DOI: 10.24425/academiaPAS.2024.151182

Where Sea Meets Land

How much can a small crustacean teach us?

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During the breeding season, adult little auks undertake numerous flights in search of the best feeding grounds and to bring food to their young. Hornsund, Spitsbergen.

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The Arctic summer is a brief but remarkable period when previously dormant nature comes to life. On land, this phenomenon is vividly illustrated by colonies of seabirds, particularly the most numerous species in the Northern Hemisphere – the little auk (*Alle alle*). These black-and-white birds are only 20 cm in size, making them one of the smallest birds in the Arctic. Beneath the water's surface, in turn, there live countless small invertebrates, especially including copepods of the genus *Calanus*. Due to their high fat content, they are a crucial food source for other animals, including fish, mammals, and seabirds. In the northern polar regions, three species dominate: *C. glacialis*, *C. finmarchicus*, and *C. hyperboreus*. They differ in their life histories and the areas where they can be found.

As the Arctic awakens, parent birds experience their busiest time, building nests and raising their young. For copepods, this is also an intense period. The dominant, older individuals accumulate large fat reserves before winter, which they will spend in diapause at greater depths. However, not all will survive until then, as fat-rich copepods are heavily harvested

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by little auks. *Calanus* constitutes the main component of the diets of both adults and young birds, making up 80–90%. This dynamic period is also a busy time for scientists, who can learn a lot from the intricate and interdependent relationships between species.

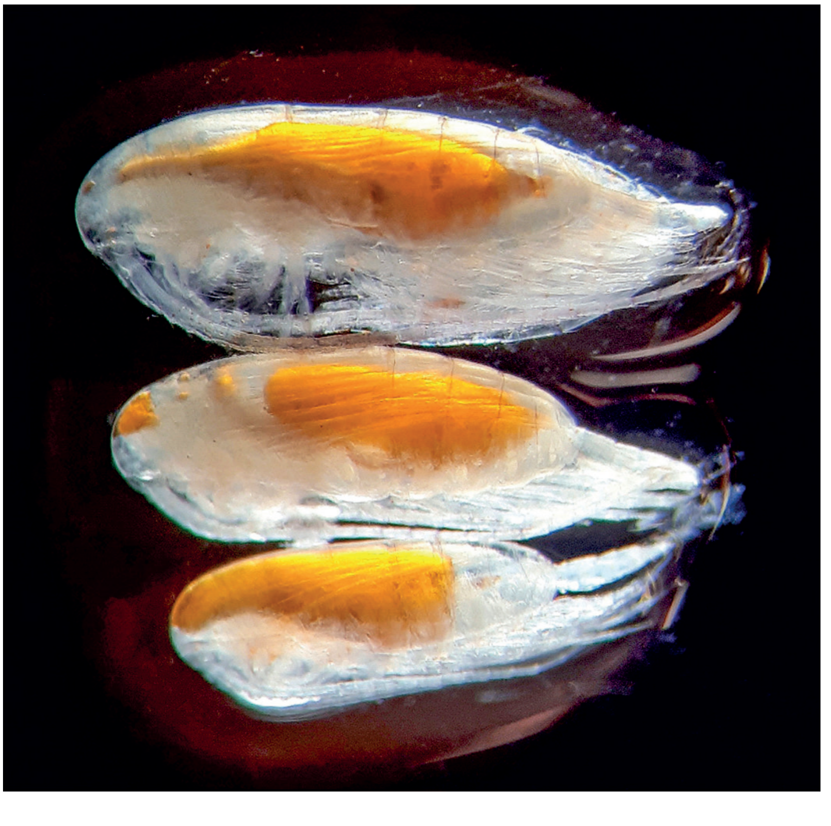
Close or far foraging trips?

Like other seabirds, little auks serve as a link connecting two ecosystems – marine and terrestrial. Due to their large numbers and bi-environmental lifestyle, they play a crucial role in transforming the terrestrial environment of the Arctic. They transport vast amounts of organic matter from the sea, enriching the nutrient-poor Arctic tundra. For this reason, they are often described as the "ecological engineers" of Arctic ecosystems.

Little auks feed their young with food collected from the sea, which they carry in a special sublingual pouch. Scientists use this unique feature to study their diet composition. The food found in these pouches is fresh and well-preserved. Samples are collected using a small spoon and then placed in plastic containers for analysis. Additionally, the studied birds are marked to avoid recapturing the same individual. After a few minutes, the little auks are released back into the wild.

The food samples, except for the proportions of the components, do not differ much from those collected directly from the sea. They mainly contain small crustaceans, including the aforementioned *Calanus* copepods. The size of the copepods consumed by the little auks is a crucial parameter in determining the quality of the food delivered to their chicks, as the size of the prey is directly related to the amount of energy they provide as part of the diet. The larger the individual, the more fat it has in its special lipid sac, which can make up to 60% of its total body volume. Through these simple measurements, we can estimate the quality of the feeding grounds where the birds forage. The research also helps determine whether the preferred large copepods are located near the colony or if the birds have to undertake long and exhausting foraging trips to feed their chicks. However, it turns out that the size of the copepods available is not the only important factor.

Calanus copepods with visible fat, colored with characteristic orange astaxanthin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Colorful diet – better vision

Recent studies have brought to light the importance of certain molecules called carotenoids in the diet of little auks. Carotenoids are the most common group of pigments found in marine environments. In chemical terms, they are divided into two classes: carotenes (such as the orange beta-carotene found in carrots) and xanthophylls (such as the red pigment astaxanthin that gives salmon and shrimp their color).

Carotenoids play a crucial role in protecting cells. Marine carotenoids exhibit strong antioxidant properties, meaning that they neutralize molecules called free radicals, which are responsible for cell aging and the occurrence of various diseases. These compounds can also provide photoprotection, inhibiting the harmful effects of UV radiation from the sun. Additionally, they enhance immunity and aid in the body's regeneration. These functions can be particularly valuable for adult little auks during the breeding season, especially while caring for their chicks, as well as for the growth and survival of their offspring. Moreover, carotenoids also significantly affect birds' vision, particularly color vision.

Animals are unable to produce carotenoids on their own. *Calanus* copepods obtain them through their diet, mainly from phytoplankton (including microscopic algae). Subsequently, these invertebrates become a vital source of these compounds for other animals higher up the food chain, including little auks. The extent to which carotenoids accumulate in these small crustaceans is evident from the fact that their carotenoid-colored aggregations are even visible in satellite images.

Research has shown that there is significant variation in the astaxanthin content of *Calanus* copepods. The amount of astaxanthin varies depending on the species' lifestyle and even the stage of their reproductive cycle. Recent studies have shown that copepods accumulate the most astaxanthin when living in their preferred optimal conditions.

The amount of this carotenoid in the birds' blood also varies depending on the location of their colony. By studying individuals nesting on Svalbard and Greenland, we found the highest levels of this compound in birds nesting near cold water masses. The diet of these birds includes a higher quantity of large, fat-rich *Calanus* individuals. This is likely the cause of the observed differences in carotenoid levels in their blood.

It is hypothesized that little auks consuming more carotenoids may find it easier to locate rich feeding grounds. We can already conclude that birds from colonies located near the most optimal water masses for copepods are in the best physical condition. The well-being of both species is therefore more closely interconnected than previously thought. Ongoing research in this area continues to shed further light on this relationship, helping us understand it even better.

KAJETAN DEJA

Samples for this research are collected in the feeding grounds of little auks aboard the research vessel "Oceania" of the Institute of Oceanology, Polish Academy of Sciences

Climate warming

The diet of little auks can help determine how the Arctic climate is changing, relying on a simple yet – as it turns out – somewhat problematic criterion. Two of the species mentioned, *Calanus glacialis* and *Calanus finmarchicus*, are morphologically very similar but have different body sizes and different living strategies. The generally larger *Calanus glacialis*, associated with cold water masses, is a typically Arctic species. Its smaller counterpart, *Calanus finmarchicus*, is its Atlantic relative. The presence of both copepod species in the diet of little auks has been considered an indicator of the "Atlantification" of the Arctic. This term refers to the increased influx of warm and saline Atlantic waters into the Arctic region, a phenomenon resulting from global climate change. Accurate identification of copepods in the diet of little auks is therefore crucial for understanding the large-scale processes currently occurring in polar regions.

Until recently, the body length of copepods was used as the main criterion for distinguishing between the two closely related *Calanus* species, and thereby as an indicator of their Atlantification. Recent studies have verified this classification using molecular methods. The research was based on the analysis of two types of samples. The first were collected from bird feeding grounds using special nets (known as plankton nets). The second were food samples. The analyses unexpectedly showed that the traditional method of identifying *Calanus* was fraught with considerable error. As many as 40% of the *Calanus* individuals examined, both in the feeding grounds and in the birds' diet, turned out to be not *C. finmarchicus*, as the older measurement method assumed, but smaller individuals of the once typically larger Arctic *C. glacialis*.

It is hypothesized, therefore, that observations previously treated as signs of Atlantification may actually result primarily from a reduction in the body size of copepods, particularly the cold-water *C. glacialis*. Furthermore, regardless of colony location, even in areas highly exposed to Atlantification, little auks were found to feed almost exclusively on the cold-water species. This indicates a higher selectivity in these birds' dietary preferences than previously assumed. The study results confirm the need to incorporate molecular methods into future research on climate change in the Arctic and to verify existing findings.

Research on Atlantification shows how polar organisms cope with the dynamic changes occurring in their environment. It helps answer whether they are flexible enough to adapt to these changes or not. Atlantification poses a particular threat to typically endemic species, those strongly linked to the Arctic environment. These include the little auk and *Calanus glacialis*. There have been observations of dwindling little auk colonies in regions most affected by Atlantification. The birds are forced to fly longer distances in search of valuable food. Often they do not return to their previous nesting sites and their chicks are in weaker condition. Although the population of little auks in the Arctic is still very high, the forecasts are not optimistic. Warmer water masses are bringing in more species better adapted to environmental changes, but of no value to birds that nevertheless turn out to prefer their traditional prey, the cold-water copepod species.

This research is conducted as part of the Orange project, funded by the National Science Centre of Poland (2021/41/B/NZ8/03830).

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