diagrams[2,5,9]. This approach can be used to measure the amplitudes of magnetic fields at the radius where the red giant burns hydrogen. For the three stars examined by Li and colleagues, these amplitudes were 102 kG, 98 kG and up to 41 kG, all of which are consistent with our understanding of how magnetic fields were generated inside the cores of these stars[5,10]. These findings strengthen support for theoretical studies proposing a scenario for how magnetic fields inside some stars relax after the star stops burning hydrogen in the core[11].

The discovery has opened the way for an extensive search for magnetism inside red giant stars[12], which it is hoped will lead to an understanding of the slow rotation rates observed in these evolved stars. A study reported earlier this year also detected magnetic fields near the core of a younger and more massive star than those analysed by Li and colleagues[13]. Both of these observational studies, together with theoretical developments in the past few years[7,14–16], demonstrate the promising future of asteroseismology for probing the magnetism of stars of all masses and ages.

Future studies might explore the spatial structure of magnetic fields inside red giants, because it is possible to constrain the topology of the field from oscillation-frequency spectra[7]. Such investigations would provide extremely valuable constraints on estimations of the transport of angular momentum inside evolved stars. This could then spark a large collaborative effort to develop stellar-evolution models that incorporate the effect of magnetic fields, based on observations, to provide better estimates of stellar ages in the Universe.

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Marine biogeochemistry

# Seasonal peak in Arctic Ocean acidity could shift

**Victoria Qutuuq Buschman & Claudine Hauri**

The acidity of the Arctic Ocean currently peaks in winter. A modelling study suggests that this peak could shift to the summer in the future — this is bad news for ecosystem functions, food webs and Indigenous communities. **See p.94**

The global ocean is gradually acidifying on multidecadal timescales. This acidification occurs when carbon dioxide generated by human activities is absorbed by the ocean, and produces conditions in which many marine organisms cannot thrive. On page 94, Orr *et al.*[1] present global simulations suggesting that future warming in the Arctic Ocean will cause $CO_2$ levels to peak seasonally in surface waters in the summer, implying that climate change will further accelerate ocean acidification. The resulting increase in acidification would double down on the already heat-stressed ecosystem, with effects that could creep up the food web — further challenging the food security, culture and well-being of Indigenous peoples in the Arctic.

Ocean acidification varies depending on local environmental conditions and processes. For example, acidification of Arctic waters is enhanced by the freshwater input from melting sea ice, precipitation and rivers[2]. The partial pressure of $CO_2$ ($p_{CO_2}$, which quantifies the pressure generated by $CO_2$ dissolved in seawater, but which can be used as a broad measure of how much $CO_2$ is dissolved) also varies naturally across days, seasons, years and even decades because it depends on a mixture of biological and physical processes.

For instance, when phytoplankton photosynthesize, these microscopic algae use light and $CO_2$ from their surroundings to produce organic matter and grow, thereby substantially decreasing $p_{CO_2}$ in the surrounding waters. By contrast, high temperatures can have the opposite effect: dissolved molecules of $CO_2$ gain kinetic energy as the temperature rises, and interact less with surrounding water molecules than they do at cooler temperatures. The $CO_2$ molecules therefore become less soluble in seawater, and have a greater tendency to escape to the atmosphere (higher partial pressure). This is known as the thermal effect.

Historically, the effect of biological processes on summer $CO_2$ levels in the Arctic Ocean have dominated over the thermal effect — $p_{CO_2}$ declines because phytoplankton blooms, even though Arctic waters warm in summer. By contrast, Orr and colleagues now suggest that future rapid summer warming of Arctic surface waters, attributable to early sea-ice retreat, will enhance the thermal effect on $p_{CO_2}$ and eventually outweigh the biological effect.

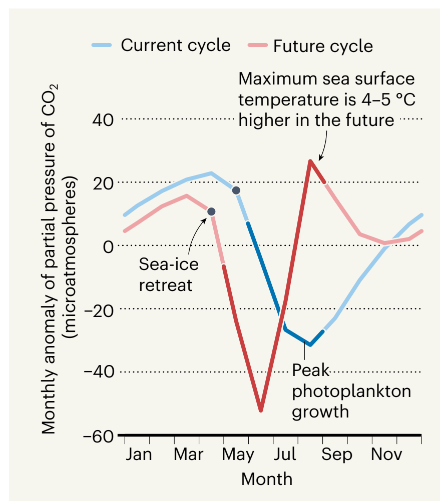


**Figure 1 | Simulations of seasonal variation in acidity in the Arctic Ocean.** Orr *et al.*[1] assessed the seasonal cycle of the partial pressure of $CO_2$ ($p_{CO_2}$, which correlates with seawater acidity) in the Arctic Ocean, using simulations from a set of Earth-system models. The simulated data are plotted as the monthly anomaly — the difference between average monthly $p_{CO_2}$ and the annual average, measured in microatmospheres. Currently, $p_{CO_2}$ peaks around April, but declines when sea ice melts, reaching a minimum in the summer months when marine phytoplankton consume dissolved $CO_2$ to grow; darker lines indicate periods of peak growth. Future global warming (simulated data are for 2091 to 2100) causes early melting of sea ice and blooming of phytoplankton, resulting in an earlier seasonal minimum of $p_{CO_2}$. However, $p_{CO_2}$ then reaches a maximum in the summer months, as a consequence of the high summer ocean temperatures. The combination of high temperatures and high acidity in the summer could be devastating for marine ecosystems.

As a result, $p_{CO_2}$ is projected to reach its annual minimum earlier than in the past (in June, rather than in July and August), and reach its annual maximum in summer, rather than in winter (Fig. 1). The transition from a winter to a summer $CO_2$ maximum is especially pronounced in shelf seas (those that submerge a portion of a continent), which are crucial harvesting areas for Arctic Indigenous communities.

The occurrence of extreme ocean acidification events associated with high $p_{CO_2}$ during the summer could have big implications for the Arctic ecosystem. Unfortunately, few studies have explored the impacts of large increases in ocean acidification on key Arctic marine species. Fewer still have looked at how combinations of ocean acidification with other stressors, such as high temperatures and changing food availability, will affect species survival[3].

Benthic species (animals that live on the sea floor) that use carbonate ions to build shells and skeletons are expected to struggle as seawater acidifies[4]. Increased acidity might also impair other biological functions — for example, the growth of certain bivalves[5] and the swimming behaviour of polar cod (*Boreogadus saida*)[6]. Such impairments can alter determinants of species' health, such as feeding behaviour, reproductive success and habitat choices. There could also be indirect effects of ocean acidification, arising, for instance, from the competition between species[7]. These direct and indirect effects at different levels of the food web can cause further ripple effects that alter predator–prey relationships and the food web more broadly.

Changes to ecosystem function and food webs would also challenge the food security of Indigenous peoples, with implications for their culture, well-being and economy. (This issue is of particular concern to both of us, because we live and work full time on Indigenous lands, and V.Q.B. is Iñupiaq (Inuit), from Utqiaġvik, Alaska). Many of the marine species that are expected to be adversely affected directly by the combination of increasing summer temperatures and ocean acidification, and indirectly by changes to the food web, are also crucial to Indigenous communities for subsistence hunting, fishing and harvesting.

For example, both subsistence and large-scale fisheries of snow crab (*Chionoecetes* species), prawn and polar cod could be challenged by changes in environmental processes and food-web dynamics. Animals that prey on shell-building creatures might also have to change their feeding habits as food sources diminish, are replaced by new species, or move elsewhere. And even species such as the beluga whale (*Delphinapterus leucas*), narwhal (*Monodon monoceros*) and walrus (*Odobenus rosmarus*) that have varied diets (consisting of benthic species and a variety of fish species[8–10]) could be affected by changes cascading through the Arctic food web. Arctic hunters and fishers already have to deal with the complications of a warming climate, including temporal mismatches in species migration and life-cycle stages, finding ways to procure and prepare foods for safe consumption, and northward shifts in many marine mammals' preferred habitat.

Orr and colleagues' study provides a troubling glimpse of how near-term climate warming and acidification could change the chemical environment at the surface of the Arctic Ocean, but falls short of diving deeper. No organism lives only in the ocean's surface layer, and warming could be much more pronounced in subsurface layers[11]. Future research needs to focus on ocean regions, such as Arctic shelf areas, that are directly relevant to the marine species that Indigenous communities depend on, and on determining the different acidity levels that produce biological effects in these species. A careful consideration of environmental processes and ecosystem functions, as well as the anticipated impacts of ocean acidification on biological, social and cultural dynamics (for example, to determine the effects of ecological disturbance on Indigenous ways of life and food security) will help Arctic communities to plan for consequential change, emerging vulnerabilities and increased risks.

But let's end on a hopeful note. Orr and colleagues' study shows that the reported seasonal changes are unlikely if efforts to mitigate climate change prevent the global temperature from rising by more than 2 °C above pre-industrial values — all the more reason for the world to redouble its commitment to these efforts.

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Scientific community

# Narrow hiring practices at US universities

## Cassidy R. Sugimoto

An analysis of faculty members employed at academic institutions in the United States reveals that most employees were trained at just a few universities. The finding provides insights into how hiring perpetuates inequalities. **See p.120**

For those hoping to land a coveted academic faculty position in the United States, a doctoral degree from one of just a few institutions can make a big difference. Wapman *et al.*[1] demonstrate on page 120 exactly how important this pedigree is. They examined tenured and tenure-track faculty members who were employed at US PhD-granting institutions between 2011 and 2020, and find that 80% of US-educated faculty members received their doctoral degrees from just 20% of universities. The authors' data set provides sobering insights into how hiring practices perpetuate inequalities throughout academia.

Wapman and colleagues' data — which they obtained from a faculty census compiled by the Academic Analytics Research Center — encompass 295,089 faculty members in 10,612 departments across 368 institutions. The authors categorized these departments into 107 fields and 8 broader domains, to facilitate comparisons between different areas of research spanning all disciplines. The data contain information about each scholar's gender,