News & views

Ecology

A whale of an appetite

Victor Smetacek

Reaching a deeper understanding of the ocean ecosystems that maintain whales might aid conservation efforts. Measurements of the animals' krill intake indicate that previous figures were substantial underestimates. **See p.85**

Baleen whales are the largest known animals that have ever lived. They feed on centimetre-sized prey by filtering seawater through plates of frayed, bristle-like combs, termed baleen, that are fixed to their upper jaws. Previous estimates of the food requirements of whale populations indicate the animals' enormous food demand[1]. In the Southern Ocean near Antarctica, before the whaling era, the krill biomass consumed by whales alone is estimated to have been 190 million tonnes annually[1], an amount substantially greater than the entire annual world fish catch in modern times[2]. Intense fishing by humans has decimated ocean fish stocks in a few decades. By contrast, whale feeding seems to be sustainable, as evidenced by hallmarks of the animals' evolution, such as their long lifespan and high degree of specialization geared to the consumption of just one prey – krill.

On page 85, Savoca *et al.*[3] report their analysis of feeding by baleen whales. They found that all seven species studied consume up to three times more prey biomass than expected from previous estimates. The authors also address the issue of the extra food required to support this revised prey tally. How could natural selection reward such gluttony in whales?

The authors present a comprehensive data set of observations from three oceans. They tracked the movement of whales tagged with sensors, and, using an acoustic method, monitored the animals' densely concentrated prey. This allowed the authors to record the whales' feeding behaviour and prey-consumption rates.

Savoca and colleagues investigated two categories of baleen whale that had different feeding modes. Blue, fin and humpback whales feed by lunging at dense swarms of krill (species of shrimp-like crustaceans in a grouping called euphausiids). Blue whales feed exclusively on euphausiids, whereas fin and humpback whales also target small, swarming fish. Right whales and bowhead whales feed continuously (in an approach called ram feeding) while swimming open-mouthed through dense aggregations of copepods (mosquito-sized crustaceans) that dominate the biomass of zooplankton worldwide, but that swarm only in certain regions.

Previous research[4,5], using data from tagged whales to inform hydrodynamic models, found that the animals expended more energy than expected in processing the immense volumes of water that pass through their dense meshes of bristles, to retain organisms only several centimetres (krill and small fish) or up to 20 millimetres (copepods) in length. Lunge feeding has extra costs. A whale charging a krill swarm directs all the energy of its powerful muscles into acceleration and into opening its gigantic mouth to engulf huge volumes of water, together with the portion of the swarm that does not manage to escape (Fig. 1). The bigger the gulp, the more prey are trapped in the mouth – but, also, the more energy is invested in the act of feeding.

Whales need that extra food reported by Savoca *et al.* to thrive, raising a fundamental ecological question. Did they build their enormous biomass on what was offered by the ecosystem, thereby hogging resources in the food chain – greedy gluttons out to get big? Or did they use that extra energy gained from feeding to condition their environment to increase food supply – acting as gigantic, hard-working ecosystem engineers?

Savoca *et al.* address the issue of the krill food supply for whales by focusing on the Southern Ocean. Records indicate that, during the whaling era, about one million whales were killed there. From calculations based on the new findings, before their deaths, these animals would have consumed approximately 400 million tonnes of krill annually, of which at least 50% would have been eaten in former whaling grounds in the southwestern Atlantic Ocean. The authors argue that, because the biological productivity of that ocean region is controlled by the iron supply, by eating iron-rich krill and discharging iron-rich faecal plumes in the surface layer, whales were substantially enhancing phytoplankton growth (Fig. 1), and

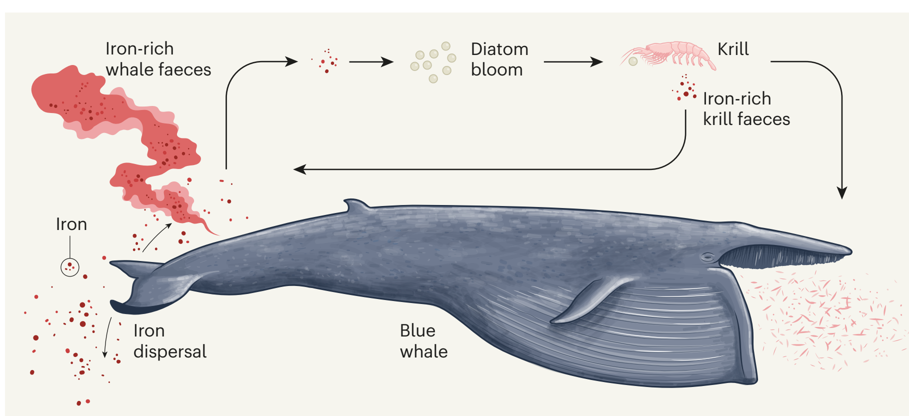

Figure 1 | A whale-driven iron cycle in the oceans. Savoca *et al.*[3] present data revealing that whales eat up to three times more prey than was previously thought. A system of iron cycling aided by whale activity might help to make such a high level of feeding sustainable, and could explain why krill stocks fell when whale numbers declined as a result of whaling. Iron availability limits productivity in ocean waters, and when whales eat iron-rich prey such as krill, they convert prey protein into blubber and aid iron cycling by defecating the iron-rich prey remains. Whale faeces might provide a source of iron for phytoplankton such as diatoms and drive diatom blooms. Diatoms, in turn, can move iron along the food chain when they are eaten by krill, which also excrete iron in their faeces. Whales can also aid iron availability by mixing ocean waters through their vigorous tail movements.

thus boosting the availability of food for krill[6,7].

Iron is almost insoluble in seawater, and the bulk of this crucial element in productive ecosystems exists in living biomass. Krill are exceptionally versatile animals, and can channel their astoundingly diverse food sources — phytoplankton such as diatoms, sea-ice algae, fluff settled on sediments, copepods and other zooplankton — into their biomass. This enables krill populations to act as a gigantic, mobile iron reservoir. Observers during the pre-whaling era described the sea surface as being coloured red by swarming krill, and reported that water spouts of feeding whales stretched from horizon to horizon[7].

Making the reasonable assumption that the former krill stock was three times the size of the whales' annual krill consumption, I estimate that such stock, spread out evenly over the whaling grounds (an area of approximately two million square kilometres), corresponds to 300 krill per square metre, which would be enough to colour the surface of the water red. That biomass of krill would hold enough iron, if released through biological recycling, to fuel a massive bloom of diatoms in the water column below. In reality, roving krill swarms would probably have been concentrated in offshore regions that favoured the accumulation of diatom blooms, which the whales would have fertilized with the iron from their faecal plumes.

Left undisturbed, diatom blooms form snow-like aggregates that sink to the deep sea three to four weeks after an initial iron fertilization, taking the iron with them[8]. A roving krill swarm once grazed down a diatom bloom that my colleagues and I were studying, leaving behind clouds of loose, slowly sinking faecal threads full of undigested food and living cells[9]. If a feeding whale had pursued this swarm, the turbulence associated with the animal's energetic swimming, lunges and filtration would have dispersed the threads and mixed their contents into the water column, rather like the way in which manure is ploughed into a field. The energy invested in such actions would have a larger return for the whale in the form of blubber amassed from subsequent feeding. This must have been an optimized, sustainable recycling ecosystem, which operated at high levels of biomass in the past — the more the merrier.

Krill started declining after the decimation of the whales, with the last large-scale surface swarms having been recorded in the early 1980s[10]. Removal of a predator is often accompanied by a rise in prey numbers, and this surprising decline in krill is consistent with a model in which whale-aided iron cycling supported the growth of krill populations. Krill biomass is now a fraction of what it once was, and the hugely productive ocean pastures dominated by diatoms, described in the 1930s[11,12], have since reverted to the classic iron-limited, high-nutrient, low-chlorophyll, microbially dominated state that is now characteristic of large areas of the ocean's surface. This degraded ecosystem dominates the former whaling grounds, presumably because the hard-working whales are almost completely absent.

A 2020 survey that found 55 blue whales in former whale-feeding grounds made the news as a sign of hope (see go.nature.com/3bffqla). However, the fact that it was newsworthy is alarming. How can a handful of whales, subsisting on the meagre food offered by the vagaries of nature in a degraded ecosystem, ever restore one of the previously hottest hotspots of animal biomass on the globe[13] if not helped by humans? We have in our power the means to mimic the iron fertilization mediated by whales to create diatom blooms, to feed the krill and thereby to feed the whales. This might restore the former pastures of plenty whose evolution the whales worked so hard to shape. The open-ocean experiments necessary to test this hypothesis[6] are waiting to be carried out.

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Coronavirus

An algorithm to target COVID testing of travellers

Ziad Obermeyer

Optimizing the testing of incoming travellers for COVID-19 involves predicting those who are most likely to test positive. A machine-learning algorithm for targeted testing has been implemented at the Greek border. **See p.108**

It seems an obvious combination: machine learning and the fight against COVID-19. And yet, despite intense interest and increasing availability of large data sets, success stories of such combinations are few and far between. On page 108, Bastani *et al.*[1] describe a system that they designed and deployed at points of entry into Greece, starting in August 2020. The algorithm, which is built on a method called reinforcement learning, markedly increased the efficiency of testing for the coronavirus SARS-CoV-2, and contributed to Greece's ability to keep its borders open safely. The work also provides a clear warning about the shortcomings of the comparatively blunt policy tools that most other countries continue to use.

Testing is a problem that machine learning is well suited to solve. Imagine a border-control agent on a Greek island. A flight has just landed, and the agent's task is to identify and detain anyone who has COVID-19. The agent might want to test all arriving passengers, but the testing capacity on the island is very limited and, more generally, it is never possible to test 100% of any population 100% of the time. The alternative — shutting down the border completely, in an economy highly dependent on tourism — has its own perils. These would include not only a huge financial cost associated with the loss of jobs and income, but also the negative effects of such losses on public health[2]. So the border agent faces a difficult decision: who should be tested?

As has been noted[3], the value of a test depends on its eventual outcome. In this scenario, a negative test generates only costs: the cost of testing and a delay for the traveller. By contrast, a positive test generates tremendous benefit: prevention of all the cases of COVID-19 that a traveller infected with SARS-CoV-2 would have caused. So, in deciding who to test, the border agent's optimal strategy is clear: predict which travellers have the highest likelihood of testing positive, and test them. This strategy maximizes the value of testing, because it detects the most travellers with COVID-19 using the lowest number of tests.