The Changing Arctic Ocean: implication for marine biology and biogeochemistry

Announcement of Opportunity

Issued on 26 October 2015
Outline Proposals deadline: 16.00 GMT on 8 December 2015
Full Proposals deadline: 16.00 BST on 17 March 2016

1 Summary

Outline proposals are invited for a new Research Programme on the Changing Arctic Ocean and the implications for marine biology and biogeochemistry.

The outcome of this Research Programme will be a better understanding of how changes in the physical environment (ice and ocean) will affect the large-scale ecosystem structure and biogeochemical functioning of the Arctic Ocean and the potential major impacts.

It is expected that this announcement will lead to the funding of up to 4 proposals that address the programme's objectives. Due to the international nature of Arctic research, it is anticipated that funded proposals will have strong international partnership. Up to £8.4m is available for this call to fund up to four research projects with a maximum cost to NERC of £2.1m for each proposal.

A workshop will be held on the **5 November 2015** at the Jurys Inn, Birmingham, to ensure the research community is aware of the NERC National Capability available to support this research, such as the facilities, infrastructure and modelling. The event will also provide a forum for discussion of the science challenges and possible approaches to undertaking the research. It will also provide an opportunity to identify potential collaborations and partnerships and to discuss opportunities for international collaboration.

Registration to attend the workshop from those interested in submitting proposals are invited by midday on Friday 30 October 2015. Attendance will be limited to 60 and places will be assigned on a first come, first served basis, however if there is a high demand for places, NERC will look to have an institutional balance. Please register by completing the online registration form on the NERC website. Whilst attendance at the workshop is encouraged, it is not a prerequisite for submitting a proposal to this call.

Proposals for this call are invited from eligible UK researchers (see NERC Grants Handbook for standard eligibility criteria.

The closing date for outline proposals is 16:00 on 8 December 2015.

2 Background

The Arctic is the most rapidly changing environment on the planet[1] supporting diverse yet still poorly understood ecosystems. The Arctic Ocean, whilst small in size, has extensive shelf regions and contributes 5-14% to the global balance of CO_2 sinks and sources[2]. The Arctic is also intrinsically tied to global processes, whether they are climatic, environmental or socio-economic. Consequently, the Arctic is responding in unknown ways to profound changes in the physical environment as well as to multiple natural and anthropogenic stressors. The scale of these challenges facing the Arctic is immense and is further compounded by the rate of change.

Arguably the clearest evidence of change in the Arctic Ocean is the continued decline in extent and thinning of the summer sea ice. Satellite-derived estimates of sea-ice thickness and age have shown a fundamental shift from thick multi-year to thinner first year ice[3,4] and some climate models have predicted an ice-free summer Arctic Ocean within a few decades[5]. There has been a significant change in the persistence and distribution of open water and leading to modification of water column structure, stability, chemistry and circulation[6,7]. Other impacts on the marine environment arise from increased riverine discharges altering the nutrient balance, pollutant loads and optical properties.

Arctic marine ecosystems are responding to changes in ice, water and light availability, nutrient cycling, pollutants, and acidification[8,9,10]. Collectively, these multiple stressors are acting on the distribution of organisms[11,12], and the structure and functioning of food webs[13,14,15], and biogeochemical processes[1,16]. This is further exacerbated by stresses caused by human activities in

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[1] IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, Geneva, Switzerland, 151 pp.

[2] Bates, N. R. & Mathis, J. T (2009) The Arctic Ocean marine carbon cycle: evaluation of air-sea CO2 exchanges, ocean acidification impacts and potential feedbacks. *Biogeosciences*, 6,10 2433–2459.

[3] Stroeve, J. C., et al. (2012) The Arctic's rapidly shrinking sea ice cover: a research synthesis. *Climate Change* 110, 1005–1027.

[4] Swart, N.C., et al. (2015) Influence of internal variability on Arctic sea-ice trends. *Nature Climate Change* 5, 86-89.

[5] Wang, M. & Overland, J.E. (2012). An ice free summer Arctic within 30 years: An update from CMIP5 models. *Geophysical Research Letters* 39, L18501, doi:10.1029/2012GL052868.

[6] Giles, K.A., et al. (2012). Western Arctic Ocean freshwater storage increased by wind-driven spin-up of the Beaufort Gyre. *Nature Geoscience* DOI: 10.1038/NGEO1379.

[7] Rainville, L., et al. (2011). Impact of wind-driven mixing in the Arctic Ocean. *Oceanography* 24,136–145.

[8] Arrigo, K.R. & Dijken, G. L. V. (2011) Secular trends in Arctic Ocean net primary production. *Journal of Geophysical Research* 116, C09011.

[9] Tremblay, J.-E. & Gagnon, J. (2009) The effects of irradiance and nutrient supply on the productivity of Arctic waters: a perspective on climate change *In*: Influence of climate change on changing Arctic and sub-arctic conditions. Pp. 73–89, Springer

[10] AMAP (2013) AMAP Assessment 2013: Arctic Ocean Acidification. AMAP, Oslo.

[11] Hollowed A.B., et al. (2013) Potential movement of fish and shellfish stocks from the sub-Arctic to the Arctic Ocean. *Fisheries Oceanography* 22, 355–370.

[12] Johansen G.O., et al. (2013) Seasonal variation in geographic distribution of North East Arctic (NEA) cod – survey coverage in a warmer Barents Sea. *Marine Biology Research* 9, 908–919.

[13] Grebmeier, J.M., et al. (2006) A major ecosystem shift in Northern Bering Sea. *Science* 311, 1461–1464.

[14] Li, W. K. W., et al. (2009) Smallest algae thrive as the Arctic Ocean freshens. *Science* 326, 539.

[15] Lee, S. H. et al. (2013) Contribution of small phytoplankton to total primary production in the Chukchi Sea. *Continental Shelf Research* 68, 43-50.

[16] Levasseur, M. (2013) Impact of Arctic meltdown on the microbial cycling of sulphur. *Nature Geoscience* 6, 691-700.

the Arctic e.g. changes in resource extraction, maritime traffic, and noise[17]. Against this background of stress and change there are still fundamental questions relating to animal lifecycles and ecosystem function that remain unknown.

Current and future changes in the Arctic marine ecosystem and associated biogeochemical cycles will potentially have far-reaching implications for the UK environment and economy, including direct impacts on UK climate and migratory species, and therefore possible impacts on industries such as fisheries and tourism (as recently highlighted in the 2015 UK House of Lords Select Committee report *Responding to a Changing Arctic* and the 2013 UK Foreign and Commonwealth Office report *Adapting to change – UK policy towards the Arctic*). The ability to understand and predict these changes is therefore critical to enable the UK to respond to these challenges.

Arctic ecosystems are both highly heterogeneous and connected. Changes in the ocean and sea ice environment of the Arctic will generate major but unknown changes in Arctic ecosystems, affecting biological processes at every level of organisation from genetics and physiology to food webs, biogeochemical cycles, species distribution and whole ecosystems[18][19].

The focus of this programme is on developing the fundamental, and quantified, understanding required to generate projections of the impacts of future change on biological and biogeochemical processes affecting productivity, species distributions, food webs and ecosystems and the services they provide. This programme will thereby contribute to addressing the 'Managing Environmental Change' and 'Benefiting from Natural Resources' challenges in the NERC strategy.

3 Scope of Call

3.1 Programme Objectives

The overarching objective of the Changing Arctic Ocean research programme is to understand how change in the physical environment (ice and ocean) will affect the large-scale ecosystem structure and biogeochemical functioning of the Arctic Ocean, to understand the potential major impacts, and to provide projections for future ecosystem services.

The overarching objective of the programme will be addressed through the delivery of two key research challenges:

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[17] Fort, J , et al. (2013) Multicolony tracking reveals potential threats to little auks wintering in the North Atlantic from marine pollution and shrinking sea ice cover. *Diversity and Distributions* 19, 1322-1332.

[18] ART (2014) Priority sheet - Arctic Biodiversity, http://istas.sciencesconf.org/resource/page/id/11

[19] Wassmann,P. (2011a) Arctic marine ecosystems in an era of rapid climate change. Progress in Oceanography 90, 1-17
Wassmann, P. (2011b) Footprints of climate change in the Arctic marine ecosystem. Global Change Biology 17, 1235-1249.

Challenge 1: To develop quantified understanding of the structure and functioning of Arctic ecosystems.

To generate projections of the impacts of change requires quantitative and experimental analyses of the key processes that affect the distribution of Arctic organisms, structure of food webs and interactions with biogeochemical cycles.

1.1 Characterization of food webs and biogeochemical cycles in contrasting regions of ice cover.

There are major structural differences in Arctic food webs that reflect the relative abundance of high Arctic ice-associated organisms compared to sub-Arctic/boreal species[20] and changes in sea-ice are expected to have a major impact on species distributions and ecosystem structure[21] [22] [23] [24] [25] [26] [18]. Differences in productivity and zooplankton community composition associated with the influence of Arctic ice-covered waters are known to affect which species of fish, seabirds and marine mammals can be maintained in regional food webs [21] [22]. Sea-ice is also a critical habitat for a wide range of species as an area of feeding and as a substrate. Loss of sea-ice can affect access to prey and hence the breeding biology of seabirds that occur in large land-based colonies [27] [28] and habitat availability for marine mammals, such as seals, which haul out onto the ice using it as a resting area and refuge[29]. However, the composition and interactions within Arctic food webs are poorly described in most regions and particularly in areas of ice to open water transit.

The sea-ice environment influences the water column structure, light field, carbonate chemistry and nutrient supply experienced by plankton, as well as the potential for air-sea exchange of biogenic gases. Ice melt, snow melt and rainfall play key roles in controlling phytoplankton community structure of under-ice and ice edge blooms, impacting biogeochemical cycling in the water column. Vertical mixing, overturning, upwelling and oceanic transport are all intimately related to the presence and seasonality of the ice, yet there are major gaps in our understanding of how the sea-ice environment impacts food web structure, processes of energy and flows of carbon, nitrogen and phosphorus (including feeding interactions at all trophic levels and pelagic-benthic ecological links). There is also little quantification of these links and interactions or the functional roles of species and levels of redundancy in food webs. Food web structure influences the

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[20] Wassmann, P. (2006) Structure and function of contemporary food webs on Arctic shelves: an introduction. Progress in Oceanography 71, 123-128. doi:10.1016/j.pocean.2006.09.008.
[21] Berge, J., et al. (2015) First records of Atlantic Mackerel (Scomber scombrus) from the Svalbard archipelago, Norway, with possible explanations for the extension of its distribution. Arctic 68, http://dx.doi.org/10.14430/arctic4455
[22] Karnovsky, N. et al. (2010) Foraging distributions of little auks Alle alle across the Greenland Sea: implications of present and future Arctic climate change. Marine Ecology Progress Series. 415, 283-293.
[23] Joiris C.R. (2011) A major feeding ground for cetaceans and seabirds in the southwestern Greenland Sea. Polar Biology 34, 1587-1608.
[24] Grémillet, D., et al. (2015) Arctic warming: nonlinear impacts of sea-ice and glacier melt on seabird foraging. Global Change Biology 21, 1116-1123 doi:10.1111/gcb.12811.
[25]Leu, E., et al. (2011) Consequences of changing sea-ice cover for primary and secondary producers in the European Arctic shelf seas: timing, quantity, and quality. Progress in Oceanography 90, 18-32.
[26] Durbin, E.G. & Casas, M.C., (2013) Early reproduction by Calanus glacialis in the Northern Bering Sea. Journal Plankton Research 10.1093/plankt/fbt121.
[27] Gaston, T & Irons, D. (2010) Seabirds – murres (guillemots), Arctic Biodiversity Trends 2010, Conservation of Arctic Flora and Fauna, Iceland.
[28] Fort, J , et al. (2013) Multicolony tracking reveals potential threats to little auks wintering in the North Atlantic from marine pollution and shrinking sea ice cover. Diversity and Distributions 19, 1322-1332.
[29] Kovacs, K. M., et al. (2011), Impacts of changing sea-ice conditions on Arctic marine mammals, Marine Biodiversity, 41, 181-194.

magnitude of primary production, respiration, vertical export and ultimately sequestration of carbon. Hence, a major effort is required to fill gaps in knowledge of food web structure (microbial to seabirds and marine mammals) and functioning in a range of ice-ocean ecosystems that provide the basis for modelling the impacts of change.

1.2 Description of changing seasonality and its subsequent impact on biological and biogeochemical processes and ecosystems.

As the extent of sea-ice cover declines, the seasonal dynamics of regional Arctic ecosystems is changing. In many areas there is an earlier melt and later freeze with potentially multiple-freeze-melt events during a season. As the open water period extends, this increases the growing season of planktonic organisms and can change the balance of autotrophic and heterotrophic production[30]. This will affect the transfer of energy to higher trophic levels [25] and flux of carbon into the deeper ocean. The ice edge position and its timing will also affect vertical fluxes affecting pelagic-benthic links and hence benthic community structure. There is extensive knowledge of summer open-ocean processes and there have been some important international efforts to understanding winter time dark processes in high Arctic marine ecosystems (e.g. *Mare Incognitum Program* of the University of Tromsø), spring plankton dynamics[31] and how winter processes impact the nutrient inventory of the Arctic Ocean with knock-on effects for spring and summer dynamics. There are still significant and important knowledge gaps in our understanding of the transitional seasonal dynamics. The marked seasonality and strong advective regime also requires an understanding of the sensitivity of the seasonal development and spatial connectivity of food web processes. Developing an understanding of the complete seasonal biogeochemical and ecosystem dynamics over a range of different ice conditions through a combination of observations, experiments and modelling is crucial to provide a mechanistic understanding of major underlying processes necessary for generating projections of the potential impacts of future change.

Challenge 2: To understand the sensitivity of Arctic ecosystem structure, functioning and services to multiple stressors and the development of projections of the impacts of change.

Although sea-ice is the characteristic feature of Arctic ecosystems, changes are also occurring in other fundamental drivers of habitats in these regions. This includes aspects of ocean physics (temperature, stratification and circulation), chemistry (pH and nutrients), light levels [8], and toxic contaminants such as persistent chemicals and mercury[32]. The behaviour of long-lived contaminants with changing ice-regimes and exposure of organisms living in ice during ice formation and melt are currently unknown but may contribute to contaminant residues in biota within Arctic marine ecosystems[33 34].

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[30] Wassmann, P. & M. Reigstad. (2011) Future Arctic Ocean seasonal ice zones and implications for pelagic-benthic coupling. Oceanography 24, 220–231.

[31] Søreide J.E., et al. (2010) Timing of blooms, algal food quality and Calanus glacialis reproduction and growth in a changing Arctic. Global Change Biology 16, 3154-3163.

[32] Ma, J.M. et al. (2011) Re-volatilisation of persistent organic pollutants in the Arctic induced by climate change. Nature Climate Change 1, 255-260.

[33] Bustnes, J.O., et al. (2012) Temporal Dynamics of Circulating Persistent Organic Pollutants in a Fasting Seabird under different environmental conditions. Environmental, Science & Technology 46, 10287-10294.

[34] McKinney, M.A., et al. (2013) Global change effects on the long-term feeding ecology and contaminant exposures of East Greenland bears. Global Change Biology 19, 2360-2372.

Development of projections requires quantified understanding of the biogeochemical and biological processes that determine the relative success of different species, and their sensitivity and resilience, and that of the food webs in which they occur, to changes in multiple drivers.

2.1 Assessment of the impact of changing inorganic and organic nutrient supply on ecosystem structure and function.

Changes in ice formation, consolidation and subsequent melt, glacial melt, freshwater input, shelf exchange and mixing rates are expected to change the concentrations and elemental stoichiometry (C:N:P:Si:Fe) of inorganic and organic material in the Arctic Ocean. This will lead to unknown impacts on plankton autotrophic and heterotrophic community structure and therefore the balance between carbon storage and production of CO_2.

River discharge to the Arctic is disproportionately high; 10% of the global total enters 1% of the ocean volume annually. Around 60% of Arctic dissolved organic matter (DOM) is terrestrial in origin, and there is increasing evidence that these inputs are extremely labile and thus may be an important resource for Arctic microbial communities with potential implications for food webs and CO_2 production. The annual delivery of riverine DOM is expected to increase with increasing river discharge[35]. Increased DOM supply is also envisaged via increased coastal upwelling and potentially through changes to phytoplankton community structure and thus excretion rates. As much of this DOM is strongly light absorbing [36] [37] there are additional implications for ecosystem structure via modification of the surface water light field, as well as a wider biogeochemical aspect related to production and fate of photo-products including climate-active gases[38].

The freshening of Arctic surface waters from increased river discharge and sea-ice melt leading to strengthened stratification and shoaled mixed layer depths has already led to a decrease in phytoplankton community size structure[39]. The expected changes in microbial community structure [37] [40] due to changes in the concentration and composition of organic and inorganic nutrients will alter the pathways of nutrient regeneration, respiration and photochemical transformation and sinking fluxes of particulate and dissolved material in currently unknown ways [31]. This in turn will impact mesopelagic food webs, carbon sequestration, benthic food supply, and the supply of nutrients back to the surface layer. Addressing these important changes will require process studies that focus on external supply and internal cycling of carbon, nitrogen and phosphorus, and the interactions between particulate and dissolved material and mesopelagic food webs from microorganisms to fish.

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[35] Frey et al. (2007) Impacts of climate warming and permafrost thaw on the riverine transport of nitrogen and phosphorus to the Kara Sea. Journal of Geophysical Research 112, G04S58, doi:10.1029/2006JG000369.
[36] Bélanger, S. et al. (2013) Light absorption and partitioning in Arctic Ocean surface waters: impact of multiyear ice melting. Biogeosciences 10, 6433–6452.
[37] Fichot, C. G. et al.. (2013) Pan-Arctic distributions of continental runoff in the Arctic Ocean. Scientific Reports 3 doi:10.1038/srep01053.
[38] Bélanger, S. et al. (2006) Photomineralization of terrigenous dissolved organic matter in Arctic coastal waters from 1979 to 2003: Interannual variability and implications of climate change. Global Biogeochemical Cycles 20, GB4005, 5623-5640, doi:10.1029/2006GB002708.
[39] Li, W. K. W., et al. (2009) Smallest algae thrive as the Arctic Ocean freshens. Science 326, 539.
[40] Lee, S. H. et al. (2013) Contribution of small phytoplankton to total primary production in the Chukchi Sea. Continental Shelf Research 68, 43-50.

2.2 Sensitivities to multiple stressors and development of models of the life-cycles of key species, food-webs, biogeochemical cycles and whole ecosystems.

To understand the responses and the resilience of species and food webs in Arctic ecosystems exposed to multiple drivers of change requires detailed understanding of the responses, adaptations (genetic, physiological, behavioural and ecological) and resilience of individual species throughout their life histories [18]. Arctic ecosystems are dominated by species with complex life histories that are long-lived and highly adapted to the strongly seasonal environments. Many of these species are likely to be sensitive to change and their future distribution and abundance will depend on their genetic and physiological capacities to adapt or behavioural and life cycle processes that allow them to move [18]. The timing of key life history events and the potential mismatch between phenology and physical cycles could have major impacts to ecosystem function[41]. Lipid-based efficient food webs adapted to the near freezing environment are more vulnerable to environmental change than their mid-latitude analogues[31]. The advective nature of the Arctic[42] and long life spans of the key species[20] result in a strong connectivity of the basins and ecosystems, and fast downstream propagation of localised changes to the food webs[43]. Changes in any one of the above web-forming factors will lead to a major change in the food web and ecosystem structure and function. Understanding the spatial and temporal operation of these life cycles (across multiple trophic levels including plankton, fish, seabirds and marine mammals) will be crucial for developing projections of the impacts of change.

Multiple drivers of change will impact biogeochemical processes. The combined and interacting effects of increasing temperature, changing light, carbonate chemistry, organic and inorganic nutrients and metals will likely have differential impacts at different levels of ecological organisation affecting productivity and ecosystem structure, carbon storage and hence the role of these ecosystems in climate-related processes [19].

Arctic and sub-Arctic food webs support globally significant fisheries, which have expanded over the last decade[44]. Changes in sea ice and oceanic conditions are resulting in shifts in the distributions of exploited species[21] and an increased influence of lower latitude species in Arctic food webs is expected to increase the accessibility and availability of fishable populations in higher Arctic regions [11 12]. Such fisheries directly affect exploited species, but they also indirectly affect the species (e.g. seabirds and marine mammals) that depend on the same resources as prey.

To generate projections of the impacts of change requires quantified understanding of the multiple processes involved in determining responses to change. This will involve process and experimental studies focused on the critical phases of life-cycles and adaptive capacities of key species, developing mechanistic understanding of the interactive effects of change on biogeochemical and biological processes and how these impact food web structure. No single model can be used to

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[41] Hovinen J.E.H. et al. (2014) Climate warming decreases the survival of the little auk (Alle alle), a high Arctic avian predator. Ecology and Evolution 4, 3127-3138.

[42] Popova, Ekaterina E., et al. (2012) What controls primary production in the Arctic Ocean? Results from an intercomparison of five general circulation models with biogeochemistry. Journal of Geophysical Research 117, C00D12. (doi:10.1029/2011JC007112).

[43] Hop, H., et al. (2006) Physical and biological characteristics of the pelagic system across Fram Strait to Kongsfjorden. Progress in Oceanography 71, 182-231.

[44] Christiansen, J.S. et al. (2014) Arctic marine fishes and their fisheries in light of global change. Global Change Biology 20, 352-359.

address all the issues of interest, instead a range of models will be required that focus on different scales of biological organisation, such as the life-cycles of key species, food webs and whole ecosystem processes, including biogeochemical influences on productivity and nutrient cycling.

2.3 Projections of the impacts of change.

Development of projections of the impacts of Arctic change on species, biogeochemical cycles and whole ecosystems is required for the development of mitigation and adaptation measures for managing the impacts of change on human communities and economic systems. Projections of the impacts of physical and biogeochemical changes in Arctic systems are being developed through IPCC processes. The UK Earth System Model (ESM) based on NEMO-MEDUSA[45] will provide a series of circumpolar scenarios of physical and biogeochemical change over the next century. These studies can provide the basis for developing projections of the impacts of change on key species and food webs. The generation of such projections will be a major contribution to the development of the International Platform on Biodiversity & Ecosystem Services (IPBES) process assessing the impacts of future change on biodiversity and ecosystem services[46].

Analyses are required that examine resilience, sensitivity and thresholds of biogeochemical cycles, species and ecosystem processes. Projections of future change will assess the sensitivity of key species to multiple drivers and examine changes in the distribution and abundance of key species, the interaction of biogeochemical and ecological processes and the structure and functioning of ecosystems under different climate change scenarios. Development of projections should include appropriate analyses of model sensitivity and associated uncertainty. Understanding how future changes in food webs will impact key ecosystem services will be crucial for sustainable exploitation of these resources. Activities under this challenge are expected to include analyses of how changes in Arctic ecosystems will impact, and be affected by, human activities (including fisheries, transport and resource exploitation) and develop understanding and projections of potential ecological and socio-economic impacts of change.

3.2 Proposal Requirements

Proposals will be required to contribute toward both Challenges by addressing one or more of the deliverables in each Challenge:

Challenge 1 deliverables

- Quantified description of the seasonal and spatial development of Arctic food webs and associated biogeochemical cycles in varying ice conditions that will be used for validation of a coupled ocean model.
- Improved mechanistic understanding and parameterization of key physical, chemical and biological processes governing productivity and ecosystem structure.

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[45] Yool, A., et al. (2013) MEDUSA-2.0: an intermediate complexity biogeochemical model of the marine carbon cycle for climate change and ocean acidification studies. Geoscientific Model Development 6, 1767-1811.

[46] Eamer, J., et al. (2013). Life Linked to Ice: A guide to sea-ice-associated biodiversity in this time of rapid change. CAFF Assessment Series No. 10. Conservation of Arctic Flora and Fauna, Iceland.

Challenge 2 deliverables

- A series of mechanistic models of responses of individual species, food webs and ecosystem structure and functioning (including biogeochemical cycles) to key drivers of change.
- Coupled models of the seasonal and spatial development of Arctic food webs and associated biogeochemical cycles. These should facilitate projections of the potential impacts of future change on Arctic productivity, species and ecosystems with an assessment of associated sensitivities and uncertainties.

Proposals are required to include both observational studies and modelling and they should primarily support the deliverables of Challenge 1, while allowing those for Challenge 2 to proceed.

3.2.1 Observational programme:

There is no single location that is representative of 'The Arctic' and each region is highly variable in terms of its accessibility. Therefore, a programme of research needs to be able to support relevant observations over a range of Arctic environments, yet be able to provide a focus for resources.

There are geographical and seasonal restrictions for UK research ships to access the Arctic. To meet the programme's observational requirements, it is anticipated that up to four dedicated research cruises on NERC's research ship, the *RRS James Clark Ross*, will be scheduled in the period 2017 to 2019. Theses cruises will be limited to a window of around 4-6 weeks in the summer and to high latitude North Atlantic-Arctic waters in a sector that includes the western Barents Sea, East Greenland, Fram Strait and Svalbard. Despite the apparent limitations of this, there are some important benefits of this sector being the main focus of the programme's NERC ship-based campaigns. These include:
- access to a range of sea-ice conditions and ages, a high-latitude, permanently ice-free open ocean with various water masses, nutrient characteristics and degrees of mixing and stratification, providing the necessary habitats in which to examine the functioning of the biological and biogeochemical components of the Arctic system. Also includes access to a range of nutrient regimes, including Arctic influenced waters on the western boundary and Atlantic influenced waters on the eastern boundary.
- the opportunity for combined NERC ship and land-launched campaigns (e.g. year-round deployments of Autonomous Underwater Vehicles (AUVs) from Svalbard).
- a large volume of pre-existing data (especially from the Fram Strait and Barents Sea) in which to contextualise the research coming out of this programme.

However, a high degree of international collaboration is anticipated by projects (e.g. US, Norway, Germany, Canada, Denmark and Poland). Such collaboration could provide opportunities for UK scientists to use other Arctic research ships and land based research infrastructure for sampling as part of joint campaigns and in seasons when NERC's facilities aren't available.

It is also anticipated that the first cruise will be scheduled for the summer of 2017. As the 2017/18 cruise programme will be defined in advance of the successful proposals from this call being awarded, there may be limited technical support and equipment available for this cruise. At the outline proposal stage, applicants are only required to submit an outline of their cruise plans. After the outline proposal moderating panel, successful applicants are encouraged to speak with NERC Marine Planning to discuss the feasibility of their plans. Marine planning will also then be able to provide a list of equipment that will be available for the 2017 cruise that can be used in the development of cruise plans.

The cruise programme for subsequent years will not be defined ahead of the award of successful proposals and therefore the availability of NMF Sea Systems support and equipment will be increased.

The use of autonomous robotic technologies (e.g. aircraft, sea gliders, AUVs, unmanned surface vehicles), seabird and mammal activity recorders and tags, and moorings and autonomous profiling instruments (e.g. Ice-Tethered Profilers and Argo floats) is strongly encouraged to provide an opportunity to fill observational gaps (e.g. long transects into wider basins, focused observations in areas not accessible easily by ships, and observations capturing seasonally varying processes).

3.2.2 International partnership:
International partnerships and collaborations are anticipated as part of this call for proposals, e.g. to integrate planned international research with the UK programme, to access existing data, to gain access to international Arctic infrastructure in different regions.

An international travel fund will be made available to successful outline proposals to aid with the development of international collaboration plans. Information on how to apply to this fund will be made available after the outline proposal panel meeting.

3.2.3 Modelling:
The major focus of the modelling activity should relate to Challenge 1 and the development of coupled model(s) of the seasonal and spatial development of Arctic food webs and associated biogeochemical cycles in varying ice conditions. It is expected that these activities will result in a series of spatially resolved ecological models (e.g. of species life cycles or food webs) that can be coupled (on or offline) to appropriate physical (ocean and ice) and/or biogeochemical models.

A valuable outcome from this call for proposals would be the development of a series of alternative but complementary models. Proposed modelling activities should be independent (except in relation to already funded National Capability projects), but proposal of potentially complementary model activities between projects would be welcomed. Some post-award discussion and development of modelling aspects of different projects may be required to avoid duplication and maximize the relevance of the modelling work. Once selected, proposers will be expected to work together to integrate model activities as appropriate. An important consideration in assessment of the proposed modelling activities will be how, overall, they can contribute to the development of the ocean ecological component of the UK Earth System Model (ESM). This will require some coordination of modelling activities funded under this call with National Capability funded NEMO-MEDUSA modelling activities, as this will be the link into the UK ESM.

3.2.4 Associated studentships:
All proposals will be required to include at least one associated studentship which should be co-supervised by 2 or more of the proposal's co-investigators from different institutions**.** The cost for the studentship should be included within the total requested funds. Each studentship should constitute a distinct project providing added value to the parent large grant. The main large grant

research should still be viable without the studentship and should have distinct objectives that are not reliant on the requested studentship.

The student is expected to be able to develop novel research ideas while benefiting from working in a group environment and we strongly encourage they are trained as part of a student cohort. This could, for example, be accomplished by integrating this student into an existing NERC Doctoral Training Partnership training programme. NERC will not accept proposals where a student is the only dedicated research/staff member on a grant, including individual component grants of joint proposals.

All studentships must meet the following NERC Success Criteria:

- Research excellence: the training and training environment must include scientifically excellent and original research within NERC's remit.
- Training excellence: students are managed as a cohesive group and acquire both research and transferable skills. There is a strong and active community of students that are able – and encouraged – to integrate, work and learn together.
- Multidisciplinary training environments: the training is embedded in multidisciplinary training environments to enrich the student experience and to encourage the knowledge-sharing and interconnectivity, which benefits research within the environmental sciences. This does not mean that individual PhD topics are required to be multidisciplinary.
- Excellent students: attracting the right student. NERC funding goes to the right of 'best-fit' student: the individual whose previous training, experience and skills best suit the type of training being undertaken.

In order to be successful, applicants must demonstrate within their proposal how these success criteria will be met.

3.3 Programme Funding

Up to £8.4m is available for this call to fund up to four research projects with a maximum cost to NERC of £2.1m for each proposal.

Additional funding will be provided centrally to cover cruise-related costs on NERC research ships (~£1.25m for NMF Sea Systems cruise costs and an additional ~£1m is available for mooring and AUV costs) and data management. Proposals should include formal requests (and access costs) for any other NERC Services and Facilities (e.g. aircraft, HPC, isotope analyses, UK Arctic Research Station), where relevant.

Proposals should present a modular work plan (including associated costs) for up to 48 months. An integration workshop will be held after the full proposal moderating panel for those recommended for funding. The aim of the workshop will be to ensure that there is a coherent science and field programme (e.g. that has no science duplication and a field programme that is affordable, and cost effectively uses the available NERC infrastructure) which may require adjustment to the work plans of recommended proposals before they are awarded.

All grants will be required to start and to have returned their starting certificate by **1 February 2017**. Please note that as a result of this requirement, the normal three month start period rules (outlined in RCUK Terms and Conditions GC4) do not apply in this instance.

The NERC funding contribution will be 80% of FEC (with the standard exceptions paid at 100% FEC). Indexation at the prevailing rate will be applied at the time of award.

An associated studentship includes the student's maintenance grant and university fees. These must be requested on the proposal form as an Exceptions cost and will be paid at 100% FEC. All students must receive the minimum research council stipend (RCUK Funding for Research Training) but we would encourage this figure to be increased from other funding sources. Additional costs should be requested for items such as fieldwork expenses, conferences and consumables, as Directly Incurred costs and will be paid at 80% FEC. Applicants may request studentship funding for up to 42 months. It is expected that associated studentships will commence at the latest 6 months after the start date of the parent research project grant to ensure they occur within the lifetime of their parent award. No further funding is available for associated studentships beyond that requested on the grant proposal.

4 Programme Requirements

4.1 Implementation and Delivery

All proposals are required to involve a minimum of 3, but preferably more, eligible institutions. Proposals will also be expected to include a range of both senior and early career scientists.

Proposals may be up to 48 months in duration and will be required to start and to have returned their starting certificate by 1 February 2017.

All proposals must include milestones and deliverables to ensure that NERC and the Programme Advisory Group can monitor the delivery of the science outputs.

It is highly desirable for proposal teams to be inter-disciplinary, and should also work with international partners where appropriate.

Proposals must include at least one associated studentship. We encourage applicants to award these studentships as CASE studentships to maximise the impact of the programme for end-users, including NGOs, business and industry.

4.2 Knowledge Exchange and Impact

Knowledge exchange (KE) is vital to ensure that environmental research has wide benefits for society, and should be an integral part of any research. Outline proposals should provide a brief summary and estimated cost of their proposed KE activities, but full details are not required until the full proposal stage.

All full proposals will be required to identify their KE plan through a 'Pathways to Impact' section, with associated delivery costs. The KE plan will identify those who may benefit from or make use of the research, how they might benefit or make use of the research, and methods for disseminating data, knowledge and skills in the most effective and appropriate manner.

All funded projects may also be required to engage with programme-wide KE activities, in which case appropriate funding for which will be provided by the programme.

4.3 Data Management

The NERC Data Policy must be adhered to, and an outline data management plan produced as part of full proposal development. Applicants are advised to contact the relevant data centre to discuss their requirements. NERC will pay the data centre directly on behalf of the programme for archival and curation services, but applicants should ensure they request sufficient resource to cover preparation of data for archiving by the research team.

4.4 NERC Facilities

Prior to submitting an outline proposal, applicants wishing to use a NERC service or facility must contact the facility to seek agreement that they could provide the service required. Prior to full proposal submission a technical assessment must be obtained from the facility and included with the proposal submission. Further information on NERC services and facilities can be found on the NERC website.

4.5 Programme Management

It will be a condition of grant awards that the lead PIs of the awarded grants will work closely for the life time of the programme with the Science Coordinator and members of the Programme Advisory Group.

5 Eligibility

This opportunity is open to individuals and organisations eligible for NERC research grant funding, i.e. applicants based in UK Higher Education Institutions (HEIs), NERC Research & Collaborative Centres, and Independent Research Organisations (IROs) approved by NERC for managed mode (RCUK eligibility for Research Council funding). Please refer to the NERC Grants Handbook for details. Potential applicants should contact NERC well in advance of the submission deadline if they have any queries concerning their eligibility. Individuals are limited to involvement in no more than two proposals submitted to this call; only one of these may be as the lead Principal Investigator.

6 Workshop

A workshop will be held in order to facilitate the development of high quality proposals that will effectively use the planned programme cruises and maximise collaboration opportunities.

Workshop date: 5 November 2015
Workshop venue: Jurys Inn, Birmingham
Estimated start time: 09:30
Estimated finish time: 16:00

The objectives of the workshops are:

- to ensure the research community is aware of the NERC National Capability available to support research, such as facilities, infrastructure and modelling, as well as collaboration opportunities with potential partners;
- to discuss science challenges and possible approaches to undertaking the research; and
- to discuss opportunities for international collaboration.

Please register to attend the workshop by completing the online meeting registration form available on the NERC website.

The deadline to register to attend the workshop is 12.00 on 30 October 2015.
Individuals interested in submitting a proposal are encouraged to attend. Spaces at the workshop are limited to 60, so the number of registrations from the same research group should be managed if possible. Attendance at the workshop is not a prerequisite for submitting a proposal.

Further details of the workshop agenda and presentations will be circulated to delegates prior to the meeting.

NERC will pay essential travel and subsistence costs to support attendance at the workshop that fall within NERC guidelines for appropriate expenditure. Note that first class travel is not permitted and taxi fares can only be claimed in exceptional circumstances where there is no practical alternative.

7 Application Process

This call has a two-stage application process. An outline proposal must be submitted to be able to progress to the full proposal stage.

7.1 Outline Proposals
Closing date: 8 December 2015

The outline proposal stage will be used to identify projects that will be invited to submit a full proposal. The outline proposals will be assessed by a panel of international experts (chaired by Prof. David Thomas, Bangor University, Programme Advisory Group Chair). No more than 12 outline proposals will be invited to submit full proposals. Any sift of proposals will be made on the basis of the likely fit of proposals to requirements of the call. The panel will provide brief feedback to applicants summarising why their proposal was successful/unsuccessful. No further feedback will be available.

One outline proposal submission is required for each proposed project; this should be submitted by the lead Principal Investigator and cover all consortium components.

Outline proposals must be submitted using the Research Councils' Joint Electronic Submission system (Je-S). For all proposals please select Proposal Type - 'Outline' and then select Scheme - 'NERC outline' and the Call - 'Changing Arctic Ocean Oct15'.

Applicants must ensure that their outline proposal is received by NERC by 4pm on the closing date. Any proposal that is received after the closing date, is incomplete, or does not meet the eligibility criteria of this call for proposals, will be returned to the applicant and will not be considered.

For all proposals, the Principal Investigator must submit a completed outline proposal form together with a Case for Support.

The outline proposal form should include the expected Co-Investigators and their Research Organisations. If successful, some of the Co-Investigators would then become the Principal or Co-Investigators on the component grant proposals and not be named on the lead grant proposal.

For all applications, the Principal Investigator must submit a completed Je-S Outline proforma together with a Case for Support. All documents should be completed in single-spaced typescript of minimum font size 11 point Arial font or other sans serif typeface of equivalent size to Arial 11, with margins of at least 2 cm. References must now also be presented in minimum font size 11 point. Please note that Arial narrow and Calibri are not allowable font types as they are smaller and any proposal which has used either of these font types within their submission will be rejected. Applicants referring to websites should note that referees may choose not to use them.

Applicants should ensure that their proposal conforms to all eligibility and submission rules, otherwise their proposal may be rejected without peer review. More details on NERC's submission rules can be found in the NERC research grant and fellowships handbook and in the submission rules on the NERC website.

The Case for Support should not exceed 6 sides of A4 and should include the following summary information:

- Outline of research proposed and its international context.
- Describe the relationship of the proposal to the deliverables being addressed.
- Outline what collaborations and/or partnerships are likely to be involved.
- Outline of proposed associated studentship(s).
- Composition of the research team.
- Outline of project management plan and data management plan.
- If applicable, outline what NERC ship-time will be required, where the cruise(s) would take place, the number of science days and berths required, and the type of activities involved e.g. use of autonomous systems.
- Proposed use of any other NERC facilities (initial discussions should be held with the relevant facilities on feasibility at this stage).
- Equipment to be requested and the expected NERC % contribution required.
- Proposed Pathways to Impact.
- References.

It is the responsibility of applicants to undertake sufficient planning at the outline proposal stage to determine that the full costs of research proposed (including any facility costs) can be accommodated within the fixed financial limits of the scheme. The Resources indicated at the outline proposal stage are considered as estimates only and may be amended in a subsequent full proposal, within the financial limits of the scheme. No CVs or project partner letters should be submitted at the outline proposal stage.

Applicants should be informed in January 2016 if they are to be invited to proceed to the full proposal stage.

7.2 Full Proposals
Closing date: 17 March 2016

You must previously have submitted an outline proposal that has been invited to proceed to the full proposal stage in order to submit a full proposal. We would expect proposals to evolve between submitting the outline proposal and the full proposal (including personnel), but major aspects are expected broadly to remain the same.

Full proposal must be submitted using the Research Councils' Joint Electronic Submission system (Je-S). Applicants should select Proposal Type - 'Standard Proposal' and then select the Scheme – 'Directed' and the Call – 'Changing Arctic Ocean APR16'.

Applicants must ensure that their proposal is received by NERC by 4pm on the closing date. Applicants should leave enough time for their proposal to pass through their organisation's Je-S submission route before this date. Any proposal that is received after the closing date, is incomplete, or does not meet NERC's eligibility criteria or follow NERC's submission rules (see NERC Grants Handbook), will be returned to the applicant and will not be considered.

All attachments submitted through the Je-S system, including the Case for Support, should be completed in single-spaced typescript of minimum font size 11 point Arial font or other sans serif typeface of equivalent size to Arial 11, with margins of at least 2 cm. References must now also be presented in minimum font size 11 point. Please note that Arial narrow and Calibri are not allowable font types as they are smaller and any proposal which has used either of these font types within their submission will be rejected. Applicants referring to websites should note that referees may choose not to use them.

Applicants should ensure that their proposal conforms to all eligibility and submission rules, otherwise their proposal may be rejected without peer review. More details on NERC's submission rules can be found in the NERC research grant and fellowships handbook and in the submission rules on the NERC website.

The **lead** component of each proposal should include the documents detailed below.

i. **Case for Support,** which is comprised of four parts:

Part A – a common **Previous Track Record** (up to **3 sides of A4** in total for all Research Organisations)

The Previous Track Record should:

- provide a summary of the results and conclusions of recent work in the technological/scientific area that is covered by the research proposal, including reference to both NERC and non-NERC funded work and details of any relevant past collaborative work with other beneficiaries should also be given;
- indicate where your previous work has contributed to the UK's competitiveness or to improving the quality of life;
- outline the specific expertise available for the research at the host organisation and that of any associated organisations and beneficiaries.

Part B – a common **Description of the Proposed Research**.

This must not exceed **16 sides A4** (including all necessary tables, figures and references) and should address the following points:

- underlying rationale, scientific and technological issues to be addressed;
- relationship to programme objectives;
- relationship to other NERC research programmes;
- description of the proposed research – please describe why the work is strategically important, the key research objectives and how these will be achieved; and
- description of any proposed international collaboration.

Part C - an outline Data Management Plan (up to **1 side A4**)

Part D - a description of the Proposed Management Structure and plans, participant responsibilities, and scheduling chart (up to **2 sides A4**).

ii. A common **Justification of Resources** of up to **4 sides A4** for all Research Organisations involved, for all Directly Incurred Costs, Investigator effort, use of pool staff resources, any access to shared facilities and equipment and requests for capital costs between £10,000 and the OJEU threshold, being sought. For further information of what to include in the Justification of Resources, see section F in the NERC Grants Handbook.

iii. A **Pathways to Impact** Plan (up to **2 sides A4**), detailing:

- those who may benefit or make use of the research;
- how they might benefit and/or make use of the research;
- what will be done during and after the project to increase the likelihood of the research reaching the identified beneficiaries and maximise the likelihood of the identified benefits being achieved
- suggestions for impact activities that could be delivered at a programme level.

Any costs associated with project-level activities in the Pathways to Impact plan should be integrated into the proposal costings and be justified in the Justification of Resources section. The suggestions for programme-level activities should be accompanied by cost estimates, if appropriate, but not integrated into the proposal.

Letters of Support from named Project Partners only to confirm that support and facilities will be made available for associated collaborations and co-funding (up to **2 sides A4** each).

Each **component** proposal (including the lead) will additionally require the following attachments:

iv. A CV of up to 2 sides of A4 for each named PI, Co-I, research staff post and Visiting Researcher.

v. Application forms for access to NERC Services and Facilities, if applicable.

vi. Price quotations for equipment costing more than £25k, if applicable

vii. A Business Case of up to 2 sides A4 per item, for items of equipment above the OJEU threshold, if applicable. Further guidance regarding capital equipment costs may be found in the NERC Grants Handbook.

Where support is requested for associated studentships, this must be fully justified. All costs for the student's travel and subsistence, consumables etc. must be itemised on the grant proposal form. Further information on associated studentships is found in the NERC Grants Handbook.

8 Assessment Process

All outline proposals received which meet eligibility criteria and submission rules will be assessed by an assessment panel to shortlist those that will be invited to submit full proposals. The assessment criteria to be used for the outline proposal stage will be as follows:

- Research Excellence
- Fit to Programme Requirements

Feedback will be provided to both successful and unsuccessful outline bids.

Full proposals will be internationally peer-reviewed and final funding recommendations made by a moderating panel consisting of independent experts and members of the NERC Peer Review College where possible. Applicants will be given the opportunity to provide a written response to peer review comments prior to the moderating panel. Applicants may be invited to give a presentation at the moderating panel.

The assessment criteria to be used for the full proposal stage will be as follows:

- Research Excellence
- Fit to Programme Requirements

Associated Studentships will be assessed against the following criteria:

- Research excellence
- Training excellence
- Multidisciplinary training environments
- Excellent students

Feedback will be provided on proposals unsuccessful at the full proposal stage.

The moderating panel will make a recommendation to NERC on which projects best meet the aims of the programme. These project teams will then be invited to attend an Integration Workshop in September/October 2016, at which the proposed fieldwork activities will be discussed and a coherent field programme developed. Once an acceptable science and field programme is approved the projects will be awarded.

9 Timetable

Closing date for outline proposals: 8 December 2015
Successful outline proposals invited to proceed: January 2016
Closing date for full proposals: 17 March 2016
Decision communicated to applicants: June/July 2016
Integration workshop: September/October 2016

Applicants whose proposals have been recommended for funding will be required to attend a closed workshop with NERC to discuss programme integration. Additional funds may be available to aid in production of an effective plan.

Projects are required to commence no later than 1 February 2017.

10 Contact

For all enquiries, please contact Lisa Hole liho@nerc.ac.uk