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.

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
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.

**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.

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.

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