are important and conspicuous (because they come back to land to breed in big colonies) sentinels of the health of the marine environment.

What is the conservation status of seabirds? Not good. They are among the most threatened of all birds — based on the International Union for Conservation of Nature's Red List, 17 (5%) seabird species are critically endangered, 97 (28%) are globally threatened and 34 (10%) are near threatened, with a further five species extinct or probably extinct. Moreover, monitored seabird populations declined by 70% between 1950 and 2010. Pelagic seabirds are the most threatened, especially albatrosses/petrels and penguins.

What are the main threats to seabirds? Seabirds are under threat from invasive species, fisheries, climate change, pollution and offshore development. Ground and burrow-nesters have little defence against invasive predators such as snakes, rats, cats and pigs, which eat eggs, chicks and adult seabirds. Even rabbits and mice can be problematic — Tristan albatross (*Diomedea dabbenena*) chicks are being eaten alive by mice on Gough Island and rabbits can damage burrowing habitat. Fisheries can have profoundly negative impacts on seabirds either via bycatch (the accidental capture of non-target species) or because they compete with seabirds for food. Longline fisheries alone may kill ~160,000 seabirds each year. Industrial fisheries target shoaling fish such as sardines and anchovies that are important food for many marine predators, including seabirds, and over-fishing can deplete stocks to levels that negatively affect breeding success and survival.

Climate change may also change the spatial and temporal abundance of seabird prey, making it more difficult or costly to locate. Direct effects of climate change, such as changing sea ice, increased winter storm intensity and warming air are already impacting seabirds. Pollution in the form of oil, plastics and heavy metals have had negative impacts on seabird populations, although we still understand poorly the population-level consequences of these stressors. Offshore development in the form of extraction and renewable energy developments may also pose a threat to seabirds, although renewable energy may also have benefits by creating *de facto* marine protected areas.

That's a bit depressing, is there any hope for seabirds? Yes — seabird conservation is littered with success stories. The removal of invasive species from islands is achievable and can lead to recovery or re-colonization in a relatively short time. There are also extremely effective methods for reducing fisheries bycatch; these have been met with positive attitudes from fishers the world over, although the problem still persists. Marine protected areas may also have positive benefits for seabirds. This approach works well where fisheries closures can help retain sufficient forage fish for birds, but may also work over much larger scales by protecting important oceanographic features that create hotspots of seabird diversity.

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Quick guide

Hydrothermal vents

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What are hydrothermal vents? Hydrothermal vents are oases of life in the deep sea. They form where hot water and gases from below the seafloor mix with water and gases from the overlying ocean. Typically, hydrothermal vents are found on the seafloor along mid-ocean ridges, where magma from the mantle comes into close contact with oceanic crust due to the plate tectonics of seafloor spreading. However, hydrothermal vents were only discovered 40 years ago, and less than 1% of the seafloor has been explored, so their global distribution is still very much unknown. The chimneys venting hot water on the seafloor are only the most extreme manifestation of hydrothermal flow. Much of the oceanic crust hosts more diffuse and more expansive hydrothermal circulation that is not easily detected at the seafloor but can potentially harbor a large proportion of the total biomass on Earth.

How is life supported at vents? Although some hydrothermal vents can release water that is far too hot for life, every hydrothermal system features a thermal gradient that spans very hot hydrothermal fluids to cold seawater. These gradients provide habitats for diverse psychrophilic, mesophilic, thermophilic, and hyperthermophilic organisms. More importantly, the water exhaled from hydrothermal vents often contains elevated levels of hydrogen sulfide, hydrogen gas and other reduced chemical compounds that are excellent energy sources for bacteria and archaea. These microorganisms are the primary producers of hydrothermal vent ecosystems and are known as chemoautotrophs, analogous to the photoautotrophs that serve as primary producers in sunlight-powered ecosystems (cyanobacteria, algae and green plants). Chemoautotrophs convert chemical energy from the Earth's subsurface into biomass and organic molecules. Some hydrothermal ecosystems may persist entirely independent of the sun, although proving complete independence from photosynthesis in today's oxygenated ocean would be difficult. The primary products are used by other members of the ecosystem. Hydrothermal vent ecosystems can show extremely high biodiversity and feature dense concentrations of biomass (Figure 1), featuring many trophic levels and very large animals, all directly or indirectly powered by chemoautotrophy.

Many vent-associated animals, including annelids, polychaetes, mussels, clams and shrimp, obtain some or all of their food from endosymbiotic or ectosymbiotic chemoautotrophic bacteria. Annelid tube worms, which can grow over six feet long, have neither mouth nor anus and transport hydrogen sulfide with specialized hemoglobin in their blood to an internal stomach-like organ containing a community of chemoautotrophic bacteria. The worms are entirely dependent on their internal bacteria not only for food, but also for the synthesis of essential biomolecules such as nucleotides. Because their food is ultimately derived from chemicals venting from the hydrothermal chimneys, animals with chemoautotrophic symbionts are usually tolerant of high temperatures so that they can live as close as possible to the hot chimneys (Figure 1). The polychaete worm *Alvinella* can tolerate temperatures up to 80°C at its rear end while its head remains at 20°C, creating an extreme thermal gradient within a single organism. Some shrimp species cultivate a beard of chemoautotrophic bacteria on their mouthparts, which they incubate in warm, sulfide-rich hydrothermal fluids and then consume (Figure 1). The larvae of vent invertebrates disperse among fields of hydrothermal chimneys via ocean currents even though suitable habitats can be isolated from each other by hundreds or thousands of kilometers along the seafloor. Some larvae may even transit all the way to the ocean surface before returning to the seafloor as adults. Nevertheless, the limitations of deep-sea dispersal are evident in the strong biogeographic patterns of vent species. For example, *Rimicaris* shrimp are only found in the Atlantic and Indian Oceans, and *Riftia* giant tube worms are only found in the Pacific Ocean.

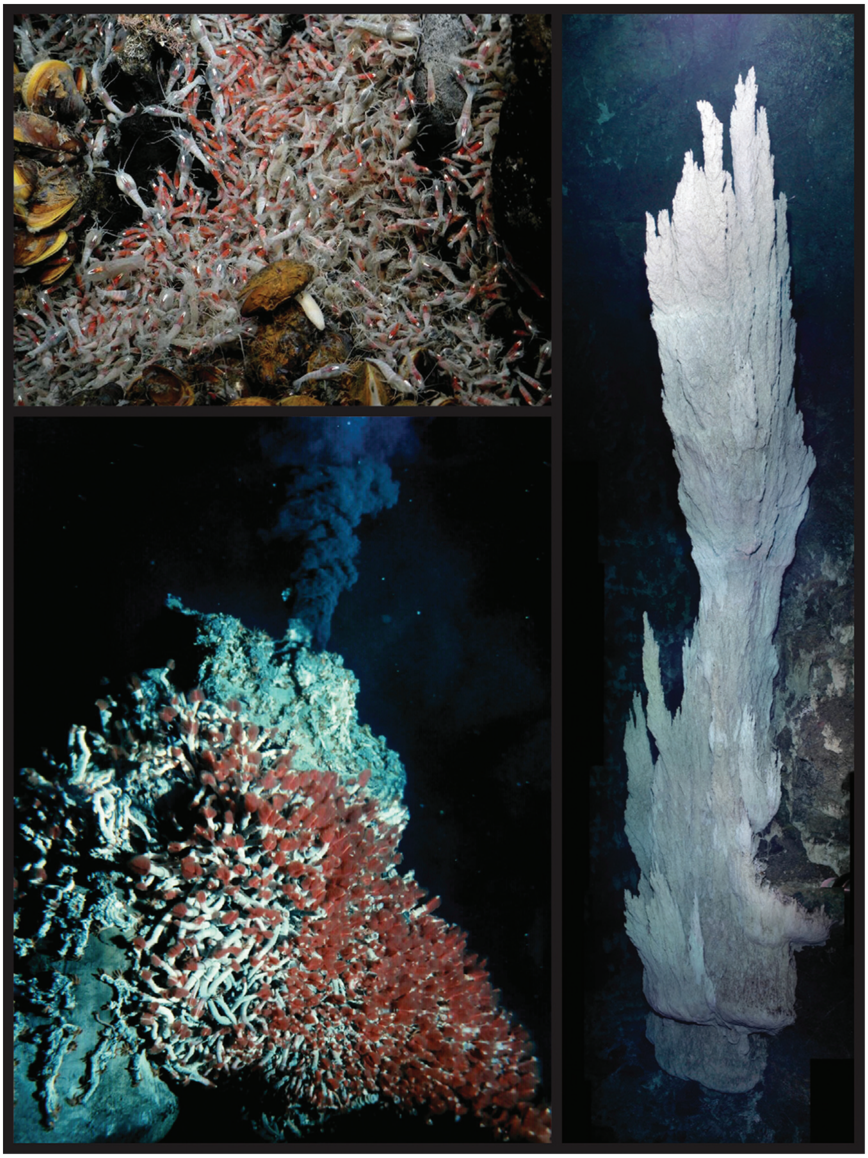

Figure 1. Hydrothermal vents.
Deep-sea hydrothermal vents support rich ecosystems that can include dense accumulations of animals such as shrimp (upper left) and tube worms (lower left). The carbonate chimneys of the Lost City (right) can reach 60 meters tall and vent fluid at much lower temperature than typical 'black smoker' chimneys (lower left). Photos: upper left: © Ifremer/Serpentine 2007; lower left and right: University of Washington.

What is the 'Lost City'? The chemistry of a hydrothermal system is determined by its host rock. The 'typical' mid-ocean ridge hydrothermal chimney is formed on basalt rock, vents highly acidic water and is composed of black metal sulfides. In contrast, there is an unusual type of hydrothermal system hosted on serpentinite rock that forms highly alkaline, metal-poor chimneys composed of white calcium carbonate minerals. These serpentinite-hosted systems are created by a set of aqueous geochemical reactions collectively known as serpentinization, which occur when mantle rocks are exposed to seawater, resulting in the oxidation and hydration of iron-rich minerals. Serpentinization reactions can release huge quantities of hydrogen gas and methane, both of which are excellent energy sources for chemoautotrophs. The most famous example of a serpentinization-driven system is the Lost City hydrothermal field on the Mid-Atlantic Ridge, serendipitously discovered in 2000, which features ghostly white carbonate chimneys up to 60 m tall that are permeated by thick, snotty biofilms of bacteria and archaea (Figure 1). The metabolic strategies of organisms living in hot, highly alkaline (pH 10–11) water rich in hydrogen and methane are currently being studied. Water venting from Lost City chimneys never exceeds ~100ºC, meaning that life is permitted throughout the hydrothermal system. Animals at the Lost City are very small but biologically diverse, and one mussel species observed on the chimneys hosts two distinct kinds of endosymbiotic bacteria, one powered by hydrogen or hydrogen sulfide and the other by methane.

Did life originate in hydrothermal vents? Many different lines of evidence point to a role for hydrothermal vents in the early evolution of life. Deep-sea hydrothermal vents would have provided a constant habitat sheltered from catastrophic events that most likely rendered Earth's surface inhospitable at various points in its early history. Therefore, even if life originated on the surface, deep-sea vents would have been a crucial refuge in times of heavy asteroid bombardment or other surface crises. Furthermore, many elements required for life, such as metal co-factors of essential enzymes, are only found in large concentrations near hydrothermal vents. Hydrothermal minerals are capable of catalyzing, in the absence of enzymes, at least some steps of carbon-fixation pathways. Experimental simulations of hydrothermal chimneys have demonstrated polymerization of DNA molecules. Moreover, the thermal gradients of ~50–100ºC across the highly porous Lost City chimneys, in particular, would have provided favorable conditions for many simultaneous chemical reactions in separate micro-chambers, which could have led to the synthesis of the first organic molecules on Earth. The inorganic compartments of hydrothermal chimneys have also been proposed as the scaffolding on which the first cell membranes could have been formed. Therefore, even if one is unconvinced that life could have arisen de novo in a hydrothermal chimney, these environments must have played important roles in the early evolution of biochemistry thanks to the rich diversity of chemical reactions and physical compartments that they host.

What have hydrothermal vents taught us about possible extraterrestrial life? They have shown that the availability of sunlight may not be the most important factor when searching for life on other planets. Instead, the most important requirement for life may be a geologically active planet, manifested in the form of plate tectonics and magmatic activity that can support hydrothermal circulation. The recent discovery of the Lost City hydrothermal field raises the question of whether serpentinization reactions could even support the origin and evolution of life without any additional geological activity. If so, then life may require only some liquid water and the right kind of rock. Interestingly, rocks capable of serpentinization are found on most, if not all, rocky bodies in our solar system. This possibility notwithstanding, our present understanding of hydrothermal vent ecosystems inspires a view of life's origin as an emergence from global geological and geochemical processes, rather than as an accident caused by a fortuitous spark in an isolated pond. Mars, Europa (moon of Jupiter) and Enceladus (moon of Saturn) are currently being explored as places where hydrothermal systems could have been active in the past and perhaps remain active today.

Where can I find out more?

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Quick guide

Cryptobenthic reef fishes

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What are cryptobenthic reef fishes? On reefs around the world, fishes display a remarkable abundance and diversity of shapes and colours. However, perhaps even more remarkable is that most casual observers on reefs probably do not see half of the fishes that live there. This 'hidden half' of the fish community is comprised of cryptobenthic reef fishes — adult fishes typically less than 5 cm long that are visually or behaviourally cryptic, and live near to or even within the seabed (Figure 1). Cryptobenthic reef fish communities can be comprised of many species and families, but perhaps the most common and widespread members are the gobies (family Gobiidae) and the blenny-like fishes (suborder Blennioidei). While small camouflaged fishes may not sound particularly exciting at first, cryptobenthic reef fishes display extraordinary diversity and are of critical ecological importance on reefs worldwide.

What do cryptobenthic reef fishes do? In short, cryptobenthic reef fishes live fast and die young. For most of them, growth, reproduction and death happen at extraordinary rates. After settlement on the reef, often in a very specific microhabitat, adult fishes spend most of their time feasting on microscopic prey, such as small invertebrates (e.g. copepods), filamentous algae, coral mucus or detritus. Most of the energy gained from feeding is used for growth, which lets cryptobenthic reef fishes grow rapidly throughout their lives. The remaining time and energy is spent largely on a surprising variety of different social and reproductive strategies, including sex changes, territoriality, and both monogamous and polygamous reproduction. Some species, like the dwarf goby *Eviota sigillata*, can produce 7.4 generations per year, which results in a steady stream of new recruits of cryptobenthic fishes to the reef. After a few weeks, it's all over. In fact, with a maximum age of just 59 days in the wild,