PROFESSORS **JØRGEN BERGE, GEIR JOHNSEN** AND **ASGEIR J SØRENSEN,** AND PHD STUDENT **INGUNN NILSSEN** ON ENABLING TECHNOLOGIES FOR ARCTIC MARINE ECOSYSTEM RESEARCH

Enabling technology for Arctic research

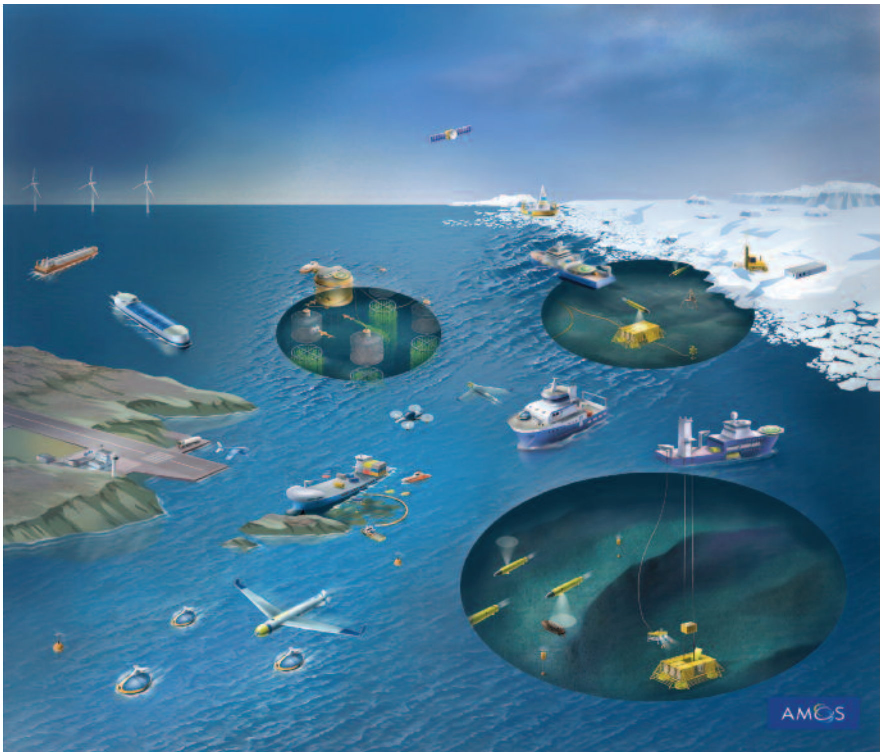
The Arctic winter and polar night are emerging as key periods during which many reproductive and other ecologically important processes occur. Recent studies have demonstrated unexpectedly high levels of activity in the pelagic zone during the polar night. These include the diel vertical migration of zooplankton (Berge *et al.* 2009) and nekton (Webster *et al.* 2013), increased understanding of the microbial community structure and function (Rokkan Iversen and Seuthe 2011), patterns of bioluminescence by different pelagic organisms (Berge *et al.* 2012, Johnsen *et al.* 2014), foraging by predators believed to rely at least in part on a visual search (Kraft *et al.* 2012), and the ability to detect extreme low light levels in certain key zooplankton species (Båtnes *et al.* 2013).

These recent discoveries, in addition to the pioneering studies by Polish and Russian researchers in the 1990s, are currently representing a dramatic shift in our understanding of the marine system. It is no longer possible to ignore the processes occurring during the polar night in order to achieve a thorough and comprehensive understanding of the Arctic marine ecosystem.

Synchronicity

By way of example, there are many types of cyclic activity in marine organisms that are highly synchronised within populations. It seems likely that marine zooplankton have a (circadian) biological clock entrained by the day/night cycle and that this clock is adaptive in initiating a migratory response even when external light cues are limited at depth. However, during the polar night, when the strongest source of illumination is no longer coming from the Sun, moonlight probably plays an important role in entraining migratory behaviour. Which species are implicated, and what the ultimate drivers are at this time, remains to be discovered.

Fig. 1 Platforms used and developed through AMOS



As shipping routes open up through the Northwest and Northeast passages and the expanding oil, gas, fishery and mineral industries become increasingly active, the risk of environmental damage in the Arctic increases. There is a growing demand for sound management, decision making and governance guidelines that rely on a thorough research-based understanding of the ecosystem, not just snapshots from the bright part of the year.

For example, we now know that many species across most phyla and trophic levels utilise the polar night for reproduction, hence increasing their potential vulnerability, particularly during this part of the year. Knowledge of the patterns and processes that characterise the entire marine habitat during the polar night is, therefore, one of the most important gaps in knowledge, preventing the informed management and sound decisions of the Arctic.

The unknown

The exploration, mapping and monitoring of unknown areas are not trivial tasks. In a research context, and particularly so when related to the Arctic Ocean during the polar night, these are often aimed at discovering or revealing hitherto unknown objects, organisms, processes and phenomena. Although there are usually one or several features or qualities that one is specifically looking for, a general understanding of an area requires the identification and corresponding mapping of basic environmental characteristics such as topography, temperature and oxygen concentration in order to get an overview of an unknown environment.

From an environmental management perspective, an understanding of the area as part of the larger ecosystem is considered important. Hence parameters to measure, choice of sensors and sensor platforms subject to operational constraints are decisions to be made and remade in an environmental mapping process. This will supply relevant data for the better accommodation of diverse and complex mission purposes with potentially multiple stakeholders representing different needs and requirements.

Complex environments

Operations in cold and distant areas with limited communication possibilities motivate research on autonomous, multifunctional, drifting observatory platforms with reliable energy supplies, adaptive functionality and optimisation of technology and modes of operation.

The ability to sample in complex environments creates a need for onboard, *in situ* and autonomous data collection, quality control and signal processing. Through the Mare Incognitum projects (www.mare-incognitum.no), we are working closely with the Centre for Autonomous Marine Operations and Systems (AMOS) at NTNU (Norway).

AMOS

AMOS is, as a ten-year research programme and a centre of excellence (2013-2022), addressing research challenges related to autonomous marine operations and systems applied in, for example, maritime transportation, oil and gas exploration and exploitation, fisheries and aquaculture, oceans science, offshore renewable energy, and marine mining.

Fundamental knowledge is created through multidisciplinary theoretical, numerical and experimental research within the knowledge fields of hydrodynamics, structural mechanics, guidance, navigation and control. AMOS is engaged in the research challenges, achievements and experiences of selected field trials related to integrated autonomous underwater operations for mapping and monitoring purposes in coastal waters in Norway and Arctic operations outside Svalbard.

Fig. 2 A combined effort involving multiple sensor-carrying platforms such as AUV under sea ice, remote sensing from a polar-orbiting satellite and a research vessel allows for a more holistic view on productivity in ice-covered waters than previously possible. Each platform is equipped with an array of sensors giving bio-geo-chemical-physical information over larger areas and depths

Cutting-edge interdisciplinary research involving technology and marine science fields such as marine biology and archaeology will provide the needed bridge to make high levels of autonomy a reality towards autonomous underwater operations.

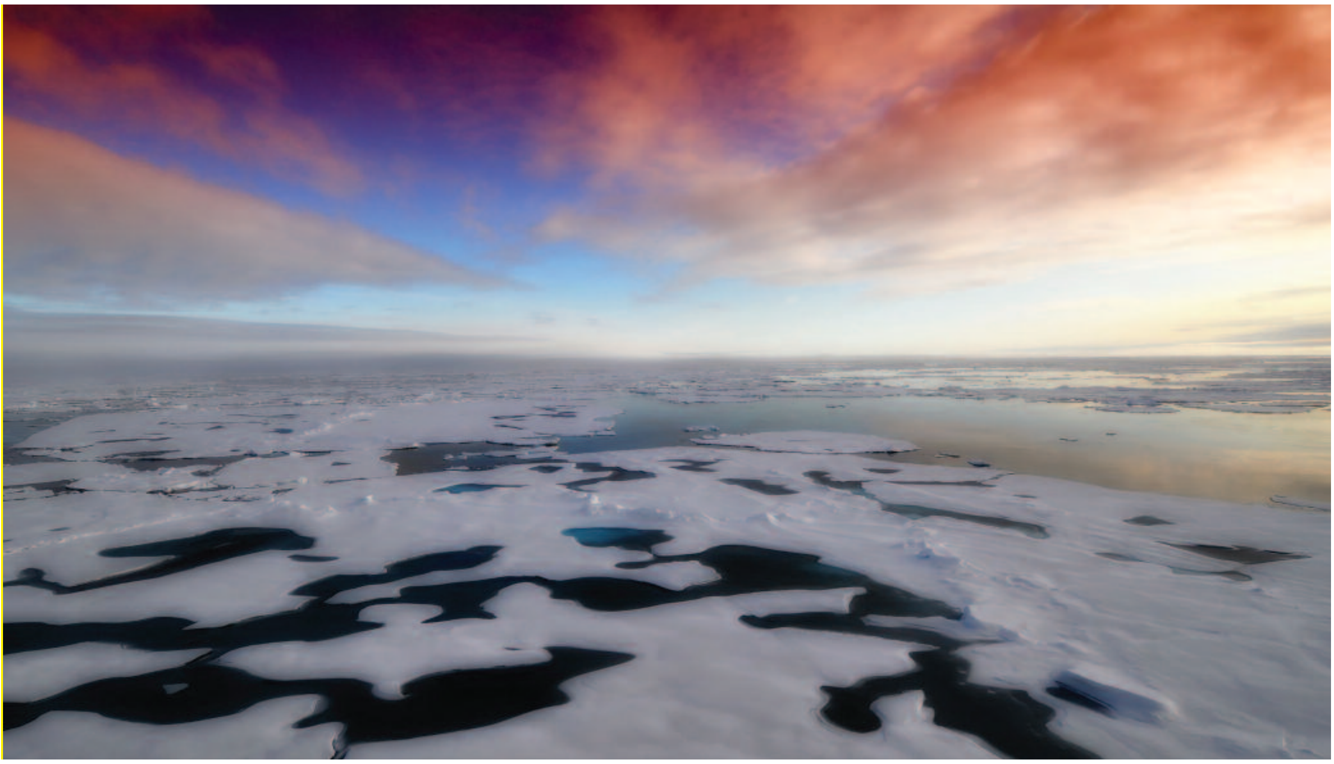
Enabling technology

Platforms included in the AMOS landscape (Fig. 1) are remotely operated vehicles (ROV), autonomous underwater vehicles (AUV), gliders, landers/moorings, floating buoys, benthic landers, autonomous sensor arrays operating in sea ice, and unmanned aerial vehicles (UAV). The work within Mare Incognitum – the umbrella for several research projects exploring the Arctic – is tightly integrated with this on-going research at AMOS and the Applied Underwater Robotics Laboratory (AUR-Lab) at NTNU.

An example on how such technological development provides new insight into ecological processes under the ice comes from a recent work, in which enabling technology allowed for sampling on broader spatial scales than previously possible. It had been suggested in the scientific literature that massive pelagic under-ice blooms occurred in the Arctic and that these were of vital importance to understanding and reliably predicting the fate of production in ice-covered waters of a warming Arctic.

Recently, however, Professor Johnsen and his colleagues have demonstrated, based upon an unprecedented campaign using an AUV under the Arctic pack ice (Fig. 2), that such pelagic under-ice blooms are most likely a result of advection of phytoplankton from open water areas, at least in the Eurasian sector of the Arctic.

Analogous studies could be designed to sample across temporal scales or extended periods in great detail to investigate, for example, the phenology of ice-algal bloom development. Autonomous measurements and observations could then guide experimental studies to test for mechanisms responsible and could provide important data for numerical models assessing ecosystem sensitivity.



Winds of change

Changes in the Arctic ocean-sea ice-atmosphere interface are leading to rapid shifts in the structure, resilience and function of Arctic ecosystems. Rapid decline in sea ice extent and thickness, increased air and ocean temperatures, increased water-column stratification, and multiple dynamic physical and chemical changes significantly alter the patterns of productivity at the base of marine food webs. Such changes are also anticipated to affect ecosystem structure and productivity higher in the food web.

Ultimately, Arctic marine ecosystem structure and productivity within the next decades may be substantially different from what we observe today. Predictions as to how Arctic marine ecosystems may change are hindered by our inability to understand the year-round response of the Arctic system.

The implementation of new enabling technologies in marine research is therefore likely to drastically increase our ability to understand the Arctic marine ecosystem as one interlinked and connected system and, moreover, will provide the essential tools needed to explore one of the least known realms of our planet – the Arctic Ocean during the polar night.

Changes in the Arctic ocean-sea ice-atmosphere interface are leading to rapid shifts in the structure, resilience and function of Arctic ecosystems

References

Berge J, Cottier F, Last K S, Varpe O, Leu E, Søreide J, Eiane K, Falk-Petersen S, Willis K, Nygard H, Vogedes D, Griffiths C, Johnsen G, Lorentzen D, Brierley A S (2009): Diel vertical migration of Arctic zooplankton during the polar night. *Biology Letters,* 5, 69-72

Berge J, Varpe O, Moline M A, Wold A, Renaud P E, Daase M, Falk-Petersen S (2012): Retention of ice-associated amphipods: possible consequences for an ice-free Arctic Ocean. *Biology Letters,* 8, 1012-1015

Berge J, *et al.*: In the dark: paradigms of Arctic ecosystems during the polar night challenged by new understanding. *Progress in Oceanography.* In press

Båtnes A, Miljeteig C, Berge J, Greenacre M, Johnsen G (2013): Quantifying the light sensitivity of *Calanus* spp. during the polar night: potential for orchestrated migrations conducted by ambient light from the sun, moon, or aurora borealis? *Polar Biology,* DOI 10.1007/s00300-013-1415-4, Electronic supplementary material doi:10.1007/s00300-013-1415-4

Johnsen G, Candeloro M, Berge J, Moline M (2014): Glowing in the dark: discriminating patterns of bioluminescence from different taxa during the Arctic polar night. *Polar Biology,* 37, 707-713

Kraft A, Berge J, Varpe Ø, Falk-Petersen S (2012): Feeding in Arctic darkness: mid-winter diet of the pelagic amphipods *Themisto abyssorum* and *T. libellula. Marine Biology,* 160(1), 241–248. doi:10.1007/s00227-012-2065-8

Rokkan Iversen K, Seuthe L (2011): Seasonal microbial processes in a high-latitude fjord (Kongsfjorden, Svalbard): I. Heterotrophic bacteria, picoplankton and nanoflagellates. *Polar Biology,* 34, 731-749

Webster C, Varpe Ø, Falk-Petersen S, Berge J, Stübner E, Brierley A (2013): Moonlit swimming: vertical distributions of macrozooplankton and nekton during the polar night. *Polar Biology,* 1-11

Professor Jørgen Berge
UiT The Arctic University of Norway

browse www.arctosresearch.net

Professor Geir Johnsen
Norwegian University of Science and Technology (NTNU)

browse www.ntnu.no

Professor Asgeir J Sørensen
Director AMOS, NTNU

browse www.ntnu.edu/amos

PhD student Ingunn Nilsen
Statoil ASA and NTNU