocean sciences. The UK's ocean science ranks second to the USA in terms of citations to research papers[1]. An indication of the strength of UK polar marine science is provided by bibliographic analysis that reveals 280 scientific papers using data collected on RRS James Clark Ross were published in ISI-listed journals during the last five years. Furthermore, this analysis does not include the extensive outputs from onshore and airborne research programmes in Antarctica that have depended on re-supply of research stations and coastal depots, and deployment of field parties, achieved by RRS James Clark Ross and RRS Ernest Shackleton. Overall, environmental science is the pre-eminent field contributing to the UK's position as the world leader in citations impact[2]. The maintenance of the health of this science base is heavily dependent on the UK having internationally competitive marine facilities and maintaining its access to some of the best international facilities via barter partnerships (see sections 6.5 and 6.6 for more information). Access to ship-time (on RRS James Clark Ross and other NERC and barter ships) is provided only for science programmes that have been graded as being of high international quality at peer review. These programmes are increasingly multidisciplinary in nature, with strong collaborations with a number of partners from UK and international institutions.

5. Science requirements

5.1 Introduction to science requirements

[1] Source: Analysis of 'Oceanography' field in Thomson-Reuters InCites tool, including citations up to 2013.
[2] Source: International Comparative Performance of the UK Research Base – 2013, BIS; https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/263729/bis-13-1297-international-comparative-performance-of-the-UK-research-base-2013.pdf.

5.1.1 The science requirements for the replacement polar research vessel reflect the current and projected needs in terms of capabilities (i.e. the science the ship will need to deliver), and in terms of capacity (i.e. the amount of seatime needed). Integral to these needs are the barter arrangements which allow access to a greater range of technical facilities (capabilities) than could be gained from NERC alone, and more efficient use of seatime, thereby effectively providing access to a greater number of sea days (capacity). The timely replacement of RRS James Clark Ross is then key to ensure that the delivery of these science requirements is not jeopardised.

5.2 Capability required of a new ice-strengthened research ship

5.2.1 In recent years NERC has consulted its science community on several occasions as to the science requirement for NERC's research ships, most recently in 2013 (meeting on the "Role of Oceanographic Ships in Marine Science: Scanning the Horizon") and 2014 (Marine Facilities Advisory Board survey of current and future marine equipment provision on board the NERC research ship fleet). The considered view is that despite on-going improvements in marine technologies that are used to sample and observe the oceans, NERC will, for the foreseeable future, continue to require access to dedicated research ships and their instrumentation.

5.2.2 For example, remote sensing has proved to be a very important tool for improving our understanding of the oceans, but many satellite observations are only able to provide quantitative data from the first few centimetres of the ocean's surface and thus cannot be used to study the ocean's interior. This is a particular challenge in high latitude polar environments where sea ice cover and highly seasonal radiation regimes present considerable challenges to the observation and interpretation of remotely-sensed data. Future developments in remote sensing will thus continue to require "ground-truth" observations and experiments conducted from polar research ships.

5.2.3 Other new and improved technologies, such as remotely operated vehicles (ROVs, e.g. Isis) autonomous underwater vehicles (AUVs, e.g. Autosub, gliders), deep-ocean observatories and moorings offer new ways to observe ocean processes and/or parts of the ocean. Developments in autonomous instrumentation also offer the capability to survey the oceans and gather unprecedented quantities of data across large, highly resolved, spatial and temporal scales, thereby reducing the need for routine ship-based surveys. However, these autonomous technologies require access to research ships capable of handling such instrumentation for their development, deployment, retrieval and maintenance. A pertinent example is the extensive use that has been made of Autosub in polar research projects, which has produced novel and important datasets, but has depended on the availability of ice-strengthened research vessels for delivery of the vehicle to remote study areas. It is anticipated that these new technologies will increase future demand for the most capable ship-platforms in order to service their needs, yet at the same time

also free-up overall oceangoing capacity for other challenging oceanographic research requiring state-of-the art ship-based facilities.

5.2.4 The importance of inter-relationships between biological, chemical, physical and geological processes, in the marine, atmospheric and cryospheric realms, is now well recognised, and their study will present a difficult but exciting challenge throughout the next 20+ years. Such research usually demands multi-disciplinary research cruises with 24/7 working and large parties of scientists, engineers and technicians, on ships with in-built flexibility of laboratory and deck spaces to accommodate the requirements of modern science. Demand for such cruises has increased in recent years and, given the move of NERC's Research Centres (RC) towards more large scale collaborative cruises (with other RC, UK Universities and international partners) and NERC's continued funding of large ocean-going and polar programmes, it is anticipated that this demand will continue at current levels in future years.

5.2.5 In many oceanographic disciplines there is a paucity of observations from times of the year when there are unfavourable conditions, and this applies particularly to the polar oceans where extensive sea ice, adverse weather and long hours of darkness make ship-based work at times other than summer very difficult. These data are however critical to improving our understanding of a variety of oceanic processes that are of fundamental importance, and they should ultimately allow for improvement of the sophisticated predictive models that are increasingly becoming important tools in oceanographic, atmospheric and climate research. A particular example is brine rejection during sea ice formation, which is a critical process in the production of the cold, saline, dense water masses that fill the deepest parts of the ocean basins, and thus plays a key role in driving the thermohaline circulation. A large ice-strengthened vessel with long endurance would therefore offer the opportunity to gather such data in remote polar waters.

5.2.6 Marine acoustic systems are critical tools in many branches of marine science, and it is therefore of utmost importance that the new polar research ship is acoustically quiet and has a hull shape that minimizes the entrainment of air bubbles beneath the transducers. The RRS James Clark Ross remains one of the best performing polar research vessels in this respect, and therefore the safest approach would be for the hull shape of the new ship to closely resemble that of RRS James Clark Ross. It will be essential to carry our extensive tank tests on scale models of any new hull design, as well as computational modelling, to ensure that bubble entrainment beneath the hull is minimized.

5.2.7 A difficulty frequently encountered in conducting research in areas where there are high concentrations of sea ice is that the ice presents a significant risk to equipment when it is being deployed and recovered, and to supporting wires or communication cables while the equipment is in the water. To overcome this problem, most polar research ships built in recent years, as well as most under construction or being planned, have a moon pool through which small and

medium-sized items of equipment can be deployed (e.g. small remotely-operated vehicles, sea-floor landers, small sediment coring systems, conductivity-temperature-depth measuring systems and water sampling equipment). As the replacement polar research vessel will be expected to spend longer each year in the Southern Ocean and to be capable of operating in at least the peripheral parts of the polar oceans in winter, it would seem likely that there will be occasions when a moon pool will allow research work that would otherwise be impossible. It is recognised, however, that inclusion of a moon pool has significant implications for the design of the ship and is therefore anticipated to have significant costs. Therefore the costs and benefits need to be carefully evaluated. If a moon pool is included in the design of the ship, it is essential that it can be closed with a cover that is flush with the adjacent parts of the hull when it is not in use, otherwise cavitation around its edges will be a source of noise that will compromise scientific acoustic systems.

5.2.8 Ship-based helicopters are widely used in polar research to deploy field parties in locations that are not accessible using fixed-wing aircraft, to input supply depots in remote locations, to carry our airborne surveys, deploy instrumentation (e.g. in hazardous locations close to glacier ice fronts), and to reconnoitre leads through pack ice for ships to follow. The availability of a helicopter deck also makes a ship more attractive to many potential commercial charterers, who often expect to be able to use helicopters to exchange personnel without bringing a ship into port. For these reasons, most polar research ships built in recent years, as well as most under construction or being planned, have a helicopter deck and hangar. For many years, UK scientists working in Antarctica were able to call on the Royal Navy's ice patrol vessel, HMS Endurance, to provide helicopter support. However, the Royal navy stopped operating HMS Endurance in 2008, and in 2011 she was replaced by HMS Protector, which does not carry helicopters. In recent years, UK scientists have continued to achieve significant outputs, including a recent paper in *Science*, through collaborations that have provided access to helicopters operating from the German polar research ship, RV Polarstern. However, such work is tightly constrained by the itinerary of the ship and UK leadership of scientific outputs from such collaborative projects that depend on foreign logistic support is often difficult to negotiate. It is recognised that inclusion of a helicopter deck and hangar has significant implications for the design of the ship and is therefore anticipated to have significant costs. Furthermore, even if such a facility is built into the ship, NERC and BAS will not operate helicopters themselves, but would consider chartering them for operations where a specific need is identified. Therefore the costs and benefits need to be carefully evaluated. If a helicopter hangar is included in the design of the ship, it could be configured to accommodate containerised laboratories when helicopters are not carried.

5.2.9 To conclude, over the next 20+ years it is likely that research programmes will continue to require access to a state-of the-art large ice-strengthened ship that can provide the good year-round operational performance that is required to continue safe operations in areas with extensive sea ice cover and during adverse wind and

sea conditions, including the capability to operate in at least the peripheral parts of the polar oceans in winter. It is essential that the ship design achieves optimal capability, within budget, to meet its science objectives. NERC will therefore undertake further consultation with its science community to refine the science requirement for the new polar research vessel.

5.3 Capacity required of a new ice-strengthened research ship

5.3.1 NERC typically programmes ca.180 science days at sea in the Antarctic and Arctic each year on RRS James Clark Ross, which is effectively all of the available ship-time after logistic commitments and essential annual maintenance have been completed. Approximately two-thirds of this science is funded by NERC through directed strategic funding (that contributes to NERC's science priorities). The remainder derives from NERC's responsive 'blue-skies' funding and other sources, including the FCO, the Government of South Georgia and the South Sandwich Islands, DEFRA (Darwin Initiative), NGOs (e.g. Pew Charitable Trusts), and both public and commercial commissioned research.

5.3.2 Demand for science days on RRS James Clark Ross has exceeded the number of days available throughout the operational life of the ship. It is therefore anticipated that demand for ship-time will stay at current levels for the foreseeable future. The current programme for vessel usage shows a full commitment to the end of 2016.

5.3.3 In order to support increasingly multidisciplinary research cruises and allow the flexibility to conduct multiple projects between port calls, the new polar research ship will need to have at least 40 berths for scientists and technicians. Moreover, the ship will require a total of 50 to 70 scientific berths for personnel movements so that it can provide effective support for onshore and coastal work in Antarctica.

6. Replacement strategy - procurement of a larger ice-strengthened ship to replace both RRS James Clark Ross and RRS Ernest Shackleton

6.1 A single polar ship will have to take on most of the logistic support work undertaken by both the RRS James Clark Ross and RRS Ernest Shackleton, as well deliver a large proportion of the sea days for polar marine science that are presently provided by RRS James Clark Ross. This is a considerable challenge and requires optimal configuration of the ship's capability and capacity, aligned effectively with other associated polar and marine infrastructure and operations, to ensure that it can deliver this dual role.

6.2 In order to achieve this, the new ship will need longer endurance and to work over a longer season near Antarctica, which will therefore require it to have a better capability in ice than the existing UK polar ships. The enhanced ice capability will reduce risk to research in areas that previously had been marginal for ship

operations and will present opportunities for research in areas of the Arctic and Antarctic that have been inaccessible to UK research ships hitherto. However, if the ship is required to visit both Rothera and Halley research stations each season this will restrict the extent of the Southern Ocean sector over which it will be able to conduct research.

6.3 The new ice-strengthened ship will need highly flexible deck and laboratory spaces so that it can continue delivery of large elements of NERC science cost-effectively. NERC will consult widely with its science community and with stakeholders about the detailed specification of scientific facilities on the new ship, including the requirements for a moon pool and helicopter deck. Such a ship will enhance NERC's current science capability and ensure flexibility and safe operation in poor weather conditions and most first-year sea ice. It will support 'leading edge' multi-disciplinary polar marine research over the next 30 years.

Table 1. Days for main types of activity in four hypothetical 2019/20 itineraries for the new vessel that are based on different assumptions regarding how logistic commitments will be met. See notes below and Appendix 1 for further details.

Itinerary	Port calls	Base logistics	Transits	Science	Maintenance
PRV1.1	52	28	107	137	42
PRV1.2	52	22	104	146	42
PRV1.3	52	21	95	156	42
PRV1.4	56	8	101	171	30

Notes:
In a typical year RRS James Clark Ross and RRS Ernest Shackleton make two calls at each of Halley, Rothera and sub-Antarctic island research stations (Signy, Bird Island and King Edward Point). RRS James Clark Ross delivers an average of 180 science days per year, typically including about 60 non-Antarctic science days, most of which are in Arctic and sub-Arctic regions.
PRV1.1 assumes two calls at Rothera and each island research station, but only one call at Halley. This option is feasible without commercial charter.
PRV1.2 assumes two calls at Rothera, but only one at Halley and each island research station. This requires alternative arrangements or commercial charter for second calls at the island stations.
PRV1.3 assumes two calls at Rothera and each island research station, but that Halley will be serviced entirely by commercial charter.
PRV1.4 assumes two calls at Rothera, but none at other research stations, for which alternative arrangements or commercial charter will be required for resupply.
Each of the itineraries includes 30 science days for an Arctic research cruise.

6.4 Unless some continuing logistic commitments are met through commercial charter or arrangements with other agencies or national Antarctic programmes, replacement of both the RRS James Clark Ross and RRS Ernest Shackleton with a single vessel will lead to a reduction in the overall number of science days available at sea, and hence a reduction in capacity across the UK oceangoing research fleet as a whole. A hypothetical itinerary that assumes an economic passage speed of 13 knots and maintenance of the current logistic commitments, except for a reduction from two calls to one call at Halley Research Station,

would result in a reduction of the number of days per year available for marine science from the recent average of 180 to 137 (Table 1 and Appendix 1, itinerary PRV1.1). This reduction in capacity can be mitigated, in part, by efficiencies gained from the enhanced endurance, navigation, cargo-carrying and cargo-handling capabilities of the new vessel, and potentially in part by bartering time on other polar vessels or chartering in alternative polar vessels for logistic supply. For example, alternative hypothetical itineraries that assume greater amounts of logistic requirements will be met in other ways indicate that between 146 and 171 days per year could be made available for marine science (Table 1 and Appendix 1, itineraries PRV1.2 to PRV1.4). However, commercial charter costs would be substantial. For example, an estimated cost for one commercial charter call to Halley is of the order of £1 million in the current market.

6.5 Barter arrangements promote an efficient and cost effective use of international marine facilities by allowing the scientific communities access to a wider range of technical facilities and geographical areas in a given year than would have otherwise been possible. The UK is one of the most active nations in exchanging time on marine facilities through international barter arrangements. The UK has barter arrangements with France, Germany, the Netherlands, Norway, Spain and the USA, which provide access to a barter fleet of 36 ocean-going and regional research ships, albeit non-polar ones. In addition, bilateral cooperation agreements between national Antarctic programmes provide additional flexibility (e.g. access to the RV Araon is available through an agreement with the Korean Polar Research Institute). Within the Ocean Facilities Exchange Group, which provides the framework for barter exchange of research ships between six European countries, RRS James Clark Ross has the highest barter exchange valuation of 15 points, matched only by the German research vessel RV Polarstern (cf. valuations of 11 points for RRS James Cook and 10 points for RRS Discovery). It can be anticipated that NERC will also require a premium barter exchange valuation for the new polar research ship .

6.6 These barter arrangements allow the UK to programme science using state-of-the-art facilities operated by our barter partners and to maximise the science that is programmed through the use of the most appropriate ships given the size and geographic location of science programmes. They are also increasingly being used for deployment and recovery of long-term moorings in remote locations in the polar oceans, so that such observations can be made without one nation having to schedule repeat cruises to a remote area. The European Polar Board is presently developing a re-energised vision for European cooperation in the polar regions which is likely to increase demand for ice-strengthened vessels though barter arrangements. Continued access for the UK research community to barter facilities is contingent on there being on-going modernisation of NERC's research fleet and an enhancement of its facilities. Operation of a state-of-the art ice-strengthened research ship will greatly enhance opportunities for UK leadership of such cooperative research.

6.7 In anticipation of operation of a single polar ship, NERC is refreshing Memoranda of Understanding (MoU) with other nations that conduct Antarctic science and logistics, such as the US, Germany, Norway, South Korea and Chile, to cooperate in emergency contingency in the rare event of severe pack ice, weather-induced delay or equipment failure. A new MoU is currently being prepared with the South African Antarctic National Antarctic Programme (SANAP) regarding science and logistics cooperation, and will include provision for UK access to the recently-built ice-strengthened ship Agulhas II. The MoU with SANAP will be signed in summer 2014. BAS is a core member of the Council of Managers of National Antarctic Programs (COMNAP) that facilitates close and prompt collaborative action in the event of emergencies.

6.8 A larger ship operating with a routine passage speed of 13 knots (compared to the average of 10 knots that is expected for the existing ships) and with a larger number of days running in sea ice must be expected to be more expensive to operate than either of the existing ships. The assumed routine passage speed is an important factor in projecting the number of days that will be available for marine science (Table 1 and Appendix 1). As the start and end of the ship's Antarctic season will be dictated by logistic requirements, any increase to Atlantic passage time would particularly impact the time available for Arctic science.

6.9 Operation of a single polar ship will also impact on the search and rescue capability that BAS could provide in the Southern Ocean and would in most cases increase the time taken for medical evacuation of any field parties working in coastal locations that cannot be reached by BAS Twin Otter aircraft. In the event of any serious mechanical problem on a single polar vessel it would be necessary to call on HMS Protector, the Royal Navy ice patrol vessel, or other operators for assistance (see section 6.7 for more information).

7. Breadth of science base that will benefit

7.1 The UK is currently among the leading nations internationally in research in fields including marine physics, chemistry and biology; marine geology and geophysics; glaciology and ice-ocean interaction studies; marine engineering and technology; environmental computational modelling; atmospheric physics and chemistry; and Earth observation – all of which need the data and samples that are collected throughout the world's oceans using NERC's research ships.

7.2 The UK is also one of the world leaders in several fields of polar science that depend on annual resupply of Antarctic research stations and coastal depots by NERC's ice-strengthened ships.

7.3 The UK currently has seagoing polar research groups in 12 highly-ranked university departments and three world-class research institutes conducting polar marine research (N.B. recently established by the Research Excellence

Framework peer review process). In addition, the data and samples collected during polar research cruises are used by many other groups in UK universities and stakeholder institutions, such as the Met Office, Hadley Centre and Natural History Museum, and in many international institutions.

7.4 Data collected on polar marine cruises underpin the resulting scientific outputs and these data are managed and made available to the global scientific community through NERC's environmental data centres including the Polar Data Centre and the British Oceanographic Data Centre.

8. Contribution to international positioning of UK science and science strategy

8.1 Polar science, oceanography and Earth science are areas of the environmental sciences in which UK research is particularly strong. Bibliographic analysis indicates the considerable strength of UK polar marine science (see section 4.2.1), and this does not take account of the extensive onshore research in Antarctica that RRS James Clark Ross and RRS Ernest Shackleton play an essential role in supporting by resupplying research stations and deploying field parties. To maintain this leadership and the international competitiveness of UK centres of research excellence requires on-going investment in state-of-the art marine facilities, including an ice-strengthened research ship, and continued access to the best international ships available through NERC's barter arrangements (see sections 6.5 and 6.6 for more information). Such access is contingent on the UK continuing to have state-of-the-art ships to barter with.

8.2 The strength of the UK in the polar and ocean sciences has ensured that it provides international leadership, influence and partnership within International programmes – notably those of the World Climate Research Programme (WCRP), the International Geosphere Biosphere Programme (IGBP), the Census of Marine Life (CoML), the Scientific Committee on Antarctic Research (SCAR) and the International Arctic Science Committee (IASC).

8.3 On-going international partnership in multidisciplinary research programmes is critical if the UK is to conduct world-class research in collaboration with world-class scientists. Over the last 5-years, 60 % of research cruises on RRS James Clark Ross have involved collaboration with international scientists and students from 38 institutions and 13 countries. One recent example of international collaboration is the very successful UK-US Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean (DIMES). This is an ongoing multi-million pound/dollar programme funded jointly by NERC and the US National Science Foundation (NSF) to determine the key mechanisms and rates of mixing in the circumpolar seas around Antarctica, and their impact on large-scale ocean circulation and climate. It has involved the injection of a chemical "dye" into the ocean in the southeast Pacific sector of the Southern Ocean, and the subsequent tracking of this dye over the course of a number of years as it has spread through

Drake Passage (the gap between South America and Antarctica) and into the Atlantic. Numerous complementary techniques were also used, including fixed ocean moorings, passive drifters, and profiling of the water column with lowered and free-fall instruments. Leading results from DIMES were published in *Nature* recently (Watson et al., 2013), with other potentially high-profile papers still in the process of being drafted. Such large-scale international collaboration is realistically only possible if the UK continues to operate a state-of-the-art polar research ship.

9. Strength of opportunity for training

9.1 In a typical year, up to 140 scientists, engineers and students gain research training and experience through participation in research cruises on RRS James Clark Ross. Up to 50 more scientists and support staff gain some exposure to marine science activities while in transit to and from research stations in Antarctica and on South Georgia. Many individuals who have gained research training and experience on RRS James Clark Ross have subsequently moved into the commercial sector.

9.2 As seagoing science has become more multidisciplinary, it has allowed for NERC's research cruises to provide for more cross-disciplinary training for scientists and engineers. One example of a multidisciplinary research programme is the “The Atlantic Meridional Transect” (AMT), which has involved 23 research cruises since 1995, 16 of them on RRS James Clark Ross. An independent review of one four-year grant award to AMT during the last decade, which funded 6 research cruises, found that the programme had contributed to 11 UK and 16 internationally funded research programmes and 21 UK registered and 7 international PhD and MRes studentships. AMT was judged by the review team to be 'an outstanding means of training' UK ocean scientists.

9.3 The greater number of scientific berths on the new polar research ship will provide increased opportunities for students, early career scientists and engineers to gain research training and experience through cruise participation.

10. Opportunity for knowledge or technology transfer, innovation and wider benefit

10.1 The recent and unprecedented changes in polar environments present both opportunities and challenges to public and private sector stakeholders, many based in the UK. For example, reductions in Arctic summer sea ice cover have enhanced access to Arctic seas and increased associated commercial activities, including oil and gas exploration, marine transport, fisheries, tourism and insurance. Similarly, over the past two decades there has been a rapid increase in tourism in the Antarctic Peninsula region. However, the safe operation and

sustainable development of these activities requires a sound understanding of the polar environments upon which to base predictions of future conditions. This, in turn, requires environmental baseline studies and a continuing need to monitor and minimise environmental impact.

10. 2 Access to research ships and to the polar oceans provides the UK ocean sciences and engineering community with significant opportunities for technology transfer. The development of innovative new instruments and sensors for use on research cruises will continue to be required if we are to improve our understanding of the Earth system. These instruments have wider public and private sector applications. For example, access to polar research ships has helped enable the development and production of sea-ice mass balance buoys for commercial sale (http://www.samsrsl.co.uk/marine-services/sea-ice-mass-balance-buoys); through their operational itineraries, the NERC polar ships have provided unique test subjects for the development of new highly durable, low friction hull coatings which reduce the need to paint ship hulls and reduce fuel costs (http://www.hydrex.be/); the specialist requirements for flush mounting of transducers in an ice-strengthened hull have provided the driver to develop new approaches to housing sensors for multibeam echo sounding systems, and the manufacturers of the system on RRS James Clark Ross consider that the installation is still the leading example among polar vessels; access via the NERC polar ships enabled Bird Island, South Georgia to be used by BAS as the test site for the development of a geolocator that subsequently achieved sales of £500K per year (intellectual property and product now transferred to Biotrack - http://www.biotrack.co.uk/geolocators.php).

10.3 The UK's research leadership in polar and ocean sciences research also provides for knowledge transfer activities, such as those of the Polar View international consortium. Polar View has been developed for the Arctic and Antarctic by an international consortium of ice charting experts including BAS. BAS leads the Antarctic node of Polar View, which provides a near-real-time sea ice information service for ship operators to help them minimise delays, improve efficiency, and take action to avoid life-threatening safety hazards, damage to vessels and potentially severe consequences for the environment. Polar View is a service delivering information products from BAS and its international collaborators based primarily on satellite data, but utilizing and benefiting from in situ observations from ships and buoys for additional observations and validation data. It is widely used by commercial and tourist shipping, and by national polar research programmes and rescue coordination centres.

10.4 The government recognises the need to deliver evidence-based policies and this is central to many of the UK's polar and seagoing science programmes. For example, for more than 30 years the UK has played a leading role in the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), which practises an ecosystem-based management approach. This does not exclude harvesting as long as such harvesting is carried out in a

sustainable manner and takes account of the effects of fishing on other components of the ecosystem. Based on the best available scientific information, the Commission agrees a set of conservation measures that determine the use of marine living resources in the Antarctic. On-going investments in polar and seagoing research that are required to reduce uncertainties in climate prediction will continue to contribute to the development of international policy via the work of, for example, the Intergovernmental Panel on Climate Change.

10.5 The UK has a strong track record in stimulating public interest in polar environments, their natural history and indigenous peoples. To maintain this track record and to contribute to the positioning the UK as a world leader in polar science, the NERC-funded polar science community will work with colleagues from Communications and Knowledge Exchange teams to deliver activities that will maximize impact from this major investment. In particular, they will work to gain widespread recognition that the UK's investment in a new polar research platform will enable world-class science that advances knowledge for societal benefit, and to achieve political, business and public engagement in NERC's polar research ambitions.

11. Peer review and consultation

11.1 The science case for the new polar research vessel will be reviewed and approved through the NERC governance bodies, including NERC Council (the top-level decision-making body for strategy, objectives and targets, and major resource decisions).

11.2 The detailed specification of the scientific capabilities and facilities that will be incorporated into the design of the new polar research ship will be the subject of a wide, NERC-led consultation across the UK research community in autumn 2014.

APPENDIX 1. Hypothetical 2019/20 itineraries for the new polar research ship

Itinerary 1.1 one call Halley two calls at islands and Rothera, Arctic science cruise

Polar research vessel 2019/2020 V1.2

Assumed open water transit speed 13 kits

Port	Arrive	Depart	Operations and Science/Notes	Distance for transit times	Minimum tranist days - Science can occur underway	Actual transit days allowed in itinerary	Dedicated Science days
Immingham	10/09/2019	20/09/2019	Load cargo for south. No southbound science, so port call 10 days	Distance Immingham to Portsmouth 271nm 20hrs	0.83	1	0
Portsmouth	21/09/2019	22/09/2019	Take bunkers and aviation fuel 1 day	Distance from Portsmouth to Stanley 7054nm 542hrs	22.58	23	
Stanley	15/10/2019	20/10/2019	Take bunkers, Mob for science 5 days port call	Distance to BI 794nm 61hrs	2.54	3	0
Bird island	23/10/2019	26/10/2019	First call 3 days on site	Distance to KEP 70nm 5.3hrs	0.22	1	0
KEP	27/10/2019	29/10/2019	First call 2 days on site	Distance to Signy 520nm 40hrs	1.66	2	0
Signy	31/10/2019	03/11/2019	First call 3 days on site, Science days start form here circa 20 days	Distance to western core box 360nm. Distance from Western core box area to Stanley 520nm 67hrs	2.69	3	20
Stanley	26/11/2019	30/11/2019	Demob science load cargo,fuel and pax. 4 day port call	Stanley to Halley 1600nm	5.12	6	
Halley	06/12/2019	13/12/2019	Relief/Resupply of Halley call 7 days	Halley to Stanley 1600nm	5.12	6	0
Stanley	19/12/2019	24/12/2019	Load cargo, take bunkers 5 days port call Mob Science for post frist call Rothera 50 science days	Distance to Rothera 1070nm 82hrs	3.41	4	0
Rothera	28/12/2019	01/01/2020	First call Rothera 4 days	Distance Rothera to Amundsen sea area 1000nm 76hrs Distance Amundsen sea area to Stanley 2000nm 152 hrs	9.43	10	50
Stanley	01/03/2020	06/03/2020	Demob Science port call 5 days	Distance from Stanley to Rothera 1070nm 82hrs	3.41	4	
Rothera	10/03/2020	13/03/2020	Last call Rothera 3 days	Distance from Rothera to Signy 850nm 65hrs	2.7	3	0
Signy	16/03/2020	18/03/2020	Last call 2 days	Distance from Signy to KEP 520nm 40hrs	1.66	2	0
KEP	20/03/2020	21/03/2020	Last call 1 day	Distance from KEP to BI 70nm 5.3hrs	0.22	1	0
Bird island	22/03/2020	25/03/2020	Last call 3 days	From BI to Stanley 794nm 61hrs	2.54	3	0
Stanley	28/03/2020	02/04/2020	Demob science Mob science circa 37 days science Scotia Sea. Take bunkers, 5 day port call		0	0	37
Stanley	09/05/2010	14/05/2020	Demob science load cargo for north 5 day port call. Direct transit to Immingham	Distance from Stanley to Immingham 7325nm 563hrs	23.4	24	
Immingham	07/06/2020	14/06/2020	Discharge cargo from South 7 day port call	Distance from Immingham to Frederickshavn 471nm 36hrs	1.5	1	0
Frederikshavn	15/06/2020	01/08/2020	Annual refit 6 weeks Mob for Arctic cruise Mob port days 5	Distance from Frederickshavn Svalbard 1500nm 115hrs	4.79	5	0
Svalbard Arctic cruise	06/08/2019	05/09/2020	30 science days + 5 days transit	Distance from Svalbard to Immingham 1550nm 119hrs	4.9	5	30
Immingham	10/09/2020	24/09/2020	Load cargo for south/ Mob science cruise				0
Total port call days. Days at bases included below		52	Assumes one call Halley/two calls islands/two calls Rothera. Also no science during repositioning direct steaming from UK to Stanley. Assumed cruising speed 13kts open water		98.72	107	137
Total at bases logistics days		28					
Total transit days		107					
Total science days		137					
Total maintenance days		42					
Total number of days		366					

Itinerary 1.2 one call Halley one call islands two calls Rothera

Polar research vessel 2019/2020 V1.2

Assumed open water transit speed 13 kits

Port	Arrive	Depart	Operations and Science/Notes	Distance for transit times	Minimum tranist days - Science can occur underway	Actual Transit days allowed in itinerary	Dedicated Science days
Immingham	10/09/2019	24/09/2019	Load cargo for south/ Science Joining and Mob science cruise enroute to Stanley. 20 dedicated science starting from Portsmouth departure port call 14 days	Distance Immingham to Portsmouth 271nm 20hrs	0.83	1	0
Portsmouth	25/09/2019	26/09/2019	Take bunkers and aviation fuel 1 day	Distance from Portsmouth to Stanley 7054nm 542hrs	22.58	23	20
Stanley	08/11/2019	13/11/2019	Demob science take bunkers, 5 days port call	Distance to BI 794nm 61hrs	2.54	3	0
Bird island	16/11/2019	19/11/2019	First call 3 days on site	Distance to KEP 70nm 5.3hrs	0.22	1	0
KEP	20/11/2019	22/11/2019	First call 2 days on site	Distance to Signy 520nm 40hrs	1.66	2	0
Signy	24/11/2019	27/11/2019	First call 3 days on site,	Distance Signy to Halley 1100nm 84.6hrs	3.52	4	
Halley	01/12/2019	08/12/2019	Relief/Resupply of Halley call 7 days	Halley to Stanley 1600nm	5.12	6	0
Stanley	14/12/2019	19/12/2019	Mob science load cargo, take bunkers 5 days port call, direct to Rothera	Distance to Rothera 1070nm 82hrs	3.41	4	0
Rothera	23/12/2019	27/12/2019	First call Rothera 4 days, then start long science cruise 50 days + tranist 10 days from Rothera	Distance to Amundsen sea area from Rothera 1000nm 76hrs. Distance Amundsen sea area to Stanley 2000nm 152hrs	9.43	10	50
Stanley	25/02/2020	01/03/2020	Demob Science Mob science port call 5 days Science cruise 30days pennisula	Distance to Rothera 1070nm 82hrs	3.41	4	30
Rothera	04/04/2020	07/04/2020	Last call Rothera 3 days	Distance from Rothera to Stanley 1070nm 82hrs	3.41	4	0
Stanley	11/04/2020	15/04/2020	Demob science take bunkers, Mob science 16 science days 4 days port call	Antarctic Peninsula area	6	6	16
Stanley	07/05/2020	11/05/2020	Demob science load cargo for north. 4 days port call	Distance from Stanley to Immingham 7325nm 563hrs	23.4	24	0
Immingham	04/06/2020	14/06/2020	Discharge cargo from South 10 day port call, Mob science for Arctic	Distance to Svalbard from Immingham 1550nm 119hrs	4.9	5	0
Svalbard Arctic cruise	19/06/2020	19/07/2020	30 science days + 5 days transit	Distance from Svalbard to Immingham 1500nm 115hrs	4.79	5	30
Frederikshavn	24/07/2020	08/09/2020	4 days Demob science. Annual refit 6 weeks	Distance to Immingham from Frederickshavn 471nm 36hrs	1.5	2	
Immingham	10/09/2020	23/09/2020	Load cargo for south port call 14 days				0
Total port call days		52	For this scenario to function, another means for conducting last call at the island stations will need to be found.		96.72	104	146
Total at bases logistics days		22	Either the FPV/Protector/other program vessel/commercial charter, cost is not known at this time. Halley				
Total transit days		104	would possibly need to have expanded fuel storage capacity. Assumed cruising speed 13kts open water				
Total science days		146					
Total maintenance days		42					
		366					

Itinerary 1.3 No call Halley two calls at islands and Rothera, Arctic science cruise.

Polar research vessel 2019/2020 V1.2

Assumed open water transit speed 13 kits

Port	Arrive	Depart	Operations and Science/Notes	Distance for transit times	Minimum tranist days - Science can occur underway	Actual transit days allowed in itinerary	Dedicated Science days
Immingham	10/09/2019	24/09/2019	Load cargo for south/ Science Joining and Mob cruise 35 days from Portsmouth departure port call 14 days	Distance Immingham to Portsmouth 271nm 20hrs	0.83	1	0
Portsmouth	25/09/2019	26/09/2019	Take bunkers and aviation fuel 1 day	Distance from Portsmouth to Stanley 7054nm 542hrs	22.58	23	12
Stanley	31/10/2019	05/11/2019	Demob science take bunkers, Mob for science 5 days port call	Distance to BI 794nm 61hrs	2.54	3	0
Bird island	08/11/2019	11/11/2019	First call 3 days on site	Distance to KEP 70nm 5.3hrs	0.22	1	0
KEP	12/11/2019	14/11/2019	First call 2 days on site	Distance to Signy 520nm 40hrs	1.66	2	0
Signy	16/11/2019	19/11/2019	First call 3 days on site, Science days start form here circa 20 days	Distance to western core box 360nm. Distance from Western core box area to Stanley 520nm 67hrs	2.69	3	20
Stanley	12/12/2019	17/12/2019	Demob science Mob Science load cargo, take bunkers 5 days port call . Science inbound to Rothera 16 days	Distance to Rothera 1070nm 82hrs	3.4	4	16
Rothera	06/01/2020	10/01/2020	First call Rothera 4 days	Distance to Stanley 1070nm 82 hrs	3.4	4	0
Stanley	14/01/2020	19/01/2020	Demob Science Mob science circa 50 days science + 10 transit days port call 5 days	Distance to Amundsen sea area 2000nm 152hrs. Distance from Amundsen sea area to Rothera 1000nm 76hrs	9.64	10	50
Rothera	19/03/2020	22/03/2020	Last call Rothera 3 days	Distance from Rothera to Signy 850nm 65hrs	2.7	3	0
Signy	25/03/2020	27/03/2020	Last call 2 days	Distance from Signy to KEP 520nm 40hrs	1.66	2	0
KEP	29/03/2020	30/03/2020	Last call 1 day	Distance from KEP to BI 70nm	0.22	0	0
Bird island	30/03/2020	02/04/2020	Last call 3 days	From BI to Stanley 794nm 61hrs	2.54	3	0
Stanley	05/04/2020	10/04/2020	Demob science Mob science circa 28 days science Scotia Sea. Take bunkers, 5 day port call		0	0	28
Stanley	08/05/2020	13/05/2020	Demob science, load cargo for north. Direct transit to Immingham, 5 day port call	Distance from Stanley to Immingham 7325nm 563hrs	23.4	24	
Immingham	06/06/2020	13/06/2020	Discharge cargo from South 7 day port call	Distance from Immingham to Frederickshavn 471nm 36hrs	1.5	2	0
Frederikshavn	15/06/2020	01/08/2020	Annual refit 6 weeks Mob for Arctic cruise Mob port days 5	Distance from Frederickshavn Svalbard 1500nm 115hrs	4.79	5	0
Svalbard Arctic cruise	06/08/2020	05/09/2020	30 science days + 5 days transit	Distance from Svalbard to Immingham 1550nm 119hrs	4.9	5	30
Immingham	10/09/2020	24/09/2020	Load cargo for south/ Mob AMTscience cruise				0
Total port call days		52	Halley would be serviced by a commercial charter. Estimated cost for one call is circa £ 1 million. Islands logistics and Rothera support is same as current model. Assumed cruising speed of 13kts open water.Underway science can be undertaken during tranists.		88.67	95	156
Total at bases logistics days		21					
Total transit days		95					
Total science days		156					
Total maintenance days		42					
		366					

Itinerary 1.4 No calls at Halley or islands. Two calls Rothera

Polar research vessel 2019/2020 V1.2

Assumed open water transit speed 13 kits

Port	Arrive	Depart	Operations and Science/Notes	Distance for transit times	Minimum tranist days - Science can occur underway	Actual transit days allowed in itinerary	Dedicated Science days
Immingham	10/09/2019	24/09/2019	Load cargo for south/ Science Joining and Mob cruise 35 days from Portsmouth departure, port call 14 days	Distance Immingham to Portsmouth 271nm 20hrs	0.83	1	0
Portsmouth	25/09/2019	26/09/2019	Take bunkers and Aviation fuel 1 day	Distance from Portsmouth to Stanley 7054nm 542hrs	22.58	23	12
Stanley	31/10/2019	05/11/2019	Demob science Mob science take bunkers. 20 day science pennisula. Port call 5 days	Antarctic Peninsula area	6	6	20
Stanley	01/12/2019	05/12/2019	Demob science Mob Science inbound to Rothera 10 science days port call 4 days	Distance Stanley to Rothera 1070 nm 82hrs	3.41	4	10
Rothera	19/12/2019	23/12/2019	First call Demob southbound science Mob northbound science Dash-7 flights for science party swap 20 science days. Rothera port call 4 days	Distance Rothera to Stanley 1070nm 82hrs	3.41	4	20
Stanley	16/01/2020	21/01/2020	Demob science, take bunkers Mob Science Port call 5 days long 50 day science cruise	Distance Stanley to Amundsen sea area 2000nm 153.8hrs- Amundsen sea area to Punta Arenas 2000nm 153.8hrs	12.8	13	50
Punta Arenas	24/03/2020	28/03/2020	Demob take bunkers load cargo 4 days port call	Distance Punta Arenas to Rothera 1070 nm 82hrs	3.41	4	0
Rothera	01/04/2020	05/04/2020	Last Call 4 days	Distance Rothera to Stanley 1070nm 82hrs	3.41	4	0
Stanley	09/04/2020	14/04/2020	Mob Science cruise 29 days science 5 days port call. Science area Peninsula	Antarctic Peninsula area	6	6	29
Stanley	19/05/2020	23/05/2020	Demob science 4 days port call.	Distance Stanley to Immingham 7325nm 563hrs	23.4	24	0
Immingham	16/06/2020	26/06/2020	Discharge cargo from South take bunkers. 10 day port call. Mob for Arctic cruise 30 days science	Distance Immingham to Svalbard 1550nm 119hrs	4.9	5	30
Svalbard Arctic cruise	01/07/2020	31/07/2020	30 days sceince + 5 days transit	Distance Svalbard to Frederickshavn 1500 115hrs	4.79	5	
Frederickshavn	05/08/2020	08/09/2020	4 days Demob. Refit 30 days	Distance Frederickshavn to Immingham	1.5	2	
Immingham	10/09/2020	24/09/2020	Load cargo for south port call 14 days	Distance Immingham to Portsmouth 271nm 20hrs	0.83		
Total port call days		56	With this scenario there are no calls at Halley or the island bases. This would assume either commercial support for them, or FPV/HMS Protector. Other options for using other national program vessels USAP/Chile/. Costs are unknown at this time. Drummlan ship costs at this time circa £1million per revolution to Halley. Assumed cruising speed 13 kts open water		97.27	101	171
Total at bases logistics days		8					
Total transit days		101					
Total science days		171					
Total maintenance days		30					
		366					

Distances between frequently-visited ports, research stations and study areas, and transit times

From To Destination	Distance and Steaming times. Assumed 13 knots open water speed.	Tranist number of days days. Science can occur whilst underway.
Distance Immingham to Portsmouth	271nm 20.7hrs	0.83
Distance from Portsmouth to Stanley	7054nm 542hrs	22.58
Distance Stanley to Bird Island	794nm 61hrs	2.54
Distance Bird Island to King Edward Point	70nm 5.3hrs	0.22
Distance King Edward Point to Signy	520nm 40hrs	1.66
Distance Signy to western core box.	360nm 27hrs	2.69
Distance from Western core box area to Stanley	520nm 40hrs	1.66
Distance from Stanley to Halley	1600nm 123hrs	5.12
Distance Stanley to Rothera	1070nm 82hrs	3.41
Distance Stanley to Amundsen sea area	2000nm 153.8hrs	6.33
Distance from Amundsen sea area to Rothera	1000nm 76.9hrs	3.1
Distance from Rothera to Signy	850nm 65hrs	2.7
Distance from Stanley to Immingham	7325nm 563hrs	23.4
Distance from Immingham to Frederickshavn	471nm 36hrs	1.5
Distance from Frederickshavn Svalbard	1500nm 115hrs	4.79
Distance from Svalbard to Immingham	1550nm 119hrs	4.9
Distance from Immingham to Capetown	7861nm 604hrs	25.1
Cape town to Halley	3345nm 257hrs	10.7
Distance from Port Stanley to Ross Sea	4000nm 307hrs	12.8
Distance from Port Stanley to Punta Arenas	530nm 40.7hrs	1.6
Distance from Punta Arenas to Rothera	1141nm 87hrs	3.6
Distance from Punta Arenas to Immingham	8072nm 620hrs	25.8
Distance Stanley to Halley	1660nm 127hrs	5.3
Distance Signy to Halley	1100nm 84.6	3.5
Distance Stanley to Weddell sea	1500nm 115hrs	4.79

Summary of the different hypothetical itineraries

PRV1.1

Total port call days	52	Assumes one call Halley/two calls islands/two calls Rothera. Also no science during repositioning direct steaming from UK to Stanley. Assumed cruising speed 13kts open water
Total at bases logistics days	28	
Total transit days	107	
Total science days	137	
Total maintenance days	42	
	366	

PRV1.2

Total port call days. Days at bases included below	52	For this scenario to function, another means for conducting last call at the island stations will need to be found. Either the FPV/Protector/other program vessel/commercial charter, cost is not known at this time. Halley would possibly need to have expanded fuel storage capacity. Assumed cruising speed 13kts open water
Total at bases logistics days	22	
Total transit days	104	
Total science days	146	
Total maintenance days	42	
Total number of days	366	

PRV1.3

Total port call days	52	Halley would be serviced by a commercial charter. Estimated cost for one call is circa £ 1 million. Islands logistics and Rothera support is same as current model. Assumed cruising speed of 13kts open water.Underway science can be undertaken during tranists.
Total at bases logistics days	21	
Total transit days	95	
Total science days	156	
Total maintenance days	42	
	366	

PRV1.4

Total port call days	56	With this scenario there are no calls at Halley or the island bases. This would assume either commercial support for them, or FPV/HMS Protector. Other options for using other national program vessels USAP/Chile/. Costs are unknown at this time. Drummlan ship costs at this time circa £1million per revolution to Halley. Assumed cruising speed 13 kts open water
Total at bases logistics days	8	
Total transit days	101	
Total science days	171	
Total maintenance days	30	
	366	