Cappelen Damm Agency *Autumn 2024*

Join us in the depths and get an insight into the wonderful life teeming below the surface of the sea, as well as the changes that are slowly happening there.

In *Rising Tides*, Even Moland conveys the most up-to-date knowledge about our seas and oceans. What role do the world's oceans play for life on this planet? How are the radical changes taking place in the ocean linked to the way we have exploited its resources? What are the most important threats to a healthy, abundant and well-functioning ocean?

The oceans are the planet's lungs, as well as a valuable source of food. Our ecological and climate crises mean that we have to readjust the way we use the oceans. Can we manage the transition from resource exploiter to attentive caretaker in time?

Even Moland, who is a diver and researcher, takes readers on a lively and knowledgeable journey below the surface of the ocean.

Rising tides

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CAPPELEN DAMM AGENCY

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Content

Chapter Summaries

Prologue

The prologue takes the reader to the Bikini atoll (Marshall Islands) and the surprising discovery of an intact ecosystem 50 years after the site was subject to a series of nuclear tests ending in 1958.

Chapter 1: The marine scientist

This chapter sets the stage for the book and narrative, by introducing the writer as a marine scientist. Also, as someone with a life-long relationship with the ocean – starting with an undramatic near-drowning experience as a five-year old when the author caught the first glimpses of life below the surface and was wrapped by the experience. The chapter then raises some of the issues that humanity is grappling with, while asserting that a knowledge revolution has provided the tools for making important and urgent decisions on how to take care of the ocean. However, different sectors and stakeholders have different relationships with the ocean. Can we share a common understanding of what is at stake, and make the transition from resource utilizers to attentive caretakers (custodians)?

Chapter 2: The ocean as a physical machine

Here the reader is taken below surface in a forceful tidal current in northern Norway, visited during the author's navy service (as diver). The fact that the dive had to be planned according to the tidal charts, and the forces at work to create the tidal cycle are explained in accessible prose. The chapter goes on describing the physics of the ocean: the global conveyor (thermohaline circulation), wind-driven upwelling, layering, mixing and stratification. How is the deep ocean oxygenated, and what is the significance of heat being transported and delivered to different parts of the planet? This is answered here. Ocean currents, their magnitude and their significance as biogeographic barriers are also described.

Chapter 3: The ocean as a biological pump

In the ocean, phytoplankton blooms when nutrients are available, and through their photosynthesis they produce life-sustaining oxygen and capture carbon. The significance and history of microplankton decarbonizing the atmosphere and slowly oxygenating the ocean is explained. The different pathways through which carbon is captured in marine ecosystems, through the food web and in the deep ocean, and finally sequestered in deep sediments is explained based on the best available science, with examples. Possible management actions with the ability to secure full effect of the biological pump are discussed.

Chapter 4: How to succeed as an ocean animal?

The reader is introduced to the challenges facing marine life during their life cycles, especially in the context of procreation. For example, expecting environmental variability in the short term while betting on a likelihood of encountering favorable conditions in the long term. How have different life histories evolved to hedge against such challenges? Vulnerability to harvesting/ fishing for different life histories is explained with appropriate species examples including sharks.

Chapter 5: Life in the ocean is place-based

Currents, depth and topography create patterns of dispersal and retention. Marine animals have home ranging behaviors or predictable migration routes. In sum, this means that life in the ocean is fundamentally place-based at different spatial scales. The author uses his own research on European lobsters to explain in-depth how individual behavior is also place-based, and links this to the emerging understanding of (marine) animal's cognitive abilities. The fact that marine life is inherently place-based has obvious consequences for management and for designing conservation in marine protected areas.

Chapter 6: Love at first glance: when humanity met the ocean

This chapter tells the story of the early humans and their dependence on the ocean during a severe climatic period, and a population bottleneck for humanity. South African archaeological findings are explained, from which it is likely to conclude that a small group of humans survived a harsh climatic period by finding a rich source of food items by the oceans edge. The high energy delivered in the seafood they utilized might have entailed an opportunity to evolve larger brains and could be a reason why humanity seems to have been 'smart from the start'. The chapter discusses how experiencing seemingly boundless resources, but being limited by simple technologies without means for capturing and keeping seafood (until relatively recently), might have cemented the long-standing impression that the sea's bounty is limitless and that the potential for exploitation of resources is vast. The concept of shifting baselines is explained. Traditional claim to areas or territories as a challenge in fisheries management is explained and discussed.

Chapter 7: The last great hunt

Fish are the last wild food that is harvested in quantity, and fishers are the last commercial hunters. The history of coming to terms with the limits to exploitation and the introduction of fisheries management is explained. The advent of fisheries biology as a scientific discipline, and the first experiences with fisheries collapses is introduced to the reader. The field of historical ecology – allowing estimations of historical population sizes and their size structure is explained as an important supplement to the more recent data on fish populations. The writer's own experience with the Canadian and US cod collapse in the early 1990s is used to set the stage for a relatively detailed account of the events leading up the fisheries collapse.

Chapter 8: From riches to hindsight

This chapter picks up the thread from the previous chapter by revealing to the reader the dire consequences of the collapse of Canadas northern cod stocks and -fishery. The hindsight and the somewhat controversial nature of the aftermath is introduced. The people that explained the chain of events, and demonstrated the overfishing are presented. The chapter then goes on to compare and contrast with the lessons learned in Norwegian fisheries, including the present-day cod crisis as it was unfolding up until the finalization of the manuscript.

Chapter 9: The ocean and climate change

Building on the physics (chapter 2) and biological pump (chapter 3) chapters, this chapter explains the different pathways through which climate change and temperature increase affects life in the ocean. The 1998 global coral bleaching event (which was experienced first-hand by the author) is used to give the reader a tangible understanding of the scale and severity that marine heatwaves have on species with a narrow temperature tolerance window. Various terminologies central to a basic understanding of climate change are introduced in accessible prose (e.g., El Niño Southern Oscillation (ENSO), Atlantic meridional overturning current (AMOC). The ocean is explained as a climate champion, having already 'saved us' from the worst effects of the CO_2 increase by sequestering roughly 25 percent of the carbon (through the biological pump) and absorbing 90 percent of the excess heat produced by the same CO_2 increase. The mechanisms through which this has happened is explained. The most likely effects of a runaway warming of the planet are discussed.

Chapter 10: Marine conservation

This chapter is central to the book's message and scope. The previous chapters have been building up to this (chapter) as the 'solution' to many of the challenges and threats that have been introduced. This is done by asserting the chronic impact of fisheries on marine ecosystems (which is invisible from the surface), and why the essence of nature conservation in the marine environment is establishing areas where this pressure is removed, in the from of marine protected areas/ marine reserves. Three 'cases' are presented in detail, namely the pioneering marine conservation work in the Philippines, New Zealand (both starting the 1970s) and finally the successful and more recent Norwegian applications of lobster reserves. The international frameworks that promote and encourage marine conservation are briefly introduced in this context.

Chapter 11: The last wilderness

The deep ocean is the next frontier for humanity's resource utilization. This chapter introduces the reader to the vast deep ocean, its depths and its 'commonness' of soft, deep sediments as the world's largest habitat – the nature type covering the largest areas of the planet. Here, the 'deep biosphere' consists of bottom fauna and microscopic life in the layers of sediment that in some areas are kilometers thick. Black and white smokers and the life that inhabit these are described. The biological wonders of this last true wilderness are still mostly unknown, but that does not mean that we are without knowledge of life in the depths. The prospects of opening up areas for deep sea mining is discussed, and the recent publication of the discovery of 'dark oxygen' is included in the text – a potential game changer for mining of manganese nodules, and for our understanding of oxygenation of Earth's ocean and atmosphere.

Chapter 12: Forging a new relationship with the ocean

This is the 'conclusions and implications' section of the book. Most of the discussion text can be found in this chapter. Here, the author asks the reader to consider the knowledge that has been shared throughout the previous chapters. The management actions and cultural changes that are necessary to bring humanity onto a path of sustainable co-existence with the ocean is argued for in this chapter. Marine conservation science has provided empirical data and demonstrated that recovery of depleted marine ecosystems is possible, also under climate change. The barriers to implementation, and how these may be overcome are among the issues this chapter touches on (without going too deep to avoid losing the reader).

Epilogue (You and me and the ocean)

In this hopeful exit section, the reader is reassured that (although there are urgent and existential challenges facing humanity, nature and the ocean) there is hope for marine life and for the ocean as our planet's life-sustaining heart and lungs. Our hope lies with science, the spreading and building of 'ocean literacy' and the policy- and cultural change that it can bring about (to which this book project attempts to contribute). The author argues that we should stimulate the curiosity innately harbored by children ('biophilia') and allow them to connect with nature and the ocean. The ocean and its creatures are just as new and inspiring to those having their first experiences with this parallel universe, despite the unavoidable changes.

The epilogue ends with a text section that takes the reader back to the Bikini atoll. The recovery of the ecosystem is explained in some detail, using concepts and terminologies that have been introduced throughout the book. The attentive reader should thus feel competent and more 'ocean literate' when reading about the phenomena that allow recolonization and recovery of organisms and animals in the ocean.

Rising Tides: The planet's vital lungs, the fragile life in the deep sea—and how to conserve it.

By Even Moland

English translation by Diane Oatley

This translation has received a translation grant from NORLA.

Contents

Prologue

The Bikini Atoll in the Marshall Islands in the Pacific Ocean was used as a nuclear test site during the years following the Second World War and up to 1958. The last bomb in a series of 23 was 1100 times more powerful than that dropped on Hiroshima in 1945. The powerful detonations had a devastating impact on the atoll and its natural features, both above and under water. Some of the islands along the ring-shaped coral atoll were wholly decimated. They were blasted into the air and their limestone bases evaporated in the extreme heat caused by the explosions. Huge craters gaped where idyllic islands had once lain. Corals were crushed into gravel and no fish could survive the pressure waves produced by the bombs. After the US stopped using the Bikini Atoll as a nuclear test site, the area was closed off and declared a “radioactive wasteland.” No fishing was permitted in the area.

Since the early 2000s, research teams began visiting the atoll to investigate the state of marine life. What they encountered underwater was an ecosystem in tip-top condition. A forgotten world full of life: schools of well-fed parrotfish, towering coral formations along the crater walls, and hungry sharks in pursuit of their next prey. Some alterations in the coral diversity were attributed to the impact of the nuclear test blasts, but 50 years later, life had re-emerged from virtually total annihilation.

The health of the ocean is at risk, but marine life has a fantastic ability to repair itself and bounce back. If it is given the chance.

Chapter 1

The Marine Scientist

A gray sky blurs into a glossy, steel-gray ocean and my gaze wanders outward to the horizon. Around 35 kilometers in the distance lies the deepest point of the Skagerrak strait in the Norwegian trench. What is hiding down there in the darkness at 600–700-meter depths? Giant sharks several hundred years old called Greenland sharks? Perhaps one or two of the last blue skates? Huge fish that live slow lives and only survive where they are left in peace, far from human interference.

Out there on the horizon, the current is stronger and the water type more oceanic than here in the coastal archipelago. At times blue and transparent, if the surface is calm when we depart on the boat from the research station in Flødevigen near Arendal, we can see the plankton net, the sediment grab or the rosette water sampler glittering far below us, suspended from the wire used to hoist the research equipment out of the depths. Perhaps today a group of bluefin tuna are out there in the blue water. Torpedo-shaped and as quick as lightning, they are the Formula 1 fish of the ocean and many fishing enthusiasts dream of hooking one. Colleagues in Sweden and Denmark have tagged individual tuna with external tags that store data (until they fall off and float to the surface) and mini acoustic transmitters that are surgically implanted in the fish's abdomen, enabling long-term study. When the tuna visit the Skagerrak strait from July to October, the tag signals are picked up by our hydrophones that are situated on the sea bed sloping towards the depths. The tuna fish seem to like the Norwegian trench. The data from the tags show that they dive to 400–500-meter depths, probably to hunt for the many schooling fish that can be found in deep ocean waters, such as members of the cod family like blue whiting and Norway pout.

On the Rødskjær islet, a solitary harbor seal is resting on its belly on the low-lying reef in a characteristically cheerful, curved banana position. It displays impressive core musculature. A few cormorants are drying off their wings after a dive. They must do so because their feathers trap water, which enables them to dive deeply and effectively. Wet feathers are but a minor inconvenience. With their heads turned to one side and their wings stretched out to dry, the cormorant poses in a familiar silhouette.

On one such quiet morning at the research station, a group of harbor porpoises came into the bay—small, toothed whales that are common along the Norwegian coastline. They were herding a school of herring before them. When they were satisfied that the school was in place, innermost in the cove, the meal commenced. The porpoises took turns patrolling the opening and corralling the school as one by one they attacked the fish. But the porpoises had to be vigilant as well, because now and then killer whales with porpoise on the menu will visit the Skagerrak fjords on hunting missions.

On another calm day we discovered a brand-new reef just outside the bay. We set out in a boat and were able to establish that the "reef" was a collection of durable, old-fashioned trawling bobbins, overgrown with a variety of so-called fouling species: barnacles, sea squirts, sponges, soft corals, stony corals and tubeworms. Tiny crabs and squat lobsters crawled through the fouling growth. The bobbins are hard plastic balls fastened in a row on the trawler's float line, and ensure that the trawl "mouth" stays open. The balls were tied together with rope. Perhaps this collection of spare bobbins had been fastened to a wrecked trawler somewhere out there in the North Sea? When the wreck had rusted away, the bobbins floated to the surface and drifted away, propelled by the currents and the winds, until they ended up close to us like a mysterious, floating island—wearing a furry coat of fouling growth from the depths.

For a long time, the focus of marine scientists was directed outward, beyond the horizon and towards their own contribution to the management of the most economically significant fish stocks, such as herring, mackerel, cod and capelin. While previously Norway as a maritime nation seemed to have "forgotten" the coastline and the fjords and the ecosystems they house, in recent years coastal research has been intensified. As marine scientists, we have contributed to putting the coastline on the research agenda. People's experiences of changes in our coastal regions have also played a role in this pivot. In many places, people experience that fish are becoming hard to find, that mussels have disappeared from their customary habitats, and that fast-growing filamentous or "turf" algae cover much of the ocean floor in the shallows. At the same time, there is a competition over marine areas and ocean space. Those who are to make decisions and set priorities need the knowledge marine scientists can provide.

Marine research and research articles are about understanding the world around us and making quality assured information available to everyone. But research does not have a monopoly on knowledge about the ocean. Fishermen and women are among the last hunters and their observations of nature are important for ensuring a successful harvest. In our times, as we experience a rapidly changing world, local ecological knowledge is also an important source of information about how things were before. Examples of such information would be the location of the spawning grounds of local herring in the fjords, the time of year during which the fish used to migrate to a spawning ground, the common size of the spawners, and the fishing methods used. In this way we can counteract what is called the "shifting baseline syndrome" in our observations of nature, and according to which every generation has a tendency to understand nature as observed in its current state, as normal and intact.

A budding understanding

Diagonal rays of white sunlight broke through the clear, bluish-green water. I could discern the bottoms of two small boats moored together side by side above me, before the appearance of two large orange and purple starfish, in stark contrast to the dark stone walls and brownish-grey seaweed, caught my attention. It was completely silent. Suddenly, the recently discovered stillness was disturbed by a splash and an explosion of bubbles beside me, as my rescuer jumped in.

On this summer day in 1979 I had, as a curious five-year-old, been crab fishing, and didn't notice that I was leaning too far over the edge of the dock. I wasn't wearing a life jacket and quickly sank towards the bottom. For the adults standing on the dock, this was a dramatic experience. For me it was the beginning of an adventure. I had discovered that there is a whole world of wondrous oddities under water and a marine scientist was born.

I now have many years of experience as a diver and marine scientist behind me. I have studied in Norway and Australia, and collaborated with colleagues from all over the world. I have experienced the magical adventure to be found in exploring the ocean and marine nature. I have seen animal species and observed their behavior with my own eyes—behavior that has a tendency to make many of them vulnerable in meeting with the human animal. But above all, I have had the chance to see that people in many places throughout the world live in close connection to the ocean and how their daily interactions with it are informed by knowledge gleaned by many generations before them—knowledge about the ocean as a source of healthy and nutritious food, about the ocean as an arena for mastering existence, and as the origin of myths and identity. All over the planet, wherever people have a prolonged connection to the ocean, there is also a culture shaped by this and even today many of our perceptions about the ocean appear to be defined by the experiences of our forebears, from a time when nature in many cases represented a seemingly unlimited abundance and our technology was simple.

It has been a while since my involuntary dive in 1979, but back then the shallower parts of the ocean had already been revealed to most of us, through the books and films of Hans Hass and Jacques-Yves Cousteau, among others. But many of the marine sciences were still in their infancy. If we move a bit further back in time this becomes even more clear. In 1951, Rachel Carson's famous book *The Sea around Us* was published, a classic among books about the ocean. It is a pleasure reading the poetic language of this book, and where knowledge is lacking, she fills the gaps in the story with wonderment and possibilities. The book was written at a time when the mid-ocean ridges had been discovered—subsea mountain chains along zones where the seabed crust cracks open as the continental plates are driven apart. But science about the continental drift was still controversial at the time when Carson wrote the book. She therefore did not include it and for that reason some of the interpretations in the text are completely out of date. In other fields in the world of science, the knowledge base was solid. This was particularly the case for physical oceanography and there was also a working understanding of the most important ocean currents that transport and distribute heat on our planet. To a significant extent, the earliest Norwegian marine scientists, among others, had contributed to this. Still, our scientific "knowledge pool" was relatively shallow.

In the 1950s, we had only just begun carrying out research expeditions dedicated to the collection of information about fish stocks that was not defined by the interest of fisheries—in other words, data that was gathered by the scientists themselves. Up until then, the purpose of fishery research had mainly been to track down fish in the ocean and in other ways assist the fishing fleet in exploiting the stocks. Fisheries biology was a new and rapidly developing field, a discipline in the intersection of biology, mathematics and economics. Great optimism was attached to such a mathematical approach to fisheries. This would secure good management of the resources. Parallel to the advent of fishery biology, the 1960s and onward saw the great "fishery collapses". This term is often used when it is estimated that less than ten percent of a fish stock remains, whereby in practical terms so few individuals of the stock are intact that the latter enters a state of low productivity, and the fisheries can no longer operate profitably. Such collapses can also produce ripple effects throughout the food web and have a long-term impact on the ecosystem. And of course, the fishing fleet can no longer harvest this particular type of fish and must switch to other species—with the accompanying risk of overfishing these as well.

In the second half of the last century, many of the marine sciences evolved from the pioneering stage into maturity—with everything this implies for well-established professional disciplines: university departments, national marine research institutes, scientific associations and international conferences. The years 1971–1980 were the UN decade for marine exploration. This alone was not sufficient to establish a solid, universal understanding of the ocean, but it was a good start. In our times we may have the opportunity to achieve a common understanding of the ocean's functions, opportunities, and limitations, based on the best available knowledge and modern tools for unlimited sharing of information. UNESCO's International Oceanographic Commission has named the period 2021–2030 the UN decade of ocean science for sustainable development.

The majority of the ocean is deep and the average depth of all the ocean regions in the world is 3682 meters. The ocean covers around two-thirds or just over 70 percent of the Earth's surface. The ocean's volume is almost 12 times as large as that of the land, ice and fresh water, if we base the calculation on average altitude above sea level for land and average ocean depth. On land, the habitable space is a relatively thin upper crust, while life in the ocean can unfold throughout the entirety of the available volume. This means that the ocean provides more than 90 percent of the available living space—habitat—on Earth. The planet Earth is first and foremost an ocean—it is predominantly an ocean planet.

The most common type of habitat in the ocean is the soft bottom, deep-sea plain, the bed of which can be from a few centimeters to several kilometers thick. Every time expeditions collect materials and extract samples from deep sea regions, new species are discovered. Observations of traces and patterns on the seabed in the depths indicate that there are organisms living there that we don't know about—although fossils can provide a hint. It is fantastic that the ocean still contains secrets and unidentified life forms! It means that the scientists who come after us will also have the opportunity to make spectacular discoveries.

Once in a while claims are made that we know less about the ocean than we do about outer space. But the fact that we haven't visited every place on the ocean floor does not mean that our understanding is deficient. On the contrary, I would claim that today we have acquired good knowledge about how the ocean works, good enough to have enabled us to reach a global consensus regarding how we can best preserve life in the ocean and secure maintenance of the ocean's functions.

A revolution in knowledge about the ocean

The ocean manages remarkably well without human beings and our fascination with technological doo-dads. But a knowledge revolution has occurred related to the ocean, to a large extent due to the technological development. New analysis techniques have enabled us to interpret tiny distinctions in the content of different minerals in animals. Substances in tissues can now disclose what a fish or other species eats—to which level of the food web they belong and where they find food. The otoliths (ear bones) of fish are comparable to a flight data recorder. The otoliths are found in the fish's head and are made of multiple layers of calcium. Besides disclosing the age of the fish, the mineral content of the different growth layers can tell us where in the world the fish has lived and where it started its life as fry.

The sciences genetics and genomics are developing at a pace that is virtually outrunning their own shadows. In terms of the ocean, such research methods have led to wholly new understandings of the kinships and contact between different populations from the same species. Sometimes this knowledge challenges the very definition of a species, because we find populations of the same species that are extremely different genetically speaking and that haven't had contact for a very long time. Their genes also contain archives of changes and these changes can be used to answer a series of questions. For example, we can find out where species came from when they migrated into and colonized an ocean region and the direction in which they subsequently spread. Changes in genes can also tell us whether a population has comprised fewer or more individuals and we can read off information of this nature extending far back in time.

The rapid technological development has also had a particular significance for the understanding of physics. For many years, a network of fixed and drifting research buoys has supplied us with data. We know, for example, how deep seawater is supplied with oxygen and why the Arctic is growing warmer more quickly than other ocean regions. In the same way that the weather report has become quite an exact science, with the help of computers oceanographers have constructed good ocean models that replicate the ocean currents in a way that corresponds extremely well with the reality, on an increasingly finer scale. Biophysical models—which combine biology and physics—enable us to study how some organisms and life stages such as plankton, eggs and larvae drift on these currents, how they are transported or held back in different waters. This can be connected to information about genetics and explain why we see distinctive population structures or patterns indicating that a type of fry in one "sink" area comes from parents in another—a "source"—or that a fish population in one region is "self-recruiting" and dependent upon local parents to endure over time.

The miniaturization of electronics is another important factor behind the increase in knowledge. Tiny electronic transmitters or satellite tags can both send and store data about depth, temperature and position. The marking of birds, fish, seals, whales, sharks, turtles and other marine animals enables us to study their movements and see how different ocean regions and habitats are connected by the animals' movements or migrations. This type of information is extremely important in our efforts to identify areas that are good candidates for marine conservation.

What shall we do with the ocean?

The ocean is an interconnected, physical and biological system that regulates the climate, controls the weather systems, purifies and recirculates nutrients, produces oxygen and stores carbon. These are scientific facts we can find in textbooks, popular science articles and nature documentaries. The ocean simultaneously has a greater and deeper significance as our origin, the "mother" of life on earth, including humankind. The conditions providing the foundation for the development of all life on the planet arose in the ocean. The beginning of life on earth was very likely connected to the processes that unfold in warm waters near regions with volcanic activity on the deep ocean floor, and the ocean is still just as important for maintaining the diversity of life as we know it. There are no optimistic industrial technology projects that will have the potential to replace or rival this system.

The primary Norwegian narrative about the ocean has been shaped by human beings who put their courage and strength to the test in meeting with the large and chaotic forces which sometimes, or over time, were overcome, enabling the extraction of great benefits: the millennia-old herring fishing activity, "the silver of the sea," whaling (Norway's first "oil adventure"), oil and gas from reservoirs beneath the ocean floor (Norway's second "oil adventure") and the development of the salmon farming industry. Previously, fishing made possible the population of the entire coastline in Norway and generated a livelihood for many. Through the structuring of fisheries for fewer and larger vessels, and the development of the new marine industries, we have evolved towards a partial privatization of the resource foundation, with prosperity for some and extreme wealth for a small group of business owners. I doubt that the capital owners at the top of today's marine industries view the preservation of vital coastal societies as their foremost responsibility.

The answer to the question "what shall we do with the ocean?" will certainly vary greatly depending on whom we ask. For many people, the ocean is a wholly natural part of daily life. The ocean is a workplace and source of livelihood for seamen, fishermen and women, fish farmers, and tourist guides and indirectly for shipowners and financiers, environmental activists, bureaucrats and politicians. Does that mean that we have the same understanding of the ocean that surrounds us? Can we then automatically share insights on changes and threats, trust the knowledge, reach an agreement and do something about the challenges? This has proved difficult.

For many people on the planet, the ocean is first and foremost an important source of healthy food and income. For them, the answer is given: we will live off it! Today and tomorrow—and throughout the future, hopefully. The faith in the idea that the ocean will "deliver" what we want to harvest or produce is highly prevalent in Norwegian society, in which professionals, politicians and interest groups formulate visions and targets for how much Norwegian seafood production should grow in the future and how the ocean will provide the basis for new industrial adventures that will secure our livelihood after the oil is gone. How are such visions and targets substantiated? Is there a basis for claiming that the ocean has a “residual labor capacity” that we have not yet exploited and which can be safely utilized to achieve growth in the seafood industries? Such faith in the ocean’s generosity is not groundless. The ocean supplies a long series of so-called supply and ecosystem services that are crucial for life on the planet and highly beneficial for the human race.

Generations of people have found fish to be a relatively stable resource which could be harvested, with the requisite skills, according to need. They became accustomed to how the fish appeared in large quantities and could be caught and utilized—annual phenomena that provided a basis for food security and prosperity. The saying “The herring is here!” is well-known in Norway. It very likely stems from a time when many hands took part in the herring fishing activity in small communities and it was a matter of putting other tasks aside and making the most of the opportunities brought by the arrival of the herring schools in the fjord. The industrialization of fisheries, the methods of which were formerly based on manual labor, in some parts of the world led to material well-being and good employment opportunities. In the same period that the development of technology skyrocketed in the fisheries, and modern-day navigation and fish-finding equipment became available, large changes have occurred in the ocean. The result of overfishing, combined with pollution and climate change, is that “the ocean’s health” has been considerably degraded.

The UN assigned “Life below water” its own sustainability target (no. 14 of 17) in 2015. This was extremely important and demonstrated that a scientific insight on how life on the planet is dependent upon a healthy ocean full of life has entered the political mainstream. This may potentially become common knowledge, but this is far from the case today. The human race is large and diverse and the same information does not reach all of us, or is not assigned the same weight. The significance of an increased understanding of the ocean has therefore been placed on the agenda by colleagues working in the intersection of ecology and society. Their message is that we must do our utmost to build “ocean literacy” in the population, so politicians will be able to implement policies in keeping with the sustainability target for “life below water.”

How do the global community and individual states react for the time being to the description of the situation? There is no shortage of international initiatives and good intentions. Agreements are signed but such agreements are not legally binding for the countries that sign them. They are guidelines and frameworks for the development of policy. Knowledge communities recommend gentle treatment of nature and emphasize the necessity of collaboration with the natural world. Strong messages from the voices of researchers within the natural sciences are a relatively new phenomenon in Norway. We have no tradition for whistle-blowing on nature’s behalf. And we hesitate a bit in ranking the different impacts—even though such rankings are extremely useful when politicians are going to prioritize measures in the short and long term.

There is cause for hope. The ocean is a robust system with good connections between different locations. This means that marine life can spread and species can re-establish populations in areas where they have been absent or depleted for a long time. Fortunately, there are examples of habitats in the ocean that are wholly pristine—pockets that have been virtually undisturbed and ecosystems that have demonstrated a strong resilience to impacts. Now we need to disseminate understanding about what contributes to such resilience and to the maintenance of a healthy ocean.

Chapter 9

The ocean and climate change

My local colleague Dominique and I steered the boat out of the passage in the lagoon by Amitié in Seychelles and continued south along the edge of the reef. Full of expectations, we dropped the anchor on a sandy patch in the seafloor, donned our equipment and performed a buddy check. At the last moment, we remembered to set up the diver ladder, which would greatly simplify the task of climbing on board again. Then we spat into our masks, gave them a rinse and finally rolled backwards into the water from our respective sides of the boat.

Around us and beneath us, the coral reef was a rolling terrain full of nodules and outgrowths. Most of the fishes were new for me and the water was teeming with life and colors in movement. We descended slowly to the bottom, knelt in the sand and took in the sight of the reef that was reminiscent of an amphitheater surrounding a patch of sand. The instrument showing the time, depth and temperature read 18 meters and 30°C. I recognized several branching coral colonies of the genus *Acropora*, the majority brownish, but also colonies in beautiful shades of green, orange and purple. Then I caught sight of a fish that was familiar to me: A white-breasted surgeon fish, an iconic species of the coral reef in the Indian Ocean. I also quickly recognized the striped "sergeant major" from the handbook I had studied during my flight. A Moray eel slithered like a snake across the seabed between the corals. I settled down and registered an intense joy over what I was experiencing.

All the same, something was off. Here and there in the amphitheater around us were some chalk-white coral colonies. They shone brightly and seemed oddly out of place amidst the abundance of color. I swam up to one of the pale corals to take a closer look, adjusting my buoyancy and movements until my mask was just a few centimeters away from the bone-white coral colony. The coral tissue, which is like a layer of skin on the outside of the calcium skeleton, was still intact, but completely transparent. My colleague signaled that he didn't know the cause of this.

Back on board, I asked Dominique if he was familiar with the phenomenon of the white coral. He couldn't remember ever having seen anything like it in any of the places where he had been diving in the island group. After we had returned to the simple house we were sharing, I pondered over the pale corals we had seen. What could be the cause? Was it common for the temperature to be 30°C at a depth of 18 meters during this time of year? Dominique replied that the start of the winter had been particularly warm, both on land and at sea.

Before I came to Seychelles, I had already experienced first-hand the unusually warm eastern Pacific Ocean. I had spent all of February and most of March on the coast of Michoacán in Mexico. Could it be that the Indian Ocean had also heated up dramatically during this El Niño year? It would turn out that in the course of the southern summer of 1997–98, a large, warm patch of surface water had formed in the southwestern part of the

Indian Ocean, which eventually spread north and eastward towards the Timor Sea. The patch reached both the Seychelles Islands and the Maldives, and in April we were surrounded by it. The temperature was two–three degrees warmer than normal for the season and the heat penetrated quite deeply into the ocean, as we had just recorded during our dive around the reef.

El Niño, “the little boy” or El Niño Southern Oscillation (ENSO), is a condition of unusually high surface water temperatures in the central and eastern Pacific Ocean near the equator. The phenomenon has been given this name because it normally occurs around Christmas time. The name “little boy” is a reference to the baby Jesus—*El Niño de Navidad*. In a large area in the eastern part of the Pacific Ocean along the coast of Peru and further south, there is usually a powerful upwelling of cool and nutrient-rich water from the ocean depths, which creates among other things the basis for abundant fishing grounds. In good periods, the harvest of Peruvian anchovies is one of the world’s largest fisheries. During an El Niño episode, the upwelling of cold, deep-sea water virtually comes to a halt due to a strong trade wind from the west, which instead drives warm surface water towards the coast of Central and South America. As a result, an enormous area of the ocean surface heats up, which in turn influences the weather in large parts of the world, and has an impact on the global mean temperature. An El Niño episode occurs every two to seven years, without any fixed pattern. During El Niño, the productivity of the Peruvian anchovy stock is reduced and the fishing activity declines substantially. The phenomenon is caused by a series of reactions to the warming of the Pacific Ocean and even though we can’t pinpoint an individual triggering factor, we can now predict the development and intensity of El Niño with relative precision.

The peak temperature for 1998 remained the highest on the temperature curve for all of seven years, the warmest year since temperature measurements began, until also that record was broken in 2005. The subsequent weeks were dramatic for Seychelles’ coral reef. The heat persisted and every day we noticed more reefs where most of the coral was bleached. A ghostlike white emanated from the bottom when we passed in the boat on our way to work on the west side of Praslin. This phenomenon is called, logically, “coral bleaching”. Corals and a number of other marine animals are hosts for a photosynthesizing type of algae called zooxanthellae, which lives in the coral tissue. These algae live in a symbiotic relationship with the coral animals and give them their color. From the corals, the algae receive a home to live in, CO2 for their photosynthesis, and nutrients from the coral animals’ metabolism. In return, the coral receives oxygen and sugar from the algae, a vital supplement to the food the coral polyps capture in the water.

When the algae become stressed due to abnormally high temperatures, a change occurs which causes the coral to expel the algae from their tissues. They become climate refugees. The coral tissue becomes more transparent, exposing the white calcium skeleton; they are “bleached.” If the heat subsides, the coral animals may survive and once again take up algae from the water. If, on the other hand, the heat persists, the coral will ultimately die. The tissue rots away and only the white, calcium skeleton remains. This was what happened in Seychelles, the Maldives and a number of other places in the Indian Ocean in April and May 1998. Soon the naked skeletons were coated with slimy, grayish-green algae. Boring sponges and tubeworms attacked the dead skeletons, which before long became brittle and fragile. When the month of June brought storms and waves, the dead corals disintegrated and many of the reefs were transformed into unrecognizable heaps of rubble. The fish swam in confusion through the ruins of what until recently had been a three-dimensional, living habitat. What remained resembled a pile of bone fragments.

For some time, we were the only ones who had any knowledge about the situation. The diving centers on the island were closed for the season, the weather was bad and nobody else was in the water as often as we were. Many people didn't believe our claims and the observations of a newly arrived northerner were not taken very seriously. But sooner or later, the state of affairs would have to be brought to light. In the course of July and August, the subject of coral bleaching and subsequent coral death was featured on the news in Seychelles. Reports came in from more and more of the islands—they had all experienced the same phenomenon. For a while it was unclear whether the reefs off the shallow plateau on which the largest of the islands are located had been spared from the worst of the heat. Dominique and I searched for hope. After a while, we found a few living corals. Some massive coral colonies of the genus *Porites* had survived. In the large lagoon between the external reef and the shore, the heat could become quite extreme on windless days when the sun was beating down. There we found a few small patch reefs of more heat-resistant coral species that had also made it through the heat wave. We were encouraged by these finds. Was there hope after all? Finally, news also arrived that the bleaching was less widespread in the remote-lying atolls.

A colleague at the Australian Institute of Marine Science wanted to find out how common such events had been previously—that corals were bleached and died out on a large scale—before there were divers and marine biologists who swam around and documented their findings. Perhaps it was more common than we'd believed? To investigate this, he developed a method similar to that used by climate researchers for drilling down into old ice to measure the percentage of different gasses in the atmosphere far back in time. The researchers invented a core drill for use on huge, massive corals. Equipped with an extra air bottle to operate the core drill—and plenty of time—they drilled into many large, old blocks of coral around the world. The largest and the oldest were found on the Great Barrier Reef off the coast of Australia. The drilled core extracted from this huge formation illustrated the history of the coral colony all the way back to the year 1572. The earliest traces of mortality as a result of bleaching were found in the early 1980s. In other words, research has contributed to demonstrating that a connection between El Niño years, coral bleaching and large-scale extermination is a relatively recent phenomenon. In the course of more than 400 years, it is only in the last 30 years that we have experienced global events in which tropical coral reefs in shallow water have perished. In many places, the warm water corals have been accustomed to stable temperatures, even those that built reefs close to the surface. The global warming we have caused since pre-industrial times has evolved too quickly for these corals to keep up and adapt.

More than 90 percent of all the coral in Seychelles died in 1998, which became the first year that coral bleaching on a global scale was established. Since then, it has become a common occurrence. We experience similar global events every El Niño year and regional events also outside the El Niño years. The largest occurrence thus far in 2015–2016 was documented and publicized through the Netflix film *Chasing Coral*. The panic that reigned in marine biology communities has been mitigated somewhat, because many coral reef ecosystems have proved to possess surprising recuperative abilities in the wake of widespread mortality caused by marine heat waves. Scientists have also discovered and documented deeper lying parts of the coral reef, where the water is a bit cooler and maintains a more stable temperature. Perhaps such deep reefs can provide refuge for the coral animals and sources of larvae that can replenish the shallower areas with new colonies during periods with favorable temperatures. Studies have shown how coral reefs with high fish abundance in marine protected areas that preserve intact fish communities, are more robust in the face of change than reefs with depleted fish stocks. Grazing fish such as Parrot fish and surgeonfish keep algae and seaweed in check, so new coral colonies can establish themselves and grow. The alternative is a phase shift, whereby shallow reefs go from being coral dominated to algae dominated. The future of tropical coral reefs in shallow water is uncertain, but nature is both rugged and adaptable when it is afforded sufficient leeway.

Temperatures are rising

We have known it for quite some time now. The temperature on the planet will rise in step with the increase in the CO2 concentration in the atmosphere. As far back as in 1896, the Swedish chemist, physicist and Nobel prize winner Svante Arrhenius predicted that a humanmade increase in the atmosphere's CO2 content, caused by the use of fossil fuels, would lead to a temperature increase. In 2022, we passed a milestone in the history of humanmade emissions of CO2 into the atmosphere. At this time, we reached a fifty percent increase in the CO2 concentration compared to the pre-industrial level, in other words, before we began fueling the industrial development with coal. The corresponding increase in the average global temperature of approximately 1.1°C may seem moderate. It is tempting to trivialize a difference of one or two degrees. It is after all a change that has no bearing on the way we dress or that reduces the need for heating in our homes. Still, those of us who live in the north know that there is a huge difference between minus 0.5°C and 0.5°C.

The temperature increase is neither evenly distributed all over the planet. It is found in patches and is more extreme in regions where the warmth arrives by way of ocean and air currents, and locally it is greater where the natural cooling systems are weakened, either permanently or temporarily. In the ocean this is particularly the case when the upwelling of cold and nutrient-rich deep water slows or stops for a period of time, which happens along the coast of South America on a pretty regular basis, as a result of El-Niño.

Anyone who has gone skiing in the mountains on a sunny winter day, knows that ice and snow function as an effective reflector of the sun's rays. This is called the albedo effect. When ocean regions become ice free due to rising water temperatures, more of the energy from sunshine is absorbed by the dark ocean surface. The loss of albedo or reflection also further intensifies warming. On land the forests have a cooling effect, especially due to evaporation in tropical regions, through which the rain forests create their own rain. Forests' local climate-regulating effect and the shade effect of trees help to preserve areas within a habitable "climate window". Today it would have been helpful had the forests which not long ago covered the islands in the Mediterranean and the land regions around this large inland sea been preserved. The albedo effect of clouds is also important and there is a fascinating connection between clouds and cloud formation, on the one hand, and marine life on the other. I have previously addressed dimethyl sulfide, the gas containing sulfur which is released into the atmosphere when phytoplankton is consumed in the ocean. The microalgae that live in the tissue of corals also expel this gas. It has long been known that dimethyl sulfide and other sulfuric gasses cause cloud formation, an increased albedo effect and thereby atmospheric cooling.

The atmosphere is heated up and cooled down, the air temperature varies between night and day, and from one season to the next. We say that air has a low "heat capacity." Water has a heat capacity that is almost four times as great and its heat holding ability is therefore four times more effective than that of air. What this means is that while the atmosphere becomes hot and cold according to the time of day, the weather and the season, the ocean is gradually being heated and retaining the heat it has "warehoused" for a longer period of time. Simultaneously, the impact of the ocean on the atmosphere is that of a huge cooling brick. Everyone who has gone swimming in cold water knows how quickly we start to shiver, even when the temperature of the ocean's surface is a stable 18–20°C on a warm summer day. In the same way that the ocean water steals heat more quickly than air does, it will spend more time heating up and hold onto that heat longer. All of 90 percent of the temperature increase, or "surplus heat" from the CO2 increase since 1970, has therefore served to gradually warm up the ocean. For the time being, this surplus heat has not penetrated the deepest layers of the ocean to any significant extent. More than half of the temperature increase has occurred from the surface down to a depth of 700-meters and three-fourths from the surface down to 2000 meters.

Due to the sluggish transfer of heat from the surface and downward to the deepest ocean zones, the effect of rising ocean temperatures will endure for thousands of years, even after we have reduced greenhouse gas emissions. The delay in the warming of the ocean has at least one fortunate and one unfortunate consequence for our work of cutting greenhouse gas emissions and reining in the climate crisis. The fortunate consequence is that the ocean functions like a thermostat as we dedicate our time to transforming our energy systems. This will continue to help us hold the temperature increase at a relatively stable level for a long time into the future. The unfortunate consequence is that we are sending the effects of global warming far into that same future. Long after we have phased out fossil fuels or reached "net zero" CO2 emissions, the changes in the deep sea will continue, in the form of warming, volume expansion, lower oxygen content, and acidification.

Here we must briefly consider the size of the ocean. We often hear that the ocean covers 71 percent of the Earth's surface and we live in fact on a predominantly oceanic planet. If we look instead at the volume of the ocean, little doubt remains about the ocean's dominance of the planet: the ocean's volume is all of 1.39 billion km3, if we base our calculation on the average depth of the ocean. This is 12 times greater than land's modest 117 million km3, based on the average altitude above sea level. When this enormous volume of water is slowly and gradually heated up, it will simultaneously expand, causing the sea level to slowly rise as well. The estimated timeline for such a gradual increase in volume, based on a warming of 1°C, is a concrete example of the effects we are sending into the future. The sea level will rise slowly at first, an estimated 0.6 meters after 100 years, four meters after 2000 years and seven meters after 10,000 years. All of this will take place as a result of the same temperature increase of 1°C, which we have already caused. If the temperature increase exceeds this, the sea level rise will increase correspondingly and the effect of the melting of ice on land is not included in these calculations.

Global warming is progressing more quickly than the models have been able to predict

In 1998, the US Navy released classified data confirming that the changes will quickly become greatest furthest north. Many readers have perhaps seen the iconic photos of a submarine tower sticking up through the ice. Since 1958, and throughout the entirety of the Cold War, the US Navy's nuclear-powered submarines measured ice thickness while carrying out military exercises under the ice near the North Pole. The submarines' upward looking sonars could be used to measure sea ice thickness above them as they crossed the Arctic Ocean on secret missions. The data showed that the thickness had been quite stable up until the mid-1980s, after which it was drastically reduced.

Although we have long had a working understanding of the connection between an increase in the CO2 concentration in the atmosphere and rising average temperature, it was not until the 1980s that climate research expanded into a mega-science. Over the course of this decade, a deeper understanding of global warming quickly developed. When the first report from the intergovernmental panel on climate change (IPCC) was released in 1990, the message was clear: humanmade CO2 emissions had contributed to at least one-half of the observed temperature increase of 0.3–0.6°C in the past 100 years. If we continue a "business as usual" emissions trajectory, we will see a warming of 0.3°C per decade.

The large screen on the wall displayed a digital version of the Earth in real time, including ocean currents, air currents, cold and warm zones. What we saw was the visualization of an "earth system model," a mathematical model that was fed all the available data to create a digital version of the planet's climate system. "It's not perfect," our guide told us, "but we can simulate quite realistically the impact of the temperature increase on different places on the planet."

In 1994 I was back in the USA visiting my American host family and my host brother Peter, who at the time was attending college in Boulder, Colorado. The USA's National Oceanographic and Atmospheric Administration has one of its research centers there and we joined the daily tour for visitors. At the center, they were working on one of the early "earth system models," a kind of digital twin of the Earth's entire climate system. In a room a computer was humming away, the components of which occupied a number of large cupboards and a large box on the floor. The room was a bit reminiscent of a set from the Kubrick film *2001: A Space Odyssey.* Through the glass casing that covered the electronics inside the huge computer on the floor, we could see several broad magnetic tapes slowly winding from spool to spool.

Even in the mid-1970s, the early climate models[1] showed that the temperatures in polar regions would rise far more quickly than in other parts of the Earth. Many were skeptical about the climate models that calculated the temperature increase. "It's just a model, after all," was a widespread reaction when the subject was discussed at this time. Perhaps scientists did not do a good enough job of explaining what such a model is? We use mathematical models for many purposes that we don't question. The daily weather report is perhaps the most mundane example and the climate models have been based on the weather forecast models. The challenge in creating good models is to a large extent about scale; the smaller the grid squares or blocks of air or ocean that are to be calculated, the more detailed and realistic the model will be. At the same time, this makes the model more cumbersome to run; in other words, the calculations require the fastest and best computers in the world.

The skepticism about the climate models would turn out to be unfounded. To the extent that they have been mistaken, they have unfortunately erred on the side of optimism, because they have been too conservative: the climate changes in the warmest and coldest regions on the planet have evolved more quickly than in the majority of the climate models' most probable scenarios. This is often because it is difficult to calculate the strength of the "self-reinforcing effects" of warming.

Higher temperatures in seawater that is transported into the Arctic have caused the ice to become increasingly thinner and younger. Today the ice in the Arctic is the youngest and thinnest that it has been since 1958. Since the early 2000s, the measurements done have been more representative and cover a much larger area due to the use of the satellites in the US ICESat program and the European Cryo-Sat program. More than 70 percent of the sea ice in the Arctic is now one year old. This means that it freezes in the winter and melts in the

[1] Climate models are an important tool in climate science. See https://snl.no/klimamodeller

summer, and does not survive from one year to the next. Compared to perennial sea ice, it is thinner, melts more quickly and breaks apart more easily, which makes it more vulnerable to the wind and weather, such as rain. Large parts of the Arctic Ocean are now ice free in the summer and several of the fjords in Svalbard are ice free year-round. When the seawater in the Arctic is free of ice, more heat from solar irradiation is absorbed by the dark surface of the ocean, due to reduced albedo effect. This self-reinforcing effect and the scope of it is one of the reasons why the warming of the Arctic has progressed more quickly than the climate models were able to predict. Now this factor has been better integrated into the models and recent simulations indicate that the entire Arctic Ocean could be ice free during the summertime by 2030. The Earth system models that have been developed by research communities in several places in the world are today used to perform joint calculations followed by ensemble evaluations. As a result, the calculations capture more potential outcomes and the future prognoses have become more precise.

A number of Norwegian marine research colleagues have in recent years contributed to greater understanding of other mechanisms which have also contributed to a rapid change in the Arctic and the consequences for the ecosystem and animal life. For example, drifting sea ice from the Arctic Ocean plays an important part in keeping the Barents Sea stratified and cool. Colleagues have explained how a battle against warm and salty Atlantic water is taking place in the depths of the Barents Sea. Freshwater from melting sea ice leads to stronger stratification of the seawater, because fresh water has lower density and lies on top of heavier, saltier water. With a reduced supply of sea ice and fresh water, the stratification disappears and instead we get a convection mixing salty and warm Atlantic water all the way up to the surface. As a result of this, the climate in the Barents Sea has already become less Arctic and more Atlantic. This has significance for species diversity in the marine region because the Arctic species are pushed to the north. But when bottom-dwelling fish species meet the northern edge of the shallow Barents Sea (which is a so-called shelf sea), the next stop is the deep Arctic Ocean. For species that are not adapted to a life in open waters, there is thus a limit to how far they can migrate in accordance with the climate changes.

The Arctic cod is a slender, little cousin of the Atlantic cod. It grows to a mere twenty-five centimeters in length and weighs approximately 100 grams. Nonetheless, it is a tough little fish and a keystone species in the ecosystem of the Barents Sea. Because it has "antifreeze" in the cells of its body, it is able to live and thrive in the sub-zero seawater where temperatures can drop to minus 1.8°C. The Arctic cod spawns under the ice and lives on a diet of zooplankton. It is at risk of becoming food for fish, seabirds, seals and whales. My scientist colleagues discovered that it is spawning farther and farther north in the Barents Sea. The region offering the ideal conditions for this important species is shrinking apace with global warming and is facing an uncertain future. Polar bears and several species of marine mammals in the Arctic rely on ice floes in their life cycle, for hunting, for rest, and to give birth and nurse their young. Scientists are working intensively to understand how the abrupt changes will affect these species. Some will perhaps be able to adapt but we must also expect that some of them will have great difficulties in an Artic region without sea ice in the summertime.

In the Antarctic most of the ice is in the form of enormous glaciers on land. The glaciers slide slowly towards the coasts where they rest on solid ground below sea level, but the movement of the glaciers is halted by gigantic, floating glaciers called ice shelves. One of the great elements of uncertainty within climate science is what will happen if the ice shelves were to disintegrate. Will the melting of ice on land accelerate? If so, the sea level rise will accelerate as well.

Two old ice shelves in the far north on the continent of Antarctica have already disappeared. After having remained stable for approximately 12,000 years, ever since the last Ice Age, the large Larsen A ice shelf broke away and disintegrated in 1995. There were no witnesses to the breaking away of the gigantic, floating glacier, but a few years later, in 2002, the same thing happened to Larsen B. Thanks to satellite images, the fate of the Larsen B shelf could be studied in greater detail. 3250 km2 of ice, just slightly smaller than the entire Hardangervidda national park in Norway, with a thickness of 200 meters, broke away from the glacier to which it was attached and then disintegrated in the course of three weeks. For a long time, it drifted off in the form of relatively small floes. Scientists have later been able to explain the cause: an extreme weather event called “atmospheric rivers” supplied a long-range transport of a warm, high-humidity air stream. Phenomena of this nature played a part in causing these ice shelves to break apart. The hot, humid air that arose far from Antarctica functioned like a hair-dryer that produced meltwater on the top of the ice shelf. The water ran down through cracks, seeping into the ice and softening it to such an extent that large ocean swells which formerly had no impact on the hard ice were able to break up the enormous ice shelves. Recent findings about ocean warming around Antarctica indicate that it is highly probable that the remaining ice shelves further south will suffer the same fate in the course of this century. This will very likely come to pass even if we succeed in meeting the Paris Agreement goal for emissions cuts, the target of which is to limit global warming to 1.5°C.

Heat Waves in the Ocean

A period of lovely, warm summer weather is something we all long for during the long Arctic winter here in the north. If we experience an extended period of particularly pleasant, warm weather, we often refer to it as a heat wave. And just as heat waves occur on land, global warming is causing heat waves in the ocean. Large patches in the surface layer can heat up dramatically and such patches can endure in the form of large gyres (eddies) with long lifetimes—long enough that organisms unaccustomed to long-term temperature increases experience difficulties and in the worst case, perish. In the spring of 2024, we have established that 2023 was the warmest year since reliable measurements began in around 1880. In the course of the northern summer, the recorded Atlantic Ocean temperatures reached historically unprecedented highs. Towards the end of August, a number of ocean regions had recorded temperatures of 3°C above the norm. Even though the ten warmest years have all been measured in the past decade, we have experienced several dramatic temperature spikes previously. The year 1998, with which I began this chapter, was one such peak on the curve and is still ranked in fourteenth place. For me, it became a year during which I would get a taste of wholly unknown concepts and learn a great deal about the effects of climate change.

Something was brewing even back in 1997, one of the warmest summers in the measurement series of the Norwegian Institute of Marine Research in Flødevigen. There the ocean temperature at one meter's depth has been measured daily since 1918. In the summer of 1997, the recorded temperature reached 18°C or more for all of 63 consecutive days and the temperature did not drop below 18°C until September 9. This unusually warm summer was also my first season as a commercial diver at a company that provided services for the aquaculture industry. Otherwise, I was a student and the diver job was a good opportunity to learn about the industry. In Sunnfjord we awakened to a yet another sunny day accompanied by bird song. The summer heat had settled into the house and the scent of freshly cut hay and flowers drifted through the open window. After several weeks in a row of exceptionally good weather, Western Norway was transformed into the world's most beautiful water park, as if designed by the Norwegian romantic nationalist painters Tidemand and Gude. Day after day of calm weather and scorching sunshine had their effect on the fjords: they grew warm. Then we were summoned to a salmon farm where the workers stated that the fish had lost their appetites. Scarcely any fish came to the surface during feeding bouts.

At this time, it was still common for fish farming cages to be situated close together in connected sea facilities, like square cages in a single grid, two across and often six or eight in length. Only a few had installed underwater cameras for surveillance of the fish's behavior. We prepared ourselves for diving. The water was clear and the sun provided good illumination, so large parts of the offshore facility were visible from a distance, even under water. It was evident that the fish were extremely stressed. Packed tightly together, they swam around and around in the cages as deeply as they could. The cage bottoms were cone-shaped and there wasn't much room where the fish most wanted to be. We could see that there were already a number of fish on the verge of losing the battle over space. The following days were long and we worked non-stop. The warm water of the surface layer contained less oxygen and eventually the fish started to die as they consumed what little oxygen was available in the warm fjord water. The mass mortality event started in the cages located close to the middle of the facility. We lay on the bottom of the cages filling hoist nets with dead fish until late into the night. To help mitigate the crisis, we moored a device close to the facility, a raft with large, submergible and slow-moving propellers that generated a water current that flowed in towards the cages. Circular cages that were moored alongside the facility were released from their moorings and slowly towed further out in the fjord. We monitored the situation from under water and observed the behavior of the salmon carefully. The majority were rescued, but the event gave the fish farmer a good scare. He was obliged to evaluate whether this arm of the fjord was actually suited for housing such a large fish farming facility during a heat wave.

The marine heat waves that reached Southern Norway in the late 1990s have been documented in Flødevigen's temperature measurement time series. It was the same story: the ocean surface became warm and the heat wave persisted. For a while it was unclear whether the record-warm summers had any effect on marine animals and plants along the coast of Southern Norway. In 2002, two diving scientist colleagues from the Norwegian Institute for Water Research (NIVA) performed diving investigations at stations that had not been visited since 1996. The coastal environmental monitoring program had in the meantime made the outer coastline a priority, where it was held to be important to monitor any signs of impact from long-range transport of pollutants in the form of nutrients. When the team of the two research colleagues visited the more protected stations, it became clear that the species sugar kelp had more or less disappeared since the last visit in 1996. Could repeated episodes of seawater temperatures that exceeded the species' tolerance level for growth and well-being be a probable cause of the disappearance? This has subsequently been better understood and confirmed through comparisons with other areas that experienced similar disappearances.

Many places where the sugar kelp formerly thrived are today dominated by fast-growing, filamentous algae, often called "turf algae." These algae utilize nutrients and sunlight for rapid growth and compete effectively over space. Unfortunately, turf algae provide a much poorer habitat for marine animals than sugar kelp, and there is a connection between small animals and the growth of turf algae. Snails and amphipods (small crustaceans) graze on filamentous algae and can efficiently contribute to holding their growth in check. If these small animals disappear as a result of an overabundance of mesopredators—small and medium sized fish that feed on them—none will remain to curb the growth of turf algae. We can therefore help nature combat turf algae by protecting small-fish predators such as pollack, cod and sea trout, and ensure that instead of ending up in the frying pan, the largest and most voracious specimens and their functions remain, even in fished ecosystems, by introducing a maximum size limit for these species.

The mystery of the missing mussels

At a certain point in time after 2010, people began claiming and reporting that no blue mussels were to be found in the usual locations where formerly they had harvested them in Eastern and Southern Norway. For several generations, many people had enjoyed collecting this tasty and easily available resource in the vicinity of their cottages or homes, often in the same places. It therefore came as a huge surprise when they discovered that the mussels were suddenly gone.

On a cold, clear winter day, I took a break from my work to look into the situation. I walked out to the smooth, bare-faced rocks along the shore and down to the intertidal zone, the foreshore area where marine plant and animal life begins. There were strips of ice on the rocks and the belt of black lichen (tar lichen) that covered the rock in the splash zone was damp and slippery, so I had to watch my step. On the rocks near the mid-tide level were dense colonies of barnacles, encrusting crustaceans that capture food by beating their filter-feeding appendages (cirri). The relatively large size of some of them indicated that they had been attached here for some time. Perhaps they had been spared the abrasion of sea ice the winter before? Unoccupied areas between the barnacle colonies were probably due to the movement of the sea snail known as the common limpet. These cone-shaped snails grind down the edge of their shells to achieve a perfect fit with the terrain in specific locations in the intertidal zone, attaching themselves there to retain moisture and avoid being eaten by birds at low tide. The snails take the chance of moving about when the waves wash over their dwelling places, or when rising or ebbing tides place them in the splash zone during the night. The snail grazes by scraping algal growth off rock surfaces with its rough rasping tongue (radula).

Between the barnacles, small mussels had attached to the substrate with their solid byssal threads. The majority seemed to have used the barnacles' calcium plates as an anchor point and they were all the same size—around 1.5 centimeters long. It was these small creatures in particular that I was looking for. These were mussels that had settled down here as larvae ripe for tethering during the previous summer. They now faced an uncertain future. A flock of common eiders bobbed on the water surface just a few dozen meters away from me. They would graze on the nutritious mussels in the course of the winter. The common or sugar starfish species are also voracious mussel eaters. They will creep up to the intertidal zone at high tide and eat mussels in their own unique fashion: the starfish pries open the two shells, and its stomach bulges out and slips into the crack. Enzymes that kill the mussel are expelled from the surface of the stomach and the starfish ingests it directly. In the spring perhaps there won't be a single mussel left here?

The reports about mussel disappearances were of course taken seriously. The challenge was that we didn't have good data to compare with. In the last chapter I explained about the excavations that have shown that people have gathered and eaten mussels in Norway for at least 9000 years. Nonetheless, no systematic mussel mapping had ever been done in Norway. A marine research colleague and mussel expert launched an ambitious project: he created a network of stations in the fjords of Southern Norway, and then he set out swimming. In areas he couldn't access by boat or that were obstructed by high water levels, he used a wetsuit, diving mask, and snorkel to document where the mussels are found today. It will thereby be easier to monitor the conditions in the future.

Our colleagues in Sweden have established a change in the growth sites and occurrence of mussels. In places where previously there had been mussels in the intertidal zone, on rocks, in cracks or between stones, they were now obliged to search for "upside-down habitats": under pontoons, beneath the rungs of swimming ladders or on the bottoms of mooring buoys. Other scientists hold that we have reached a tipping point. Life in the intertidal zone is after all quite stressful for mussels, but when the conditions are ideal, they can withstand all the abuse they suffer here: below freezing temperatures at low tide or abrasion from sea ice in the winter, scorching sunlight, desiccation and warming at low tide in the summer, fresh and dirty floodwater in the spring, or large quantities of precipitation during other times of the year. In addition to the episodic disturbances, the warming leads to gradual changes. The darkening or "browning" of coastal waters is an effect of increased plant growth on land, due to which greater quantities of colored dissolved organic matter finds its way into the ocean. When sunlight no longer penetrates as deeply into the water, this has consequences for algae that require light to carry out photosynthesis and grow. As the coastal water has darkened, the lower growth depth limits for a number of species of seaweed and kelp have become shallower.

Marine heat waves during which mussels experience extended periods of high surface temperatures is clearly unfavorable. In keeping with the climate changes, it is likely that some of these stress factors have been cranked up a notch, at least, as a result of which mussels no longer thrive in parts of their former habitats. This does not mean that the mussels have disappeared for good. They are alive and well somewhere nearby, but at slightly greater depths or in more exposed locations with stronger currents and water circulation. Mussels can be cultivated on ropes hanging from rafts or horizontal systems of ropes suspended on buoys, and they remain an obvious candidate for a future marine food resource. At the same time, we can make good use of their properties as filter feeders to improve conditions in fjords and coastal waters containing excessive amounts of nutrients.

Ocean acidification – the "evil twin" of climate change

The ocean and the atmosphere are closely interconnected. It is tempting to say that the two are actually one system, in that the atmosphere contains water vapor instead of water in a liquid phase, and the ocean contains the same gasses as the atmosphere, dissolved in water's liquid state. Between the surface of the ocean and the atmosphere a constant exchange of gasses takes place. This exchange can be described through a law of physical chemistry, one of the gas laws known as Henry's law. This law basically states that the quantity of dissolved gas in a liquid is proportional to the gas' pressure above the liquid. When we burn fossil fuels such as coal, oil and gas, the content and subsequently the gas pressure (partial pressure) of CO2 in the atmosphere increases. According to Henry's law, there will be a corresponding increase in the amount of CO2 dissolved in seawater. Since CO2 is a weak acid, this increased content will increase ocean acidity.

Seawater is in principle far from acidic. It is in fact on the opposite end of the scale measuring pH and we say that the ocean is "basic" or alkaline. Seawater tastes salty because it is saturated with large quantities of dissolved minerals, especially calcium, carbonates and other "anions." This is what makes the water basic. Many organisms in the ocean have shells or an external skeleton made up of calcium carbonate. We generally call this simply calcium. Many phytoplankton and zooplankton, as well as snails, mollusks, shrimp, lobster and crabs, have shells made of this mineral. Since seawater is saturated with dissolved minerals, these species simply take whatever they need in the way of carbonate ions (CO32-) from the water. They can then use these to build or maintain a shell of calcium carbonate (CaCO3), as long as the species has developed specialized cells to carry out this task. When we speak about ocean acidification, we actually mean a degradation of seawater's basic or alkaline characteristics. When less carbonate ions are available in seawater, absorption of carbonate from the water becomes more energy-intensive. The organisms need to adapt to the new reality and keep up with the gradual acidification.

For the time being, studies indicate that the marine animals investigated tolerate the degree of acidification we have caused up to the present day, but that future levels can present a challenge for a number of shell-building species. In the Arctic there are small, free-swimming snails called butterfly snails that live freely in water bodies and are important species in the food web. Some of the species have very thin and light-weight houses. In experiments carried out in Svalbard, scientists simulated anticipated acidity levels for the year 2100. When they measured the effectiveness of the shell-building cells of the sea snail species *limacina helicina*, they found that the rate was reduced by 28 percent. The experiment demonstrated that it becomes in fact more difficult to absorb carbonate ions and build shell as ocean acidity increases. The ocean has become thirty percent more "acidic" since pre-industrial times and according to calculations, it will be fifty percent more acidic by the end of the 21st century, if the emissions curve is upheld.

Acidification is not evenly distributed throughout the planet. Because colder seawater can hold more dissolved gas, the CO2 absorption in the surface layer is much greater in the Arctic and Antarctic than by the equator, and in these regions, ocean acidification is progressing more quickly. In the north, the effect is therefore two-fold: both warming and ocean acidification are occurring more rapidly. Acidification will be curbed when we reached "net zero" or stop emitting CO2 into the atmosphere, but the acidification of the deep water will continue for a long time, as water containing greater amounts of dissolved C02 is gradually circulated and mixed more deeply into the ocean.

What if we are unable to curb CO2 emissions?

A maximum atmospheric warming of 1.5°C is an important milestone, one which we should not exceed if we are to prevent the planet from approaching several dangerous tipping points. For example, there is a high risk that the inland ice of Greenland and the West Antarctic ice will be destabilized and melt if global warming reaches around 2°C. The permafrost in Siberia and Northern Canada is also at risk, and melting is already underway. This is a particular cause for concern because large quantities of the effective greenhouse gas methane (CH4) will be released, which will occur with the thawing of decomposed and partially decomposed organic matter stored in the permafrost.

As I am writing this, the temperature increase is already just above 1.1°C. What will happen to the ocean if we fail to limit the emissions quickly enough to stop global warming and instead trigger runaway warming? A study from 2016 calculated the global warming in such a scenario. The study found that the ocean's ability to absorb carbon would decrease towards the end of the 21st century, which would increase the average global temperature by approximately 8°C around the year 2300.

In such a scenario there is a danger of losing the valuable deepwater formation system that now sends oxygen down to deeper layers, whereby we will end up instead with a stronger stratification of the ocean. What will happen if the precious delivery of oxygen to the ocean depths is debilitated? Is there a possibility of this becoming a reality? These are some of the big questions related to global warming. One thing that is absolutely certain is that the ocean has delayed atmospheric warming considerably. More than 90 percent of the "surplus heat" has been captured by the ocean since 1970—and predominantly in the uppermost layers. There are already signs indicating that the deepwater formation in the North Atlantic, which is called the Atlantic meridional overturning circulation (AMOC), is slowing down. New model-based calculations indicate that due to an increased freshwater supply from the melting of ice on Greenland, AMOC is being weakened and is headed for a tipping point, upon which deepwater formation can collapse within a period of 100 years. This will have a number of serious consequences for marine life. First, it will lead to a loss of much of the ocean's productivity. A strongly stratified ocean in which only the surface layer contains oxygen will quickly become low in nutrients and resemble the Black Sea as it is today, where life can only exist in the upper 100 meters of the water column. Below this, the Black Sea is without oxygen or "rotten." It contains hydrogen sulfide (H2S) which smells like rotten eggs.

The upwelling of deep water (see Chapter 2), which will continue where wind systems drive surface water away from the coast, will become a double-edged sword for life in the stratified ocean. Nutrients from the depths will be welcome, but the oxygen-free deep water will also contain hydrogen sulfide, which is poisonous for most organisms. Toxic "belches" of this nature have already occurred in regions with powerful upwelling. An example is the Benguela upwelling system along the coast of Africa in the southern Atlantic Ocean. Northerly winds produce Ekman transport of the surface layers, so the northern moving Benguela current is pushed out to sea and cold, nutrient-rich water wells up along the mainland. All the nourishment that is made available by this system provides the basis for large-scale production of phyloplankton near the ocean surface and the algae that are not eaten and are a part of the food web "snow" downward onto the seabed. When the dead algea decomposes, the oxygen in the zone close to the seabed is consumed and hydrogen sulfide is formed in the oxygen-free decomposition driven by sulfur bacteria. In Namibia such "rotten" bottom water is sometimes transported to the surface in such large quantities that fish die and people have to stay indoors until the wind has blown away the toxic and foul-smelling gas.

The second probable effect of a strongly stratified ocean will also have a grave impact on life on the entire planet. The ocean's enormous volume and ability to distribute heat between different depths has enabled it to absorb and store large quantities of energy. If the thermohaline circulation is curbed and altered in a stratified ocean, the ocean's capacity to absorb and store carbon and heat will therefore be drastically reduced. Then we lose the deep-sea thermostat effect and other parts of the climate system will have to absorb the heat instead. In practice, this will mean that cooling must predominantly take place through evaporation and radiation, and the ocean's surface layer, the atmosphere, and land masses will maintain temperatures that can be far too high for life as we know it to thrive on the planet.

Climate changes constitute a threat to the health of the ocean and life on the planet. It is therefore important to disseminate the contents of this chapter. I personally found grounds for hope in 2015 when I started working with coral reefs and small-scale fisheries in the Red Sea. This small and virtually landlocked sea has been able to offer its species extreme variability in the form of desiccation, warming, and seclusion. Because it is located so far north, the temperature can vary from 24°C in the winter to 34°C in the summer, a wholly extreme seasonal temperature difference for a coral reef ecosystem. Surrounded by desert on all sides, the stress from land runoff is minimal to non-existent. As a result, the coral reefs have received "training" in warming; they seem to be robustly resilient to climate changes. Along the long coast of Sudan is one of the world's most intact coral reef ecosystems.

In May 2024, it appears that the El Niño event which resulted in record high temperatures in 2023 is in the process of abating. Earlier in the spring, as the southern summer was coming to an end, I followed the updates from the helicopter flyovers done by colleagues at the Australian Institute of Marine Science along the Great Barrier Reef. Yet again they have documented that the heat led to a so-called mass bleaching of coral, where large areas of different segments of the 2300-kilometer-long barrier reef have been affected. Simultaneously, diver teams from a number of institutions have observed large local variations in the degree of bleaching severity. Perhaps the coral in the Great Barrier Reef is in the process of adapting to the new "normal". The least robust variants are becoming rarer while those with the greatest heat tolerance are for the time being soldiering on. There are also examples indicating that intact ecosystems are more resistant to the changes—they have a greater degree of resilience. We can to a large extent contribute to fostering this through preservation and restoration. The time has come to work with nature conservation also under water.

(END SAMPLE)