The ocean is our future

KIEL MARINE SCIENTISTS ON
A TIME TRIP TO 2100

2100

future ocean
KIEL MARINE SCIENCES

2100

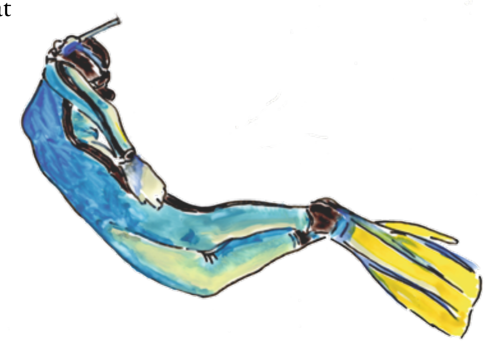
Illustrations by Corinna Kraus-Naujeck and Kerstin Mempel (artist group Blauschimmer).

The oceans mean well with humankind. They are a vital source of food and a regulator of Earth's climate. They make it possible for trade to flow to all corners of the world, while their beauty provides solace to our souls. And are we grateful? No: we exploit them, poison them with our effluents and emissions – and show scant interest in their health.

The marine researchers who have joined forces in the Cluster of Excellence "The Future Ocean" in Kiel, Germany, are scientists of international standing who normally publish their work in specialized journals and monographs without judging the oceans' need for protection. Here, however, they explain why we must change our minds and return to responsible stewardship of the oceans.

The authors explore the most varied aspects of the oceans in their daily work – the creatures that populate them, the sea surface, the currents that course through them and the sea floor with its great bounty. They tackle complex issues while always seeking to find answers that are as straightforward as possible. Yet even they can sometimes find no answers.

In *The Ocean is our Future* scientists give us easily understandable insights into their fields of research. Each takes us on a personal journey through time: to the oceans of 2100. Some of their visions are dramatic, some pessimistic and some optimistic; some express heartfelt wishes. Their perspectives are as diverse as the colors of the sea. Yet what unites them is their common endeavor: to motivate people to handle their most valuable habitat with greater awareness and more concern for sustainability.



“We must take the oceans seriously.
It is here that much of our future will play out.”

MARTIN VISBECK

MARTIN VISBECK

Keeping a watchful eye on the ocean through the generations – A drama in three acts

__Prof. Dr. Martin Visbeck__ is head of the Cluster of Excellence "The Future Ocean", deputy director of the GEOMAR research centre, and a member of numerous international working groups. His research focuses on ocean circulation and climate dynamics in the Atlantic.

Prologue:

For thousands of years, we humans have treated the oceans as if they had infinite width and depth. We could take out whatever we wanted, and put in whatever we needed to get rid of, nobody cared. Only toward the end of the 20th century have we learned that the oceans are a finite and limited resource.

Act one:

Just a small splash as the bucket reaches the surface. Wilhelm Heinrich, the first officer, flexes his strong arms as he pulls the bucket of seawater onto the deck. He then holds the thermometer to get a reading of the sea surface temperature: 18.7° Celsius. Officer Heinrich nods his head in approval, the colder temperatures are surely a sign that Europe is coming closer and the long voyage is coming to an end. He carefully enters his recording in the logbook of the Flying P-Liners. He wouldn't know that many years later climate researchers would have liked to have known whether his bucket was made of metal or canvas, if the reading was taken in the shade or exposed to the chill wind, or how long he had waited after the bucket was on deck. All of these factors might have contributed to a "true" temperature reading of 18.8° or even 18.85° Celsius.

Officer Heinrich checks the trim of his square sails, quickly calculates the number of miles covered over the last 24 hours, and feels fairly certain: The ship will reach the port of Hamburg in less than two weeks. He may use the help of the Diesel engines if necessary because the first ship in port gets the best price for its cargo, and bonus pay for the crew as well. To him the ocean is his workplace, he loves the wide open spaces, the rough yet taciturn life at sea. He dreams of his son becoming an officer as well, perhaps even a captain of a whaler. Merchant shipping and fishing are dependable jobs to feed a family. He also dreams of telling old seafaring tales to his grandchildren, of the struggles to round Cape Horn, of dolphins and whales in the Horse Latitudes, and of glorious sunsets on the High Seas. Wilhelm could not imagine that square riggers would some day be used only as museum ships or to entertain visitors during tall ship parades. Or that containers would revolutionize maritime shipping, and international treaties would be needed to ban whaling to protect those giants from extinction.

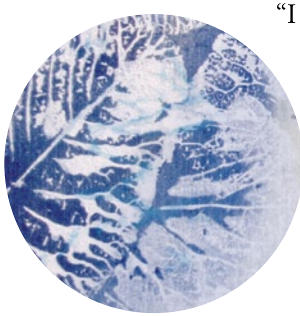
Act two:

"Ten minutes to station" the crackling sound comes over the intercom. Marine researcher Marna Wegner appreciates the heads-up warning, not all of the officers are as mindful. Her eyes wander from the computer screen to the navigation display: Indeed, only two miles to the station. Time to pull on the boots and put on the helmet, and prepare the CTD for deployment. The CTD is a highly sophisticated measuring probe lowered on an 8 km long wire attached to the research vessel METEOR. This is Marna's fifth research cruise into the North Atlantic, and she knows the routine of deep temperature and salinity measurements quite well. She is the watch leader now and has two students assisting her. Fortunately, the seas have calmed down and her entire team is up and ready. Only a few days ago she had to do most of the work herself as both of the students were seasick and unable to work. The data will be transferred to an international data center via satellite phone within a few hours but the final calibration must still be done by carefully checking the salinity probes at selected depths. To Marna and oceanographers in general, it makes a huge difference if the salinity value is 34.73 or 34.74, a difference so small that it can't be detected at first glance.

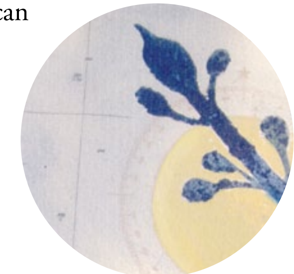
There are times, perhaps after her watch at 5 in the morning, when Marna gazes over the horizon and dreams – of how beautiful the ocean is, and how much more enjoyable it could be without the constant humming of the Diesel engines. To just once listen to nothing but the ocean itself. Marna also realizes that she spends too many months of her life as a researcher at sea. That much of the routine sampling could be done by robots. During the last conference she attended she heard of instruments that cut through the ocean like dolphins, surfacing every 4 hours and transmitting the data to the lab via satellite – so-called Gliders. What an idea! And then she starts worrying about her future, her project-funded position, never knowing if funding will be extended on time. She's thinking of starting a family but when is the right time to do it? Lots of questions about the future. But one thing is certain for Marna: She loves the sea, and she never wants to live too far from it. She fondly recalls Grandpa Wilhelm's stories – of faraway lands and sea monsters and man-eating natives. Just one aspect she never liked, when Grandpa would insist that women on board are harbingers of bad luck ... "Poppycock" she would retort ... hoping that her children and grandchildren would still be able to enjoy the beauty of the sea, walk the shores, and deeply inhale the fresh air of the sea … but just how certain could she be of that?

Act three:

On the other side of that thick glass pane, a huge grouper swims by. Luiz catches a glimpse of it out of the corner of his eye but doesn't really pay attention. These groupers are simply there, just an omnipresent part of Delta-7, the new underwater research station. This grouper was given a new set of chemicals two weeks ago, and the amoeba culture of his bioreactor had to be replaced as well. The manufacturer had promised a life cycle of 2,000 hours but the efficiency had dropped below acceptable after only 1,200 hours. Luiz and his team have been living inside of Delta-7 for two months, experimenting with a swarm of artificial groupers which allows the scientists to monitor the coastal waters. “Back in the old days,” Luiz recalls, “robots were mostly made of metal, rigid, inflexible, and highly wasteful.” These groupers have bioreactors for energy generation, and artificial muscle fibers for propulsion. “Propellers are no longer needed, too bulky, noisy and inefficient”. The researchers live below the surface inside the Delta-7 modules. Energy, nutrients, and air are produced from the sea itself. After work, Luiz dreams of his family, his two children, that’s all the government would allow. They live 2,000 km from the Delta-7 station. He can’t go to the nearby beach without a protective suit, too many toxic substances have accumulated, waste products from the marine enery plant onshore. Luiz finds himself able to tolerate that, after all the area around Delta-7 generates 15 per cent of the world’s energy and allows his family to live a comfortable life far inland. And at least he is able to communicate with them at any time, using his new 3D vison system, except the touch module doesn’t work right. He says “My daughter laughs when I try to tickle her with that, not because of the sensation but because of my clumsy efforts.”



“I think it is great that we are able to observe and monitor the ocean at all times, and that we can record the changes as needed,” he says with a sense of satisfaction. But then he remembers the stories Grandma Marna told, of seagulls screeching along the harbour, beachside skinny-dipping at night, and – with a little bit of luck – marine plankton glowing during the full moon. “Life is good,” Luiz says, and he is glad that the major unrest of his parents‘ generation is over and done with. “They should have been more considerate of social justice and less selfish back then” he thinks out loud, “then the transition to a sustained society would have been less bloody. But that's history, and today we know how to understand and utilize the ocean, and not take more than we can put back. I hope and wish that my grandchildren will love the sea as much as I do, and that they will be able to walk the shores once again."



The swarm of artificial groupers and affiliated sensors is designed to detect all changes in the environment and forward this information to the coastal resource managers. There are also swarms of larger robots cruising the open ocean. They utilize the temperature difference between the warm surface layers and the cold abyssal sea to produce energy for their crucial mission. They still don't have any bioreactors or self-regenerating sensors. "That is the second grand innovation of our grouper systems," says Luiz with a hint of pride and satisfaction.

Epilogue:

The oceans are a vital part of our environment, or perhaps the most important link to our human habitat. They supply oxygen to our atmosphere and facilitate transportation routes for global commerce. The oceans host the largest integrated eco system on Earth, they produce food and swallow our waste products. Our generation faces the challenge of shaping the use of marine resources such that sustainable development becomes the Number One priority. It is within our power to minimize the flow of excessive nutrients in rivers and waterways, to keep plastics out of the ocean, and to closely regulate the discharge of greenhouse gases, such as carbon dioxide, oil products and radioactive materials. Together we can preserve the ocean of the future as a beautiful and useful resource, and we can minimize the dangers and risks the oceans hold for mankind.

“The deep sea is the final great frontier of our planet”

SVEN PETERSEN

Mineral resources from the deep sea

SVEN PETERSEN

Dr. Sven Petersen *is a mineralogist at GEOMAR. He works on the mineralogy and geochemistry of marine sulfides, as well as on toxic metals in the marine environment and submarine hydrothermal vents. Employing autonomous underwater vehicles, Petersen also investigates the preconditions and prospects for the future extraction of resources from the sea.*

The deep sea is the final great frontier of our planet. It is accessible only with great difficulty and at great expense. Nonetheless, its potential as a source of mineral resources has attracted significant interest in recent years. Three resources are of primary importance: manganese nodules in the abyssal plains, cobalt-rich manganese crusts on the slopes of extinct volcanos, and massive sulfides that form at spreading centers where new ocean floor is created.

We have known of the existence of such resources for over a century. The first manganese nodules were recovered from the deep sea floor of the central Atlantic by the **Challenger Expedition** of 1872 to 1876, but at that time their relevance was not recognized. Manganese nodules are lumps of minerals ranging in size from a potato to a head of lettuce, which cover vast areas of the deep sea floor. They are composed mainly of manganese, iron and silicon and are formed by precipitation of metals from seawater and porewater fluids in sediments. The nodules form very slowly, growing only a few millimetres in a million years, and therefore cannot be considered a renewable resource. The greatest densities of nodules occur off the west coast of Mexico, but they are also common in other areas of the Pacific and, to a lesser degree, in the Indian and Atlantic Oceans. It is not the manganese which is of greatest economic interest to industry, however, as the name might suggest.

The Challenger Expedition was a 3½ year research mission undertaken by HMS Challenger, a British navy corvette, which shed much light on the structure of the ocean floor and the location of islands.

There are more than enough onshore occurrences of this metal to last us for the next few decades and beyond. Of rather more importance are the elements copper, nickel and especially cobalt, which are present in lower concentrations and make up a total of around three per cent by weight. There are also traces of other metals such as molybdenum and lithium as well as rare-earth metals, which are needed for various key technologies.

Manganese is used by the steel industry. It removes oxygen and sulfur from the steel, and hardens the material. Manganese is also used in alkaline-manganese batteries.

For a long period of time after the discovery of the **manganese** nodules little interest was shown in these potato-shaped objects on the ocean floor. Then, in the 1960s and 1970s, fears of an imminent resource crisis began to grow, a concern shared by the Club of Rome. This global think tank of politicians, scientists and economic experts warned of impending resource shortages and dramatic price rises as a result. Consequently, individual nations and several business consortiums searched intensively for resources, not only onshore but also at sea. They invested a great deal of time and money exploring the deep sea in general and manganese nodules in particular, investigating their potential and developing technologies to use them. But ultimately the Club of Rome's predictions did not materialize. Successful exploration and research of onshore metallic minerals eased the markets, and marine activities were put on hold again. However, during the years that followed, other potential resources in the deep sea were discovered and investigated. These included mineral occurrences associated with "black smokers" and the cobalt-rich manganese crusts on the slopes of the submarine volcanos of the west Pacific. The enormous price increases of recent years, triggered by the appetite for resources of nations such as China, India, Brazil, Indonesia and others, have resparked the interest of politicians and industry in the potential of marine mineral resources.

Manganese crusts develop on all underwater rock surfaces. Like manganese nodules, these metals are also precipitated from the surrounding seawater, but they contain three times more cobalt, ten times more tellurium and three times more rare-earth elements than manganese nodules. They grow just as slowly as manganese nodules, meaning that thicker crusts are only found on ancient, inactive volcanoes. The most substantial crusts occur at water depths of 800 m to 2500 m on the flanks of old submarine volcanoes in the west Pacific, where they cover large areas of the ocean floor. We need only to imagine a volcanic landscape under water to comprehend the difficulties involved in mining these deposits. The rugged terrain places exceptional demands on mining technology. It is unsurprising, therefore, that the mining of crusts has not yet gone beyond the conceptual study stage.

One of the most unexpected deep-sea discoveries of recent decades has resulted from observing hydrothermal vents on the ocean floor. Here, in an area where no sunlight penetrates, a thriving community of sea life has been found – a previously inconceivable notion. These hydrothermal vents form at submarine plate boundaries where volcanic activity and cold seawater interact, exchanging heat and minerals from the rocks of the Earth's crust. At these deep-sea oases, as they are also called, microorganisms live off of chemical substances released through "black smokers" into the sea at temperatures of up to 400° Celsius. The microbes process hydrogen sulfide, for example, and provide the basis for endemic communities. The black "smoke," which forms when the hot solutions meet the cold seawater, consists of metalliferous sulfur compounds, which also pile up to form chimney-like structures and mounds. The metals that form these mounds include not only iron, copper and zinc, but also the precious metals gold and silver. Accumulations of some of these elements have aroused the interest of industry. Iron is not considered of special significance because there are enough onshore deposits that are cheap and easy to mine, but the copper, zinc and gold content is sometimes substantial. We now know of more than 250 occurrences around the world in water depths of up to 5000 meters. Most of these, however, have a diameter of only a few tens of meters and contain negligible amounts of metal. Few mineral occurrences are of real economic interest due to their size and chemical composition.

The amounts of copper, cobalt and nickel in manganese nodules and crusts are comparable to those onshore, but for various reasons – economic, technological and environmental – there are no immediate plans to exploit the mass resources of manganese nodules and cobalt crusts. Nonetheless, investigation of these deposits continues, driven primarily by the economic interest of industrialized nations and emerging economies in ensuring a reliable resource supply. The "massive sulfides", on the other hand, present better prospects. Mining of these small, metal-rich occurrences is soon to commence. Paradoxically, we can assume that marine mining of massive sulfides will not have a major influence on the worldwide supply of resources, because most deposits are rather small and the total tonnage of metals contained in these deposits is low when compared to land-based occurrences. Demand will continue to grow in the industrialized nations, driven in part by new technologies. For instance, the manufacture of an electric car requires about three times more copper than a gasoline-powered car. Over the long term this will inevitably lead to marine mining of manganese nodules and cobalt crusts. We may assume that in 2100 there will be ships sailing the oceans as extraction platforms, conveying minerals mined from the ocean. This does not mean that onshore mining will be reduced or even discontinued, as the ever-growing demand for metals will still need to be satisfied. To ensure the survival of species, national and international marine **refuge areas** will protect large expanses of the sea floor from mining activities. Protective zones will also have been established in the immediate vicinities of mining areas to enable recolonization to neighboring locations from hydrothermal vents.

There is currently a global debate on whether to designate international marine refuges in order to protect areas with special biological or geological features from fishing, resource extraction and all other uses.

"Our knowledge of the ocean gives cause for concern."

MOJIB LATIF

MOJIB LATIF

The ocean at the turning point: Where should the journey go?

__Prof. Dr. Mojib Latif__ is a climate researcher and head of the Ocean Circulation and Climate Dynamics Division at GEOMAR, and a member of numerous international working groups. His research focuses on the predictability of natural climatic fluctuations and the impact of humans on climate. Latif is tireless in his efforts to inform the general public and motivate them to actively work against climate change.

Our seas are suffering. Humankind is putting them under increasing stress. Not only are they impacted by climate change and human exploitation, we have turned the underwater world into our rubbish dump. Oil, toxic waste, plastic, synthetic fertilizers, sewage … they all end up in the sea. "If in doubt, throw it out" – and why not dump it in the sea? That's our attitude at present. With the sea apparently so vast, our small amount of trash can't hurt … can it? We can't hear the distress signals. Still waters run deep, as they say, and the sea is simply a silent and unnoticed presence. But our sins are building up, slowly, imperceptibly. The ocean's temperature, salinity, and chemical and biological properties are gradually changing, and entire ecosystems are changing with them. And this is bound to affect many processes that we do not yet understand. But a clear message is coming from the monitoring data: ocean change is occurring. And it's a message that we need to hear and understand – for nothing less than the future of humankind is at stake.

We have reached a watershed. Will we succeed in protecting the world's oceans, or are we incapable of learning? Despite the warnings, humankind is still burning vast quantities of oil, coal and gas to generate energy, releasing of carbon dioxide (CO_2) into the atmosphere. Since the start of the Industrial Revolution, atmospheric CO_2 levels have risen by a staggering 40 per cent. And there's no sign of improvement: the annual climate conferences regularly end in failure, while carbon dioxide continues to warm up Earth's surface, the lower atmospheric strata and the sea. This greenhouse effect is in fact a perfectly normal process, which helps to ensure optimum living conditions on Earth. Without atmospheric **greenhouse gases** such as water vapor, methane or, indeed, carbon dioxide, Earth would be an ice-bound desert with surface temperatures well below freezing. But more carbon dioxide in the atmosphere reinforces the greenhouse effect and inevitably causes temperatures to rise. The 20th century experienced the most rapid average temperature increase for thousands of years: 0.7° Celsius.

Greenhouse gases are gaseous substances in the atmosphere that influence the radiative balance and contribute to global warming. They can be of natural or anthropogenic origin.

This might appear to be a minor amount of global warming – less than 1° Celsius – but its effects are unmistakable. Almost all the world's glaciers are shrinking rapidly. Arctic ice cover has shrunk by around 30 per cent over the last 30 years, and global sea level rise averaged almost 20 cm over the course of the 20th century. Without an active and binding commitment to protect the climate, global warming of a further 3 – 4° Celsius is expected by the end of this century – a temperature increase on a scale and at a speed unprecedented in human history.

So far, the seas have done us a big favor by cushioning the impacts of climate change. Almost half the carbon dioxide emitted from our burning of fossil fuels since the start of industrialization has been absorbed by the oceans, along with much of the atmospheric heat generated by excess greenhouse gases. For that reason, global warming has remained at a relatively low level so far. Surely that's a good thing for humankind! Well, not necessarily. So far, the seas still seem to be on our side and are helping to cancel out our countless transgressions. The question is: for how much longer?

It has been almost 40 years since the Club of Rome published its report The Limits to Growth, which argued that relentless resource consumption would plunge humankind into a deep crisis. The report predicted that conditions would change only gradually at first, and this is what we can see happening in the seas today. But it also warned, based on modeling, that systems – whether biological or economic – can change very rapidly with very little warning, reaching a tipping point that could have dramatic consequences for humankind. Today's ocean warming is putting marine ecosystems under massive pressure to adapt. Numerous marine organisms have a very low tolerance to higher temperatures. For example, we know that some tropical coral species will die off if temperatures increase by much more than 1° Celsius – a death sentence for the unique ecosystems that surround and depend upon them. With climate models predicting an ocean temperature rise of more than 2° Celsius by the end of the century in a worst-case scenario, this will spell the end for almost all the world's tropical coral reefs.

Carbon dioxide absorption is also causing acidification of the oceans. This is already measurable and mainly affects the waters in the polar regions at present, because solubility of carbon dioxide is an inverse function of seawater temperature – the colder it gets, the more CO_2 is absorbed. Alongside rising temperatures, acidification is a further **stress factor** for the world's oceans related to climate change. By the end of the century, this acidification could well reach a higher level than at any time in the past few million years. But there are other stressors too, such as the progressive contamination of the seas with numerous substances that we accept as a matter of course. Dramatic and spectacular disasters – such as the massive oil spill in the Gulf of Mexico and the nuclear contamination of the Pacific from the Fukushima reactor – are just the tip of the melting iceberg. No one knows exactly how the seas will react to global change. What seems certain, though – based on our data about the state of the world's oceans – is that there is every reason to be concerned.

Stress is a mental and physical response on the part of living organisms that is triggered by specific external stimuli and enables an organism to cope with particular pressures. In the course of evolution, stress has resulted in organisms being better able to tolerate pressures.

Various international conferences (Rio, Kyoto) have sought to establish agreement on binding rules to reduce anthropogenic emissions of CO_2 and other greenhouse gases. Such rules are implemented at the national level by climate change mitigation goals. Germany, for instance, aims to reduce its greenhouse gas emissions by 40 per cent from the 1990 baseline by the year 2020.

Based on our current knowledge, we can be sure that if we continue to pollute the seas as we are doing today, they will be unable to adapt, leading to severe degradation of our oceans. The effects are hard to predict, but they could well be catastrophic. For example, the seas' efficiency as a major carbon sink could decrease, leading to accelerated global warming. In that case, even more radical reductions in carbon dioxide emissions would be needed in order to reach specific **climate goals**. Pollution could also severely impact on the seas as a source of food – which we are still using unsustainably, the problem of overfishing is all too familiar – causing serious damage to ecosystems and dramatically worsening hunger in the world. These are just some of the reasons why we cannot continue our experiment with the Earth System, despite our lack of absolute certainty about its effects. There is never any "absolute certainty" in science – but the well-founded assumption that we are on completely the wrong track should be a good enough reason to abandon our present course as swiftly as possible.

There are so many other options available to us. Solar and wind are, practically unlimited sources of energy. After all, they provide enough energy to move the vast amounts of water in the oceans. We should harness this potential. Nature has valuable lessons that we can learn. Photosynthesis is a good example: it shows us how to create growth from solar energy. Why shouldn't this principle be applied to the economy as well? Protecting our environment offers us a positive economic perspective. We have no option but to pursue new pathways – to protect our oceans and, above all, to protect ourselves.

My vision for 2100 is this: we will have stopped putting our oceans under stress. Instead, we will be treating them with the utmost care and respect that they deserve. Solar, wind and geothermal will form the basis of our energy supply. They offer us long term prospects, for they can supply all the world's people with affordable and, above all, clean energy. Global carbon-dioxide emissions will have fallen dramatically, and global warming will have stabilized at a level that no longer poses a threat. Ocean acidification will have slowed down considerably. There will be no more oil spills and no prospecting for oil in the Arctic or other sensitive areas. Nuclear power will be consigned to the history books, for we will have energy in abundance. And air quality in many urban centers will have improved – there will be no more plumes of smoke from industrial chimneys. In short, all the world's people will enjoy a better quality of life.

Simply by switching to renewable energies, humankind could do much to ease the pressure on our oceans. If we get the message that we need the oceans and can use them without degrading them, the sea will remain our ally and will continue to provide us with adequate food and nourishment. Biodiversity will be preserved, and a view of the ocean will continue to delight and thrill. Instead of being a foul and stinking cesspit, our seas will still be the brilliant diamond that can be seen and marveled at from space.

“Coral reefs are oases of biodiversity in the sea.”

WOLF-CHRISTIAN DULLO

WOLF-CHRISTIAN DULLO

Coral reefs: Flower gardens of the sea

***Prof. Dr. Wolf-Christian Dullo** leads the “Paleoceanography” research unit at GEOMAR. His research interests include climate and the condition of the oceans in the course of Earth’s history. Dullo analyses scleractinian coral reef carbonates to draw inferences for worldwide sea level fluctuations and climatic changes.*

Coral reefs are oases of biodiversity in the sea. People have long been attracted by the wonderful colors of the reef builders and reef dwellwers. This attraction, in addition to a generally increasing interest in nature’s diversity, is likely to have been one of the reasons that corals became highly desired objects in natural history collections of the late 17th century and 18th century. Due to their shape, corals were often labeled “flowering animals” and Carl Benjamin Klunzinger appropriately entitled his monograph (1877) on the stony corals of the Red Sea “Abhandlung über die Blumenthiere” (‘Treatise on the flowering animals’). No one who has experienced the many colors of a tropical coral reef first hand will be able to resist the enchanting beauty of what is probably the most complicated marine ecosystem, even though it wasn’t untill in the 20th century that humans achieved the technical capability to spend any significant length of time in this habitat.

Coral reef ecosystems have a long geological history, and their development through time has been significantly influenced by the evolution of the organisms which build reefs. Initially algae and bacteria formed communities, followed by calcareous and siliceous sponges and corals, very much different from the stony corals we know today. These early reef builders nevertheless created reefs of great thickness, the remains of which we can see today as exposed carbonate bedrock in many areas. Today's reef corals first appear at the beginning of the Mesozoic era (Triassic) about 250 million years ago. They differ from their earlier ancestors by the presence of zooxanthellae, small green algae that live in symbiosis within the coral tissue, providing their host with energy from photosynthesis. The corals in turn provide protection for the algae. These modern stony corals formed the massive carbonate formations of the Northern Limestone Alps and the Dolomites at a time when this region was still covered by the sea. This close relationship between the geological manifestations of carbonate mountain ranges and coral reefs has led geologists to don goggles, snorkels and diving gear – instead of taking their rock hammers into the field – to dive into the fascinating and colorful underwater world to learn more about the development and structure of reefs.

Ecosystem:
Spatially defined part of the biosphere in which organisms and their habitats interact.

It is a completely different experience to swim around in an **ecosystem** like a fish; it takes time to familiarize yourself with this very different world, especially if you use your scuba gear to dive to greater depths where a variety of blue hues take over from the broad color spectrum of the shallow areas. It is an impressive phenomenon that many red fish and red coral species live in depths at which red as a color is physiologically invisible; everything is blue. The great transparency of the water around tropical coral reefs is another unusual feature that fascinates visitors. At noontime daylight can still be seen as dim light even at a depth of 350 m if the sea is calm. The sun is still visible as a disc from depths of up to 160 meters under similar conditions. Tropical coral reefs thrive primarily in regions characterized by very low nutrient concentrations which prevail along the eastern coasts of the world's continents.

Stony corals, however, are not limited to tropical shallow water regions. As early as the 18th century, fishers using nets reaching to great depths found such corals off the coast of Norway. It was thought for a long time that these discoveries could only have come

from sparse populations occurring on the seabed and not from actual reefs. However, great advancements in the diversity and quality of marine scientific observation instruments have yielded the initially very surprising result that these deep-water or cold-water corals can form equally magnificent, diverse and colorful reefs. Their vibrant colors are the most astonishing, as organisms cannot perceive these colors at the depths at which cold-water corals occur.

Both of these reef systems host a great number of reef dwellers, and especially smaller fish species find excellent hiding places here. Therefore, this type of reef ecosystem is well known as a nursery ground for fishes. Excessive fishing has already resulted in significant damage of these highly sensitive ecosystems especially above and around cold-water coral reefs. Their tropical shallow-marine "cousins" are equally threatened by fishing, particularly by fishing activities concerning trade in marine fish species for aquariums. In Indonesia, huge areas of coral reefs have already died since not only fish but also stony corals, and colorful snails and mussels have become collectors' items. The greatest and most immediate threat to corals is posed by fishing activities, which contribute to the destruction of both reef types.

Unbridled **tourism** is an additional threat to tropical reefs. Moreover, corals are affected by global change such as global warming and acidification. Cold-water corals and tropical corals cannot tolerate any further increases in water temperature. Ocean acidification strongly affects the ability of corals and all other calcifying organisms to produce calcium carbonate. The wonderful fringing reefs around the main island of the Seychelles are long gone. If C. B. Klunzinger, the medical doctor and zoologist mentioned above, were to travel to the Red Sea at Hurghada in Egypt today, his chances of studying the "flower animals" would be slim. Much of the coral cover has been destroyed. Massive stony corals of tropical seas could also be termed "trees of the ocean" since they have growth

Diving tourism harms the sensitive reefs due to anchoring, trophy hunting or the simple carelessness of divers.

rings like trees that document their annual growth. These massive species have a life span of several hundred years and are thus incorruptible witnesses of global change. Their skeletons record almost month-by-month the surrounding sea surface temperature and other environmental changes.

My vision for the ocean in 2100 is that the reefs that are still pristine will remain that way and that some of those under threat or damaged may regenerate. This appears to be almost utopian wishful thinking taking into account the poor state of coral reefs worldwide. However, salmon are again moving up the river Rhine today, something completely unimaginable 40 years ago. Only sustainable use of these ecosystems can help both seas and reefs! That sounds good but the impression remains that such a call will fade away before

anything happens. Why is that? We can only succeed if we put our own house in order. If we look at our own families with their limited resources it is obvious that we can not buy everything we want. It is the same in the sea – its resources and "stores" are not limitless. We often have to abandon certain wishes to achieve other things. However, sacrifices are only made where empathy and true affection are found. My wish is that the ocean will be looked upon as part of the human family. Only then will it be regarded with affection and treated differently. This call for accepting the ocean as a "family member" is not rooted in mystic zealotry but justified on the basis that we simply could not live without the ocean. To give but one reason, it provides about 70 per cent of our daily oxygen requirements, i.e. the air we need to breathe. It is inextricably linked with our very existence!

"The economic costs of fishing are underestimated and more fish are caught than is economic viable."

MARTIN QUAAS AND TILL REQUATE

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TILL REQUATE

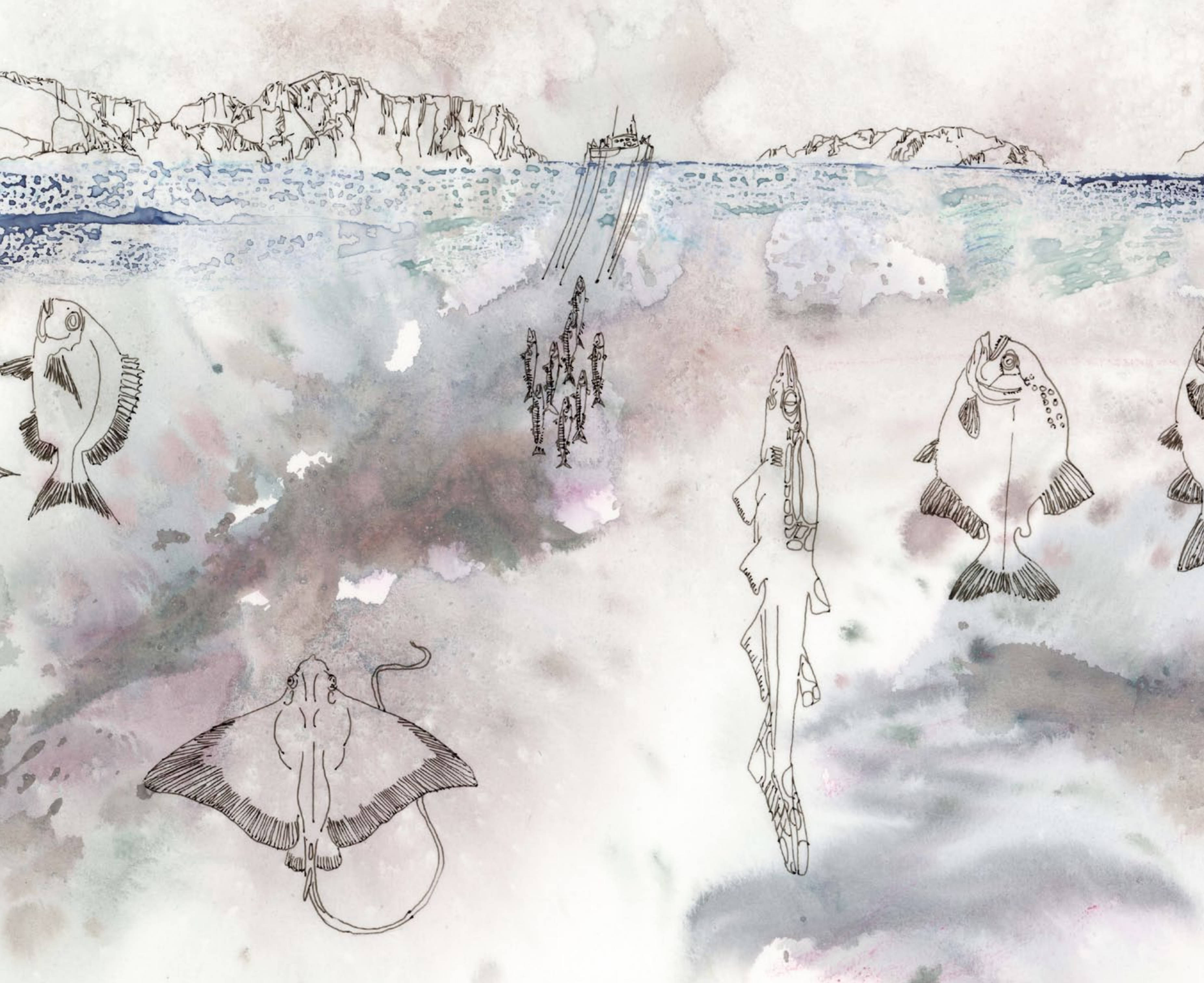
Do fish have a future?
The parlous state of marine fishing
– Causes and solutions

Prof. Dr. Martin Quaas *is professor of economics at the CAU in Kiel and studies the use of "living resources" in the Cluster of Excellence "The Future Ocean". He develops and analyses sustainable fishery management strategies by combining knowledge from natural science and economics.*

Prof. Dr. Till Requate *is a professor of economics at the CAU. In his research fields of environmental and resource economics and policy he focuses particularly on the effectiveness of climate policies. His research interests also include the thematic area "overfishing of the oceans", in which he develops new fishery management strategies.*

Fish is a vital source of food for humankind and plays an essential role in livelihood security, especially in poor regions of the world. With the steady increase of global catch volumes over many decades, numerous economically relevant fish stocks are now classified as overfished or depleted. According to the latest report from the Food and Agriculture Organization (FAO, 2011), the world's marine fish stocks are now in a worse state than ever before.

There are, undoubtedly, many causes of overfishing, but the problem mainly arises because marine fish stocks are a "common pool" resource: a fish, once caught, belongs to the fisherman or fleet operator, whereas no one really owns a fish that is still in the sea. Nonetheless, viewed in economic terms, a fish in the sea has a value by virtue of the fact that it reproduces and continues to gain weight, so the fishing yield will increase in the future if more fish stay in the sea. The cost of the fish being caught is that this value is lost; economists term this the "shadow price". In the case of overfished stocks, this shadow price may even exceed the market price obtained for the landed fish. However, the stocks of fish in the sea are a common pool resource, so in open and unregulated fishery with



no restrictions on access or on fishing activity, the fishers do not pay the true economic price, i.e. the shadow price, of fishing. In this scenario, the economic costs of fishing are underestimated and more fish are caught than is sustainable.

Sustainable management of fish stocks – which means no overfishing – would allow high profit margins to be achieved, so it is surely in the fishers' own interests to accept restrictions on access to these marine resources as well as caps on catch volumes. And indeed, in some fishing grounds under national jurisdiction, various mechanisms are in place to limit access and catch volumes. Effective instruments include landing fees (a charge based on the amount of fish actually caught), caps on catch volumes, and fishing quotas. These mechanisms can be supplemented by fishing bans in specific areas and/or at certain times, especially in spawning grounds or during the spawning season.

From an economic perspective, individual transferable quotas (ITQs) are a particularly appealing way of regulating fisheries. Under this regulation, the total catch for a specific fishery is capped. Fishers who are operating less economically are likely to sell some or all of their quotas and perhaps even leave the industry, while the most efficient companies can purchase additional ITQs. In the long term, the effect of this is to concentrate the quotas in a small number of fishery enterprises, thereby ensuring that the total allowable catch is achieved at lower cost. Ultimately, economic instruments such as landing fees or ITQs aim to ensure that, in their fishing decisions, fishers take account of the shadow price as defined above. If the total allowable catch is sufficiently low, the quota price matches the shadow price. Some countries who are able to control the **fishing grounds** that lie **within the limits of their national jurisdiction** without intervention from any neighbors – Iceland and New Zealand being prime examples – are managing their fisheries very successfuly on the basis of these tradable quotas. They have thus managed to stabilize major fish stocks within their 200 nautical mile limit or even rebuild them and restore their productivity.

Every state that borders on the sea has a designated zone in which it has the exclusive right to extract or use resources (fish, oil, etc.). This zone normally extends 200 nautical miles from the coast.

Experience has shown that drastic cuts in the total allowable catch do pay off. In recent years, for example, we have seen a remarkable recovery of **cod** stocks in the Eastern Baltic since the European Commission – after years of wrangling around the negotiating table – finally agreed to substantial quota reductions, backed by far more rigorous enforcement. Our calculations indicate that if this rigorous management strategy continues, this fishery will yield annual profits well in excess of EUR 100 million within a few years.

Cod is one of the most important eating fish in Europe. Since 1970, however, several stark have collapsed worldwide due to overfishing.

Fisheries management works best when a single country controls the major fish stocks, as is the case with Iceland, New Zealand and several other nations. In fishing grounds with several or many coastal states, on the other hand – such as the Mediterranean, the North Sea and the Baltic Sea – fisheries management is much less effective or does not work at all. There are various causes: among other things, individual countries may give preferential treatment to their own fishers (in the short term) by failing to adequately monitor compliance with fishing restrictions. Furthermore, fishers from different countries may not trust each other to adhere to the agreed regulations. Instead of limiting efforts and capping catch volumes, many governments therefore do the very opposite, by subsidizing fishers who – in a situation of free access to resources and a highly competitive environment – do not make a profit or perhaps even show a loss. This makes the situation even worse. Every year, more than USD 10 billion is paid to fishers in the form of fuel subsidies or via modernization programs around the world, 80 per cent of it in the industrialized countries.

According to calculations by the World Bank, the global fishing effort should be reduced by 44 – 54 per cent in order to maximize total economic benefits from global fishery, i.e. in order to achieve maximum economic yield. The World Bank estimates the loss of future net benefits due to overfishing to be in the order of USD 50 billion annually – a substantial figure compared with the total annual landed value of fish globally, i.e. around USD 90 billion. Unfortunately, however, ongoing enforcement and monitoring of the necessary regulations is difficult and costly. If a particular fishery is highly profitable, fishers may be tempted to drive up their earnings even further by making illegal landings. Around one-third of fishery products reaching the market is thought to come from illegal fishing or fishing activities that circumvent international agreements. Illegal, unreported and unregulated (IUU) fishing obstructs efforts to conserve and maintain fish stocks. IUU fishing also involves vessels that are registered in countries whose own standards do not meet those adopted by the international community or who lack the capability to establish control mechanisms. IUU fishing therefore mainly harms artisanal fishery in the coastal regions of developing countries.

The EU's approach to fisheries management and especially its quota regulations are inadequate, but the situation outside the 200 nautical mile limits, and also off the coasts of many poor countries (especially in Africa), is infinitely worse. The lack of regulation and the inability of many countries to enforce fishing restrictions have resulted in massive depredations here. The use of state-of-the-art technology to locate schools of fish, including modern sonar, is exacerbating the problem. So far, the European Union countries have taken little action to curb these depradations. On the contrary, they indirectly support this type of conduct by Chinese fleets, for example, by "laundering" illegally caught fish at transit points on EU territory, such as the Canary Islands.

Our pessimistic vision for the oceans in 2100 is that many fishing nations will still be avoiding stringent short to medium term fishing restrictions. Instead, increasingly efficient fishing fleets will have decimated stocks to an even greater extent in order to meet the still rising demand in economically powerful countries. As a result, stocks within the 200 nautical mile limits of the African countries and, later, of many other countries as well will be completely depleted. In the few fishing nations with sustainable fisheries management, by contrast, the fishing industry will make a substantial contribution to prosperity, as it is the only industry capable of supplying wild fish, which are in great demand and extremely expensive.

However, we have an optimistic vision for the year 2100 as well, and it is this: by then, the fishing industry and policy makers will have recognized that "less in the short term" means "much more in the mid and long term". European and other fishing nations will be committed to ending the rapacious fishing activities off the coasts of the **developing countries** and will respect these countries' property rights over their fish. A sustainable fishing industry can thus develop, safeguarding the livelihoods of numerous fishers while supplying billions of people worldwide with high quality fish and seafood.

Developing countries with fish-rich waters, such as the West African states, are often unable to ward off the plundering fishing fleets that deplete their waters with large trawlers, because they lack the vessels required to carry out monitoring.

"An interesting experiment is underway, with a precarious outcome."

MARTIN WAHL

MARTIN WAHL

Biotic communities in the midst of change

__Prof. Dr. Martin Wahl__ is a marine biologist at GEOMAR. His research areas are biodiversity, global change and stress ecology. Wahl studies biotic communities at the sea floor, focusing on species interactions within the community as well as with their environment.
He is particularly interested in the defense strategies of marine organisms with regard to predators and foulers.

Bladder wrack in the North and Baltic Seas can tolerate temperature fluctuations of plus 35 to minus 10 degrees Celsius. Bladder wrack and blue mussels, as well as common eelgrass, can survive in both fully marine (35 psu) and almost fresh water (6 psu). For many species in the Baltic Sea, temporary oxygen deficiency (< 1mg/L) is not really a serious problem and neither is oxygen super-saturation. Almost all marine organisms living in shallow waters, and especially those in the intertidal zone, are also largely unharmed by temporary extreme UV radiation. In marginal seas and bays, acidity (pH) fluctuates seasonally in a range between 7.3 and 8.3; on the surfaces of algae the acidity even ranges between 6.5 and 10 – and that's a daily variation! Many other environmental conditions also fluctuate enormously between habitats, times of day and the seasons. Numerous marine organisms apparently tolerate these changes easily.

Given such impressive tolerance ranges the projected changes resulting from climate change would appear to be ridiculously small: a few degrees warmer, a few psu less saline, half a pH unit more acidic, and a couple per cent more of oxygen depletion or UV radiation. Especially in shallow and marginal seas like the North and Baltic Seas most species could not only live under these slightly changed conditions but would also be able to continue to reproduce.

So what's all the fuss about? Shouldn't we, the inhabitants of northern Europe, just be looking forward to the milder winters and warmer summers?

Functional capacity of a species refers to its ability to succeed in its environment and to reproduce there.

Unfortunately we can't. For organisms, it's not just about sheer survival but also about how they continue to exist. If the shift in environmental conditions results in physiological stress, the organisms' **functional capacity** is compromised. Moreover, the individual stressors do not impact the organisms separately but all at once. And the sum, or rather the product, of all the individual minor negative impacts resulting from the projected changes will have far-reaching consequences of systemic importance.

Some species will be able to adapt in time through evolution. This is likely to happen primarily by way of selection of existing genotypes suited to living under the new conditions, or by way of immigration of such genotypes.

Many other species, however, will be maladapted, at least during a transition period, and thus their performance will be impaired. The direct impacts on the organisms may be inconspicuous, but indirectly they may have far-reaching consequences: primary production, growth and reproduction rates; resistance to parasites and pathogens; and defenses against predators or epiphytic growth will decline. Taken one by one, these impairments may be insignificant, but they can amplify each other considerably.

Here are two examples to illustrate this type of amplification: An increase of a few degrees in summer water temperatures impairs the chemical defenses of the brown alga *Fucus vesiculosus* (bladder wrack) and simultaneously increases the metabolism and thus the appetite of its most important predator, the isopod *Idotea balthica.* As the alga's rate of photosynthesis and, in turn, its growth also slow down, the loss of tissue caused by increased predation can no longer be compensated. Less photosynthetically active tissue means less energy gain and therefore less compensatory growth, weaker chemical defenses

and thus further loss of tissue due to predation. Denser plankton blooms (in warmer water and with increased eutrophication), for their part, reduce light availability for benthic algae, exacerbating their energy loss, especially at their lower limit of distribution, leading to the consequences described above. Due to the "amplifiers" – growth rate, defense efficiency, and predation – slightly warmer and more nutrient-rich water conditions thus result in a swift decline of the important bladder wrack. Similar "amplifier chains" (decelerated growth, thinner shells, hungrier crabs) will lead to the disappearance of blue mussels due to the projected warming and decrease in salinity in the eastern Baltic and the Baltic Proper, despite the fact that the higher temperatures and lower salinities have little direct effect on the mussels.

Biological interactions with other species are the ecological levers that can potentiate small direct effects of climate change, magnifying them into profound disruptions. Bladder wrack and blue mussels are species of key ecological importance in the Baltic Sea. Their decline, which in turn will be amplified by corresponding increases or decreases of other species and the immigration of new species, will lead to a cascade of other biological shifts.

Consequently, the biotic communities on our coastlines will reorganize. What exactly the end result will be cannot be foreseen. It remains to be seen whether the newly structured communities will be able to perform important ecological functions such as oxygen production, protection of juvenile fish, biomass production, sediment stabilization and many more as present day communities do. An interesting experiment is underway, with a precarious outcome.

My vision for the ocean in 2100 is that many biotic communities will be newly organized. Some of the species that are common today will have become rarer, will have migrated to more favorable climate zones or have gone extinct. Some of the species that are rare in the current biotic communities will have become more abundant as future environmental conditions match their optima more closely than today's, or because their competitors, predators or parasites have become rarer. Some new species will be present due to introduction or immigration. The important issue to the ecosystem and ultimately also to us will be whether the essential ecological functions will continue to be present in the newly constituted communities. Only a functionally equivalent "exchange of species", e.g. **macroalgae** for macroalgae or filter feeders for filter feeders, will ensure that a future biotic community can provide services similar to today's. Only if each of the important functions is fulfilled by multiple species will the system be fairly robust in the face of disturbances and stress. If sufficient numbers of species and diverse species remain in a given region, we may hope that the capacity for ecological self-organization will allow for the restructuring of our biotic communities without significant losses in functionality.

Macroalgae are brown, red or green algae that form large bodies. They are usually anchored to the sea bed by a "root-like" part of their body. Macroalgae can form huge kelp "forests".

“Our vision for the ocean in 2012 is that we have established other forms of energy production so that we no longer need to depend on the ‘life-saving’ CO_2 uptake of the ocean.”

BIRGIT SCHNEIDER AND STEFANIE MAACK

The ocean – An unlimited CO_2 sink?

BIRGIT SCHNEIDER AND
STEFANIE MAACK

Over the past one million years of Earth's history, atmospheric concentrations of the greenhouse gas carbon dioxide (CO_2) have continuously varied between 180 and 280 ppm. These CO_2 ups and downs were followed by temperature oscillations between glacials and warm climate periods. Since CO_2 in the atmosphere acts as a greenhouse gas, and its solubility in sea water is a function of temperature, the positive relationship between CO_2 and temperature, as has been detected from air bubbles in Antarctic ice cores, is still relatively easy to understand. Nevertheless, there are numerous unanswered questions arising from the clear saw-tooth like pattern of the climate record of the last one million years. For example, what determines the lower and upper limits for CO_2 concentrations in the atmosphere? Which change occurred first and probably drove the other, CO_2 concentration or temperature? What processes triggered the changes?

Current research efforts are focusing on the understanding of the pathways of carbon (C) when cycling through the individual reservoirs of the climate system (atmosphere, ocean, land biosphere). In the atmosphere, carbon primarily exists in the form of carbon dioxide (CO_2), in the biospheres of land and ocean it is organically bound (Corg)

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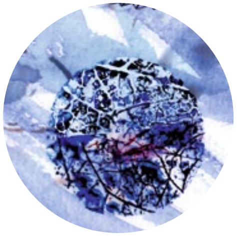


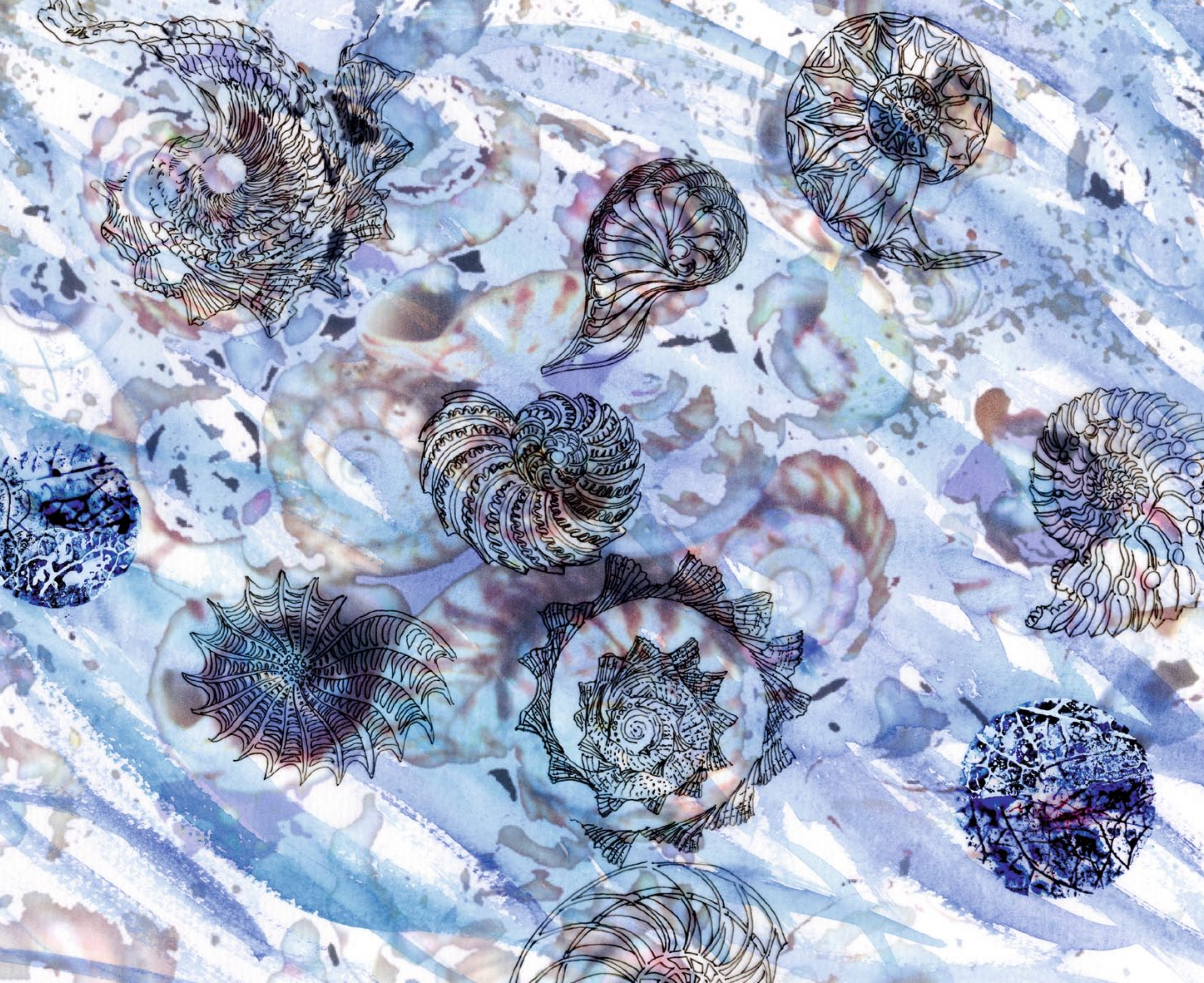
in plants and soils. The largest repository, however, is seawater, where approximately 60 times as much carbon is dissolved as is contained in the atmosphere. In pre-anthropogenic world these three reservoirs are continuously exchanging carbon with one another, whereby the amount in each reservoir may change, but the total amount remains constant. Consequently, during cold glacial periods there was a shift of carbon from atmosphere and land into the ocean, while during transitions into warmer interglacial times the ocean released the additional carbon stored during glacials.

CO_2 is exchanged between atmosphere and ocean, when a gradient between the partial pressures of CO_2 in the atmosphere and the ocean develops. Such a CO_2 flux is achieved primarily through three mechanisms, referred to as ocean carbon pumps. The first carbon pump is called the solubility pump. It is based on the fact that the solubility of CO_2 in sea water is dependent on temperature. The colder the surface water, the more CO_2 it can absorb. In the North Atlantic, for example, where surface waters originating from the Gulf Stream cool down on their northward flow path, they absorb CO_2 from the atmosphere. When the cooled water masses sink at high latitudes, e.g. in the Greenland and Labrador Seas, CO_2 enriched water is transported into the deep ocean, thus preventing further exchange with the atmosphere. When water masses return to the surface and become warmer, the previously absorbed CO_2 can be released back into the atmosphere. The term biological pump refers to the uptake of CO_2 by marine algae during photosynthesis. These organisms transform dissolved carbon in the water into biomass (Corg), which, after death of the algae sinks to greater depths, where the formerly fixed carbon is released from the biomass by microbial decay and transformed back into

dissolved carbon. This means that with a greater amount of algae growth, the ocean is able to absorb more CO_2. The third mechanism for CO_2 exchange between ocean and atmosphere is commonly called the calcium carbonate counter pump. Some marine algae form carbonate shells. During the process of carbonate precipitation carbon dioxide is released to the water and may thus also escape into the atmosphere. The solubility pump, however, plays the greatest role for the CO_2 storage capacitiy of the ocean.

With the burning of fossil fuels (coal, oil and gas), humans are increasing the total amount of carbon into the system, where it drives global warming as a greenhouse gas (CO_2). Up to now only around half of the anthropogenic CO_2 emissions remain in the atmosphere; the other half is taken up in approximately equal amounts by ocean and land. In the future, CO_2 will continuously be absorbed by the ocean as long as the CO_2 partial pressure keeps increasing in the atmosphere. The proportion of absorbed CO_2 to that remaining in the atmosphere may, however, change. One reason this is expected is that CO_2 solubility decreases with the rising temperatures resulting from climate change. In addition, there is a change in the chemical equilibrium of the surface water, which leads to a decreased buffering capacity and thus lower CO_2 solubility. Furthermore, changes in ocean circulation can decrease nutrient input at the surface and thus decrease biological productivity. It is also anticipated that the land biosphere, which is presently a sink for anthropogenic CO_2, will become a CO_2 source in the future due to increased microbial decay of carbon in the soils as a result of climate change. All of these processes are **positive feedback mechanisms** in response to the initial rise of CO_2 in the atmosphere, and they will thus further enhance climate change. The efficiency of the marine carbon sink will thus notably decrease.

A positive feedback mechanism is an interaction between mutually reinforcing effects, for example the increase of CO_2 in the atmosphere which causes a rise in temperature and vice versa.



Our vision for the ocean in 2100 is that the capacity of the ocean to take up carbon has not decreased. This can only be achieved by significant reductions in anthropogenic CO_2 emissions worldwide. This achievement will require not only effective policies to mitigate climate change, but also a fundamental and comprehensive change of attitudes in society. In our vision, the objective of growth is replaced by the objective of equilibrium. It is not enough to take an isolated look at the ocean and climate change. Already today, we are facing drastic and sometimes irreversible consequences for the ecosystems and thus for our economies. Such consequences are not caused only by excessive CO_2 emissions, but they are also due to a general overuse and misuse of our natural resources. In our vision, through a well-balanced, capacity-oriented use of resources, we will be able to prevent these consequences.

"Never before has a single species been able to bring about such drastic and sustained changes to our planet as those that are presently emerging."

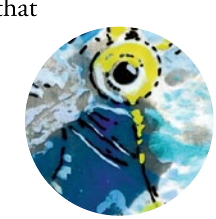
ULF RIEBESELL

ULF RIEBESELL

Disconcertingly unique: the Anthropocene

__Prof. Dr. Ulf Riebesell__ is a head of the research unit biological oceanography at GEOMAR. His research interests are cycles of carbon and other matters in the ocean and the driving biological processes behind them. Riebesell studies the impact of ocean changes on marine organisms and ecosystems, particularly with respect to acidification. He employs large mesocosm systems (research tanks moored in the sea) to simulate the conditions in the future ocean.

We call it the Anthropocene: the age in which the impact of human activity on the environment is comparable to or even more significant than natural influences. The Anthropocene began with the start of industrialization, around the year 1800. Although it is still by far the shortest epoch in the geological time scale, it could go down as an unparalleled period in Earth's history. Many times since Earth's origin, organisms have been able to bring about permanent changes in the environmental conditions on our planet. Just consider the release of oxygen by photosynthesizing protozoans beginning about 2.5 billion years ago. The change from an oxygen-free to an oxygen-rich atmosphere made the development and expansion of animal life possible. Or think about the first colonizations of land at the end of the Silurian Period around 420 million years ago, first by simple mosses, then followed by rapidly developing plant and animal populations in the Devonian. Even in light of these far-reaching transformations, the Anthropocene could represent a unique age in Earth's history: Never before has a single species been able to bring about such drastic and sustained changes to our planet as those that are presently emerging.



Looking back at Earth's history, however, we recognize another important fact: change is the norm. Environmental conditions are continuously changing and organisms adapt to them. The crucial factor, however, is the rate at which change occurs. If it happens gradually, as has been the general rule throughout Earth's history, the mechanisms of evolution work efficiently. Better adapted species supplant others that fall victim to the changes. It becomes critical, however, when changes in environmental conditions take place more rapidly than evolutionary adaptation. This can result in mass extinctions. The best known of these is the mass extinction at the Cretaceous/Paleogene boundary 65 million years ago, when a meteorite impact near the Yucatán Peninsula wiped out 50 per cent of all the species on Earth, including the dinosaurs.

We may also be faced with a mass extinction at the end of the Anthropocene. This possibility is supported by the fact that the rate at which carbon dioxide (CO_2) concentrations in the atmosphere are increasing is many times greater than during past epochs. Climate change will thus occur at a correspondingly rapid rate. There is, however, another consequence for the ocean. Around a quarter of the CO_2 presently being released by humans is absorbed by the ocean, which can be considered an invaluable service because it prevents an even more rapid change in the climate. Carbon dioxide reacts in the ocean to form carbonic acid, and the water becomes more acidic. This is where the rate of the CO_2 increase becomes a critical factor. If the release of CO_2 occurs gradually, over thousands to tens of thousands of years as is typical in Earth's history, then the ocean will be able to counteract the acidification by dissolving calcium carbonate from deep-sea sediments. Like the lime that we spread in our yards, the dissolved deep-sea carbonate will neutralize the accumulating acid. Through this process the acidity of seawater has remained within narrow limits during past epochs. If, as is presently the case, the CO_2 is released more rapidly than the overturning of the deep ocean, which takes about 1000 years, the buffering by deep-sea carbonate will lag behind the acidification of the ocean. The result will be a progressive acidification of the ocean, a process that, in this form and intensity, is presumably unique in the history of Earth.

Increasing acidity is taking many animal and plant species in the ocean by surprise. Carbonate-producing organisms in particular, such as bivalves, snails, sea urchins, starfish, and corals, have difficulty building their shells and skeletons under these changing conditions. But increasing acidification can also impair the growth and reproduction of many planktonic organisms that play an important role at the base of the food chain. It is still uncertain what the consequences will be for marine communities. It is highly probable, however, that unchecked ocean acidification will cause a drastic decline in **species diversity** in the ocean. Those ecosystems in which carbonate-forming organisms are important components will be especially hard-hit. These include the tropical coral reefs. In addition to the tropical rain forests, these are the most species-rich ecosystems on Earth.

Scientists assume that only a small fraction of the species present in the seas has been identified. It is thought that many new species are to be found in areas that have not yet been studied, such as large portions of the deep sea.

Cold-water coral reefs, which are distributed worldwide and are the most species-rich communities of the deep sea, could also fall victim to ocean acidification. If we are not able to significantly reduce CO_2 emissions, two-thirds of today's known populations of cold-water corals will be exposed to corrosive conditions by the end of this century. The effect is similar to decalcifying a coffee machine: the calcium carbonate dissolves in corrosive water. For the corals, this means that their skeletons will dissolve. The reefs will collapse along with their associated ecosystem.

How the Anthropocene progresses over the coming centuries is up to us. Unchecked climate change, drastic ocean acidification and mass extinctions are not unavoidable. But avoiding them will require a prompt rethinking of our habits. Both climate change and ocean acidification can only be held at acceptable levels if we are able to drastically reduce our CO_2 emissions within a few decades. Technical options to do this presently exist in the form of renewable energy production. These now need to be further developed and rapidly expanded.

But what can drive us to change our attitudes? The motivations for our actions are usually emotional. The willingness to rethink our behavior requires that we experience for ourselves the urgency of **changing course**, and that the impact of a possible failure gets under our skin. The magnificent beauty of the living communities in the sea can get under our skin. Experiencing and understanding them can help to initiate a change in attitude. Protecting them is important for all of us. The Anthropocene could end up to be an age of attitude change in Earth's history. Isn't that something we could all be proud of?

Changing course:
A seafaring concept, that requires strength and courage, and must be done resolutely.

"The road from discovery to established practice is arduous and time-consuming, but vital for progress."

MALTE BRAACK

MALTE BRAACK

Mathematical modeling of the oceans

***Prof. Dr. Malte Braack** is professor of mathematics at the CAU. His research focuses on fluid dynamics, numerics and optimization. In the Cluster of Excellence "The Future Ocean", he optimizes the predictive quality of ocean models, particularly with respect to regional resolution.*

Can the beat of an Asian fly's wing trigger a hurricane in the Gulf of Mexico? Probably not. Otherwise it would be futile to carry out numerical simulations of atmospheric or oceanic flows. Nevertheless, this image, commonly known as the "butterfly effect", highlights why it is so difficult to make forecasts regarding complex systems: what happens at the small scale has a feedback effect on the larger scale. Large-scale phenomena may be amplified or diminished as a result. On the one hand, the energy of large eddies in the ocean or the atmosphere dissipates as they decay into smaller eddies. On the other hand, however, a transfer of energy from the small to the large scale also occurs frequently. In extreme cases non-linear effects can lead to so-called bifurcations, which are associated with a loss of stability. This may initiate dynamic changes at the large scale. The genesis of tropical cyclones (hurricanes etc.) is ultimately a result of instabilities of this sort. Such extreme weather events are of major short-term significance.

Seen over the longer term, at ten-year periods, climate and sea changes are slower-paced and hence gentler. We humans benefit from this, as do all other living organisms and plants. This slowness and continuity also mean, however, that we do not really notice gradual changes, such as the gradual rise in sea level or acidification of the oceans, and tend to underestimate their impact.

Numerical simulation of processes like this enables us to take a look into the future, to assess long term consequences and hence to gain time. Time that is needed, for example to develop remedial measures. Simulating the ocean poses several challenges. The processes involved must be accurately described in mathematical terms, and the multi-scale nature of the processes must be taken into account and coupled using appropriate numerical procedures. It is therefore important to develop mathematical methods that reflect reality as accurately as possible. For reasons of feasibility and efficiency, the wide range of scales described above can only be incorporated to a certain extent into a numerical scheme. The influence of small-scale effects on larger-scale events is modeled in terms of an approximation. This means that phenomena that are too small-scale to be incorporated into the mathematical model due to insufficient resolution (grid spacing) are not simulated, but their effects on the scales we think are relevant are taken into account, at least approximately, using simpler laws. Increasingly powerful computers and the mathematical development of efficient methods and algorithms will make it possible in the future to include more and more small-scale effects in the simulation directly. However, there will never be sufficient computing power available to allow a numerical description of ocean flows in which the whole spectrum of scales can be resolved.

Accurate and efficient methods and algorithms for this type of simulation are being developed in applied mathematics. Great progress has been made in mathematics in recent decades with the development of numerical simulation for many areas in which multi-scale behavior plays a role. This includes, most notably, engineering applications and their numerous facets. Application of the latest numerical methods to the field of climate sciences offers even greater potential. Because it is necessary to incorporate many submodels in the simulation tools which increase a complexity of the software used, the integration of numerical procedures in this field is very ambitious. It can be compared to the development of new operation methods or new drugs in the medical sphere: the road from discovery to established practice is arduous and time-consuming, but vital for progress. Here there is huge potential for interdisciplinary research to resolve climate-related issues.

My vision for the oceans in 2100 is that society and politicians will have been persuaded to take effective steps to combat global warming and ocean change, and that the dramatic consequences for human, animal and plant life will have been averted. My hope is that our simulations of the oceans and the global climate, which we are using now to identify scenarios for 2100 (and other periods), will have contributed in some notable measure to this. Then, in a hundred years, we will be able to perform simulations to assess how the global climate would have developed had we not put these measures in place, and we will be glad we listened and responded to the forecasts in time. By 2100 the mathematical models for processes in the ocean and numerical methods will have improved to the extent that excellence in research will not only seem, but will actually be unthinkable without recourse to these methods.

"The future ocean will be bursting with life."

RAINER FROESE

The future of fishing: Looking ahead to 2100

RAINER FROESE

Dr. Rainer Froese *is senior research scientist at GEOMAR. His research areas are fisheries biology and biodiversity structures of fish. One aim of his work is the accurate presentation of fish species and other marine animals in the internet and on other platforms.*

Assuming that common sense prevails, fishing in 2100 will have very little in common with the industry as it is today. The future ocean will be bursting with life, with extensive oyster beds and **kelp forests**, immense shoals of fish, families of whales, and an abundance of seabirds. Only a small proportion of the sustainable fish stocks will be fished, and yet fishing will supply more protein for human consumption than it does today. Fish stocks will only be fished until they reach 75 per cent of their natural population size, to ensure that they can continue to play their important role in the ecosystem as predators and/or prey despite fishing activities. Individual fish will only be caught after they have reached their maximum growth rate and have already reproduced, thus minimizing adverse effects on fish stocks and avoiding unnatural selection. The fishing gear of the future will mainly consist of "smart" traps operated by remote control, which will only catch the target species of the desired size and quality. In this future scenario, dealers can inspect the fish in the trap and select those they wish to purchase. Fish that do not find a buyer quickly are released back into the wild. The fish that are sold are removed from the traps, killed swiftly and humanely, and reach the consumer within 24 hours. The traps and fishing vessels that provide this service are powered by renewable energy and rely on a high level of automation and remote control. In future, by far the majority of fishers will be technicians who operate and maintain their systems from an onshore base.

Kelp forests are diverse and complex ecosystems and a component of certain marine coastlines. Kelp, from which they take their name, is a large, multicellular type of algae. Kelp forests provide a habitat for many mammals, fish and invertebrate species and are regarded as the underwater equivalent of terrestrial rainforests.

Although all these technologies already exist on fishing vessels today, albeit for other purposes, today's fishers think in ways that would be familiar to the whalers of the 19th century. The fishing lobby is still demanding unrealistically high quotas and more opportunities to use destructive equipment, even in protected areas. Agriculture ministers, whose portfolios generally include fisheries as well, often see no problem with plowing up the seabed in an effort to catch plaice or cod. The general public often still harbors romantic notions of its fishers resting beside their nets spread out to dry beneath a setting sun, even though the reality of industrial fishing is very different. Consumers who wouldn't dream of buying anything but free-range eggs often have no idea of the suffering inflicted on fish before they get to market. They don't realize that the fish could well spend up to 12 hours in the net, being dragged along the ocean floor, or 24 hours struggling on a hook, or might be pulled up from the depth so quickly that their expanding **swim bladder** bursts out of their mouth. They may be crushed to death under the weight of tons of fish, suffer the agonies of suffocation on board small fishing vessels, or be processed on factory ships while still alive.

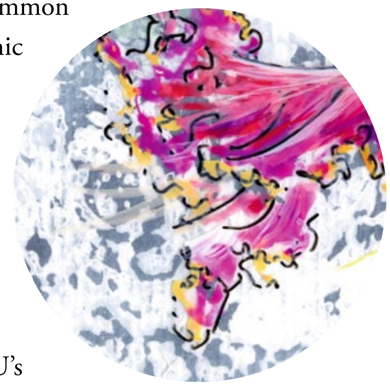
The swim bladder is an organ that only bony fishes possess. The fish can use it to match its specific weight to that of the water, and thus remain suspended.

Unnecessarily large fishing fleets and destructive fishing techniques such as bottom trawling are only possible because the fishing industry receives massive subsidies from the taxpayer. In Germany, the subsidies paid for fuel, innovation, safety equipment, etc. exceed the value of the landed catch. As a result, fish stocks worldwide are overfished and the number of severely depleted stocks is increasing. Since 1994, binding international agreements on sustainable fisheries have been in place, with New Zealand, Australia and the US being the first countries to enact their provisions in national law. The fish stocks in these countries' exclusive economic zones have now recovered, their fishing industry is making a profit, and most subsidies paid to the fisheries sector have run out.

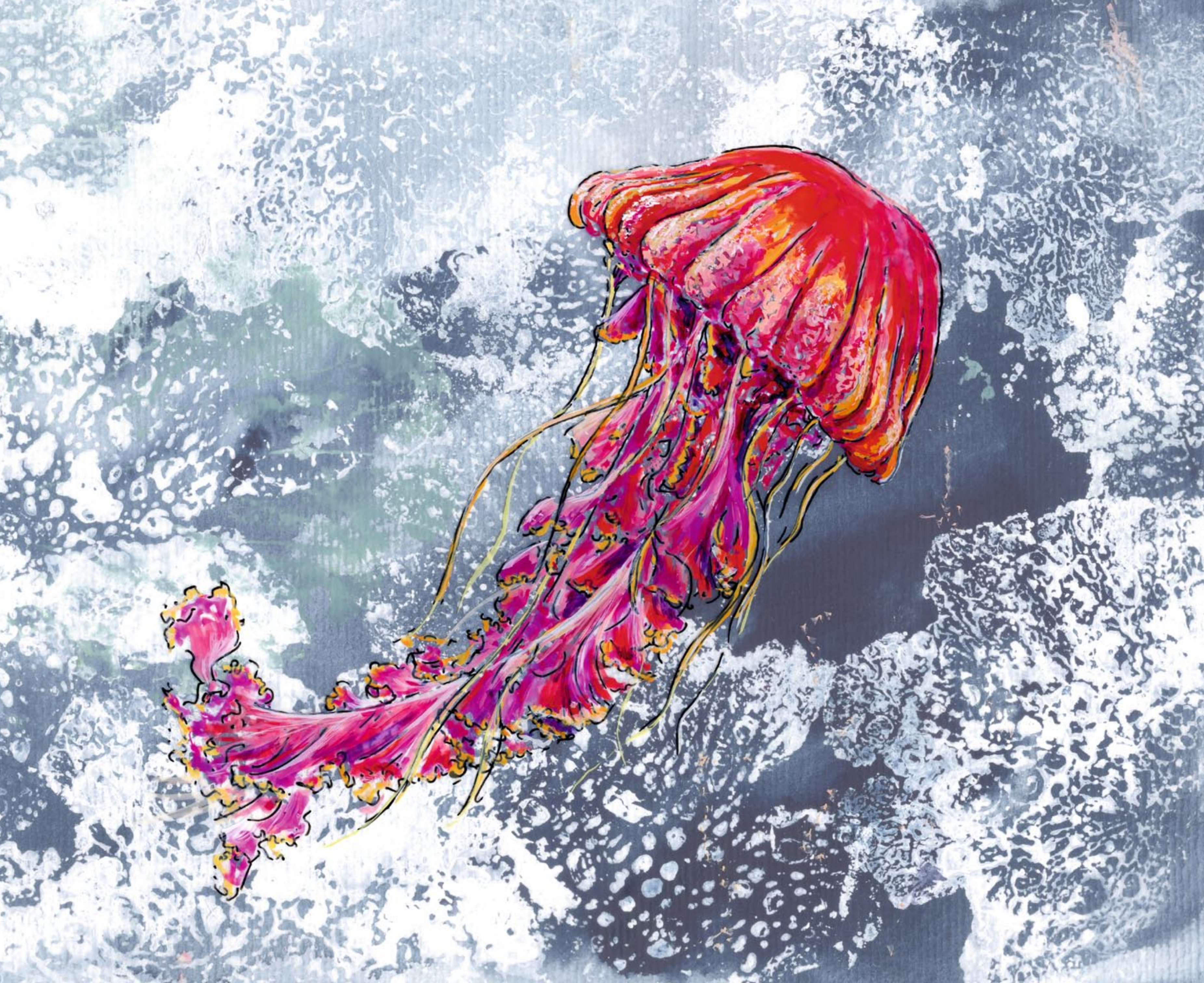
In Europe, too, decades of overfishing and the use of destructive equipment have resulted in severe depletion of stocks and inflicted massive damage on the marine environment.

In the past, at their annual meetings, the European agriculture ministers adopted ever higher catch quotas, effectively legalizing overfishing. However, campaigns launched by environmental organizations such as Greenpeace and WWF to raise public awareness, for example with brochures on sustainable fish consumption, combined with the far-sighted reaction of some market players who opted to cultivate a "green" image, have changed the political landscape in recent years. The European Commission has now presented a radical proposal for the reform of the Common Fisheries Policy, which is based on international standards for sustainable fisheries. The proposal would bring Europe into line with the standards in place in the restructured fishing industries in New Zealand, Australia and the US. It would also have a significant impact on global fish trade and would bring the world much closer to the vision for fisheries in the future ocean described above.

With its basic research, the Kiel Cluster of Excellence "The Future Ocean" is playing its part in promoting sustainable fisheries. A team of scientists at the Helmholtz Centre for Ocean Research Kiel (GEOMAR), the Kiel Institute for the World Economy, the Walther Schücking Institute for International Law, and the Faculty of Economics and Social Sciences at the University of Kiel have produced a critique of the Common Fisheries Policy, analysing the weaknesses that, from a biological, economic and legal perspective, meant that it was "designed for failure". In a paper published in the academic journal Marine Policy, they conclude that "excessive quotas ... and payment of direct and indirect subsidies by both the EU and Member States have resulted in too much fishing effort and excessive exploitation rates, resulting in low stock sizes, low catches and severely disturbed ecosystems".



In a second study, the scientists investigated whether Europe is likely to reach the goal of rebuilding its fish stocks by 2015, in line with the EU's pledge made in 2002 at the World Summit on Sustainable Development in



Johannesburg. The analysis shows that if current fishing pressure continues, 91 per cent of the European stocks will remain below target. Together with scientists from Australia and the US, the Kiel teams then carried out a third study to develop harvest control rules that are economically sound, compliant with international fishery agreements, supportive of ecosystem-based fisheries management and compatible with the biology of European fish stocks. Compared to the current **fisheries policy directives**, these rules would lead to higher long term catches from larger stocks at lower cost and with less adverse environmental impact. A fourth study shows that the yields from cod stocks in the eastern Baltic Sea will increase threefold over the next five years if the stock is managed according to the control rules. In recognition of these successes, the scientists were invited by the leading academic journal Nature to publish an article about Europe's Common Fisheries Policy in its influential World View column.

Fisheries policy directives are adopted by states or communities of states. They often stipulate catch quotas for specific fisheries that are developed through difficult negotiations among stakeholder groups, but do not necessarily consider the state of fish populations.

The findings of all the studies have been shared with decision makers and stakeholders on various occasions, including presentations to European Parliament working groups, at WWF in Brussels, at meetings with representatives of Germany's Agriculture Ministry, and at expert hearings in the Dutch Parliament. Our hope is that this interplay between science, decision makers and the general public will contribute to making our vision of a healthy future ocean a reality.

"Since we cannot prevent earthquakes,
landslides and tsunamis,
our greatest challenge is to minimize
the destruction they cause."

SEBASTIAN KRASTEL-GUDEGAST

SEBASTIAN KRASTEL-GUDEGAST

Natural hazards under the sea: Earthquakes, landslides and tsunamis

Prof. Dr. Sebastian Krastel-Gudegast *is professor of submarine hazards at GEOMAR. His research is dedicated to submarine mass wasting (earthquakes, slope slides and tsunamis). Krastel-Gudegast investigates continental slopes in the ocean. His interest here focuses on slope stability, the hazard potential and sediment transport processes at continental margins.*

When we think of the sea our minds automatically drift to beautiful sights and exciting activities such as sunsets, beach holidays and fishing. But the sea also harbors threats, including earthquakes, submarine landslides and tsunamis (flood waves). Tsunamis in particular may cause devastation of large coastal areas, as various events of the recent past have shown. More than half the world's population lives within 50 kilometers of the coast. For this reason a vital aspect of marine research is to study submarine natural hazards and to develop strategies to minimize their impact.

Earthquakes occur mainly at the interfaces between the lithospheric plates: i.e. where two plates converge, slide past or drift apart from each other. Many of these interfaces lie under the sea. The constant movement of the plates causes stress to build up, as the plates do not glide smoothly past each other. If the stress exceeds the strength of the rock, an earthquake occurs. The rupture surfaces of major quakes can stretch more than 1,000 kilometers and release a colossal amount of energy. A quake measuring 9 on the Moment Magnitude Scale (such as the Tōhoku earthquake in Japan in 2011) releases an amount of energy equivalent to roughly 38,000 Hiroshima atomic bombs. Apart from the destruction resulting from the quake itself, submarine earthquakes can trigger devastating tsunamis. The conditions needed for a tsunami to form after an earthquake are a magnitude of at least 7, a hypocenter (the point where an earthquake originates) close to the ocean floor (< 30 km depth) and a vertical displacement of the sea floor. These conditions are usually only fulfilled in subduction zones in which one lithospheric plate becomes subducted beneath another. Nine of the ten largest earthquakes since 1900 occurred in subduction zones, and all of them triggered tsunamis.

Landslides are another natural hazard under the sea. They are several magnitudes larger than those onshore. Submarine slides can reach volumes of up to 20,000 cubic kilometers and lengths of up to 800 kilometers. Submarine landslides can destroy the infrastructure on the ocean floor (e.g. platforms, cables) and trigger tsunamis. Slope failure can cause major downslope transport of rock debris and sediments. This sudden momentum sets the entire water column above the slide mass into motion.

Flank collapses on ocean islands can also trigger tsunamis. These are very rare events, however (e.g. one major collapse takes place every 100,000 years on the Canary Islands). The height of tsunamis initiated by such collapses is a hotly-debated topic and opinions vary between a few meters and several hundred meters.

Tsunamis caused by earthquakes and landslides have many things in common – but there are also differences between the two. Neither is easily noticeable out at sea, where they are small in height but very long in wavelength (some more than 100 kilometers). The propagation speed depends on the depth of the water: in the open ocean they can move at speeds of up to 900 kilometers per hour. The velocity decreases in shallow water, but at the same time the wave increases in height. Unlike wind-generated waves, if this wave then reaches land it is capable of penetrating far inland. These facts explain the name tsunami, which in Japanese characters means “harbor wave” (‘tsu’ harbor and ‘nami’ wave). The name was coined by Japanese fishers who did not notice the tsunami waves at sea, but then returned to shore to find their harbors completed destroyed. The essential

difference between tsunamis caused by earthquakes and those caused by landslides lies in their extent. Due to the great length of earthquake rupture zones, earthquake-generated tsunamis can affect entire ocean basins. Landslides, with significantly smaller areal extent, tend to generate only regional tsunamis, which can, however, be very high.
Recent examples of catastrophic tsunamis resulting from earthquakes include the Christmas tsunami in the Indian Ocean in 2004 (more than 200,000 lives lost) and the 2011 tsunami in Japan (approximately 25,000 lives lost), which also destroyed the nuclear power plant in Fukushima. Landslides, too, have triggered tsunamis in the recent past. In 1998 a tsunami destroyed a 40 kilometer strip of coast in Papua New Guinea (more than 2000 lives lost). The maximum height of the waves was estimated at 15 meters. In this case a relatively weak earthquake triggered a landslide which in turn triggered the tsunami. A good 80 per cent of all tsunamis are caused by earthquakes, the rest by landslides, volcanic eruptions or **flank collapses**. The vast majority of all tsunamis (roughly 80 per cent) occur in the Pacific Ocean, but about 10 per cent occur in the Mediterranean.
Tsunami early warning systems now exist in both the Pacific and Indian Oceans. The Indian Ocean system was set up with Germany's assistance as part of the GITEWS (German-Indonesian Tsunami Early Warning System) project.

If coastal slopes or the flanks of a volcano become instable and slide downslope, large sections of islands or continents can collapse into the sea.

My vision for the ocean in 2100 is that coastal regions will be well prepared for any hazards from the sea. Functioning warning systems and facilities along the coast should help to prevent such enormous loss of life and devastation. We cannot prevent earthquakes, landslides and tsunamis, but it is vital to minimize the destruction they cause. We will not be able to predict earthquakes, even in 2100. No research has yet been carried out to determine whether landslides display reliable precursor phenomena, but this should be a focus of future study. For this reason, efficient early warning systems, appropriate protective measures onshore, and a coastal population that is well-trained and prepared are all of crucial importance. Recent events in Japan have shown that we still have a long way to go. Japan is the best prepared nation in the world for natural disasters. For instance, the moment an earthquake strikes the trains automatically stop. Earthquake-proof constructions help to largely prevent damage to the infrastructure. Sea walls and tsunami towers as well as evacuation plans help to minimize damage and lives lost in the event of a tsunami. The population is extremely well educated. In spite of all this, the effects of the 2011 tsunami were catastrophic, particularly because the tsunami waves were much higher than expected. The scientific community now has the crucial task of decoding all conceivable records to find reliable data on the dimensions of natural disasters in various **coastal regions**. Nonetheless, there will still be victims of natural disasters in the 22^{nd} century, because the best protection will be (too) expensive, and nature will never be predictable.

Settlement pressure on coastal regions is enormous. The growth rates of coastal populations have been three times those of inland populations over the past 100 years.

"Biomimetics reinforces the need to protect ocean biodiversity, the patent library for the technologies of the future."

STANISLAV N. GORB

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Biomimetics: A million ideas from the ocean

Prof. Dr. Stanislav N. Gorb *is a zoologist at the CAU and director of the Zoological Institute. His research areas are animal morphology, biomechanics and biomimetics. Gorb strives to present biological principles in an understandable way to engineers and material scientists, in order to transfer functional principles from biological systems to technology.*

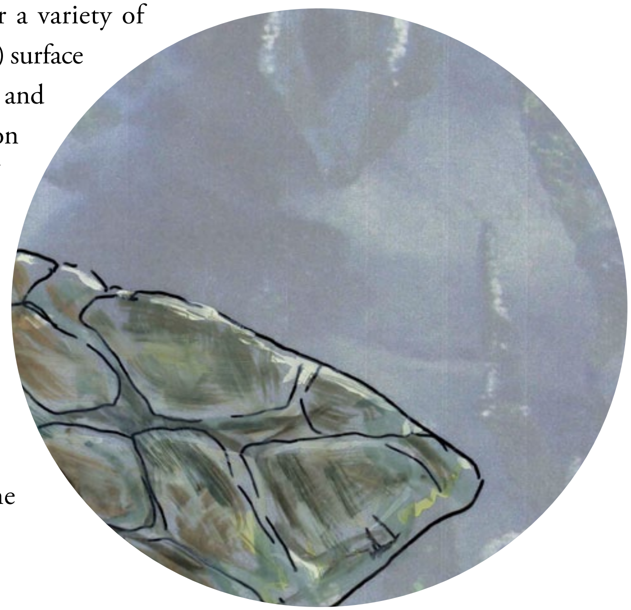
The biological diversity of the oceans is fascinating. The total number of marine species known to us is about 230,000. However, the true number of species living in the oceans is thought to be five to six times greater. Mark J. Costello at the Leigh Marine Laboratory, University of Auckland, New Zealand, has estimated the number of marine species to be 1.15 million. The reason for the huge discrepancy between the estimated and known number of species is our lack of knowledge about the smallest organisms on the planet. Ocean biodiversity is fascinating due first of all to the presence of an enormous variety of life forms, structures, materials and substances unknown in terrestrial organisms. Biologists, ecologists and evolutionary biologists have always been riveted by these creatures with their often extraterrestrial-like appearance, and by their composition, and have made them a focus of their research. Now, however, engineers and materials scientists are also taking an increasing interest in this diversity.

This is not surprising. Throughout evolution, nature has continuously acted like an engineer, solving various technical problems, and has developed an immense variety of shapes and structures for movement, such as flying, swimming, or leaping. Worthy of note, for example, are plant surfaces that remain dry under water by means of special micro- or nanostructures, or the extremely fine, hierarchically structured hairs that enable geckos

and other reptiles to stick without adhesives. Although often complex and fragile, these structures are nonetheless able to cope with extreme mechanical loads. Nature's solutions may serve as inspiration for technical innovations using biomimetics (bionics), a scientific discipline that brings together biologists and engineers to explore the immense potential of marine life for technical applications with a view to developing industrial products.

Many solutions that function well in marine organisms are based on a variety of ingenious solutions. Microstructures on shark scales, for example, minimize resistance while they swim; sponges excel with their elegant and effective lightweight construction, and fish appear to have iridescent colors solely due to their special structure without color pigments. Marine organisms are an important source of information for biomimetics because they possess a great variety of mechanically optimized forms, an enormous diversity of unusual materials, surfaces, and substances and a wealth of sensory equipment. Understanding the functional principles of marine life, materials, structures, sensory organs, movement patterns and control systems is of major scientific interest for a variety of technological fields such as (1) materials science and technology, (2) surface science, (3) adhesives science, (4) photonics, (5) sensor technology and (6) robotics. Possible innovations may also emerge at the intersection between marine biology and these disciplines. Over the course of evolution, similar functional solutions have often developed in parallel in different groups of organisms, and so comparative studies may enable scientists to find optimal approaches to tackle specific problems.

Biomimetics from the ocean has already generated several potential applications. Phil Messersmith from Northwestern University in the USA has recently taken inspiration from the

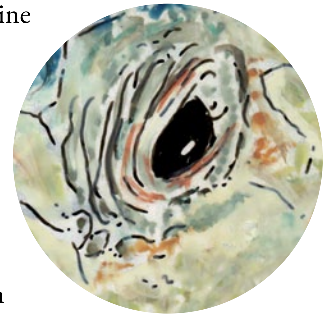


remarkable adhesive capabilities of the blue mussel Mytilus edulis to create a novel class of medical adhesives. Robust and lasting adhesion is an important quality criterion for medical adhesives, especially for applications where long term performance of the material is vital. Limitations of conventional synthetic adhesives include poor adhesion under water and allergenic potential. Overcoming these performance deficiencies requires a material that is easily administered in a clinical environment, reliably and durably bonds to target tissue surfaces in a wet environment, and stimulates minimal inflammatory insult. Proteins secreted by M. edulis to give its foot pad a firm hold on the ground are an ideal prototype for solving such optimization problems. Initial clinical testing of this biomimetic adhesive is very promising.

Diatom algae are single cell algae whose cell bodies are surrounded by a highly structured hull made up of two silicic acid shells. Up to now there are about 6,000 known species which live in fresh or salt water.

Christian Hamm of the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven has developed an innovative car wheel rim design combining enhanced road stability with reduced weight, making it a serious competitor to conventional wheel rim design. The new design is based on the shell structure of the **diatom alga *Arachnoidiscus japonicus.*** Data from electron microscopy scanning was first used to create a computer model of the shell. The complex shell structure consisting of hexagonal cells and pores is extremely lightweight, but stable. Such shells have evolved as a compromise between the need to be lightweight enough for an organism that lives suspended in water and at the same time to have a very tough shell as a defence strategy against predators. In micro-level crash tests, these shells were able to withstand pressures of over 700 tons per square meter. The biologically inspired wheel rim, which mimics the diatom shell, has been found roadworthy using simulation software, and prototypes are due for road testing soon.

These two examples raise the hope that the special properties of more than one million marine species will be a source for inspiration for many more ideas for the technologies of tomorrow. In order to focus efforts in this area, researchers actively working in the field of biomimetics from more than thirty German universities have teamed up to form the biomimetics competence network BIOKON. Within the network, marine biomimetics is a key strategic topic.



We have only just begun to investigate the biomimetics potential of marine life. Biomimetics reinforces the need to protect ocean biodiversity, the patent library for the technologies of the future. My vision for the future of the oceans in 2100 is to see at least some of this immense potential for innovation being explored and exploited. It will then be good to know that this ocean resource is infinite, sustainable, and free for all. To harness inventions from the ocean we need many active and motivated researchers to help explore these **ocean patents** and translate them into the languages of other disciplines, such as materials science. And all the while, as we take these free patents from the ocean and perhaps make a profit from them, we must not forget to give something back to the ocean.

Patents protect the intellectual property of inventors for a certain period, and may only be used subject to payment of a specified fee.

"The sea harbors partners we don't yet know."

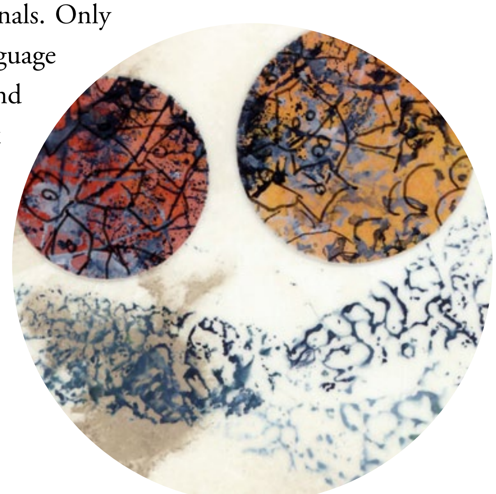
THOMAS C. G. BOSCH

THOMAS C.G. BOSCH

Our uncounted partners

__Prof. Dr. Thomas Bosch__ is a biologist at the CAU and Vice-President of the University. His research areas include evolutionary biology, developmental biology and comparative immunology. Bosch investigates the evolution and function of genes that can trigger diseases in humans. This involves studies of primitively organized aquatic organisms.

The sea harbors partners we don't yet know. In every liter of sea water there are a billion bacteria and ten billion viruses. And not only the sea; all of its inhabitants, just like humans, are colonized by microbes: fish and marine mammals contain ten times more bacteria than they have cells of their own, and around 100 to 150 times more bacterial genes than genes of their own. All of these organisms – bacteria, viruses and host cells – combine to form "superorganisms" or "metaorganisms". Communal life in this "multicultural" association takes place unseen, controlled by invisible signals. Only gradually are researchers learning to decipher the secret language of metaorganisms. Surface sensors in the cell membrane and receptors in the cell's interior constantly monitor the complex interplay between host cells and their partners. Using small protein molecules called antimicrobial peptides, the host cells can exert direct control over the composition of the microbiota. The microbes use the animal or plant body as their habitat, and in addition to communicating with each other in highly complex ways, they also have a direct communication link to their host.



Bacteria were among the first inhabitants of Earth and they have survived everywhere, no matter how inhospitable the habitat. Gigantic masses of bacteria colonized the sea bed more than 3.5 billion years ago. Like a slimy living carpet, they spread over vast areas, even managing to survive without oxygen. Eventually, after several million years, a new group of bacteria, cyanobacteria, emerged, which were able to manufacture oxygen from light, carbon and water. Over the ages that followed, all multi-celled plants and animals evolved in the constant presence of microbes. Is it any wonder, then, that continuous interaction with microbes has shaped not only evolutionary processes, but also individual development, and indeed continues to do so?

Freshwater polyps are small organisms whose boundaries to their environment are defined by relatively simple cell structures. Their simple structure and the ease with which they can be cultivated make them very useful as objects of research.

There is increasing evidence that the microbes associated with a particular organism are very specific to that organism. Every species has its own set of bacteria. Laboratory-based observations of **freshwater hydra polyps** show that different species retain their different microbiota even if kept in standardized and identical conditions for thirty years. A Brazilian student at the University of Townsville in Queensland, Australia, recently examined deep-sea corals. He found that the same bacteria always occurred in conjunction with the same coral species, even in areas far apart from each other. In other words, environmental factors such as temperature or food appear to have very little influence on microbiota composition. The decisive factor is the host. The species-specific host-microbe relationship is clearly governed by very strong selective pressure. Why might this be?

We notice how indispensible these microbes are when they are missing. For the past 200 million years at least, corals have owed their existence to the interaction between cnidarians, algae and bacteria. If corals lose their fellow residents, they bleach and die. They are only able to ward off infections if their microbial flora is intact. We have been able to ascertain in the laboratory that polyps reared in sterile conditions without the presence of bacteria

are more susceptible to fungal attack. Bacteria protect the polyps from predators. If communication between the hosts and their colonizers breaks down, the composition of the metaorganism is destroyed. Researchers led by Ariel Kushmaro of the University of Tel Aviv in Israel demonstrated some years ago that the bleaching of the Mediterranean coral species *Oculina patagonica* was due to infection with the bacterium *Vibrio shiloi*. They have now also been able to show that there is antibacterial activity in the bacteria-rich mucus layer that coats the surface of all healthy coral colonies, and presumably offers protection from invasion by the harmful bacterium.

The balance between host and microbe is a delicate one. This is confirmed by laboratory experiments. We investigated hydra polyps, whose cells produce a tiny protein molecule made up of about fifty amino acids. This protein molecule is an antibacterial **peptide** that can kill bacteria. Too much of this molecule, however, does not mean that the microbes simply disappear. Rather, it means that the composition of the microbial flora within the hydra's metaorganism changes. The host clearly uses this and other similar molecules to control the type and quantity of microbes it allows to colonize its tissue. In medicine, antimicrobial peptides are seen as a beacon of hope and a new generation of antibiotics. In nature these molecules are used as a fine-tuning mechanism to keep the meta-organism, with its complex mix of inhabitants, in a state of equilibrium. If the balance between host and microbes changes, the effectiveness of the protective bacterial shield may be reduced, giving harmful microbes an opportunity to flourish. However, it may also be an opportunity to muster a new set of allies to tackle a new set of circumstances.

Peptides are small proteins. They are a fundamental component of all organisms and often have vital physiological functions. They can function as a hormone or as an antibacterial agent.

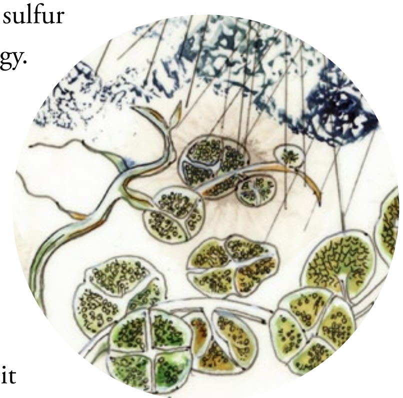
Bacteria not only protect, they also intervene in the development and behavior of animals. Margaret McFall-Ngai of the University of Wisconsin-Madison, USA, demonstrated some years ago that the light organ of the small squid *Euprymna scopoles* is host to colonies of bacteria of the species *Vibrio fischeri*, which can produce light by bioluminescence. This serves as a kind of spotlight while the squid is eating. At the same time, it helps to lighten the conspicuous shadow cast by the squid on the sea bed and make it less visible. For this to take place, the squid must first specifically attract *Vibrio fischeri* bacteria and distinguish them from among the 1800 or more other species of **bacterioplankton**. The immune system of the squid must then learn to tolerate these new partners, and finally the growth of host and bacterial cells must be coordinated. Meanwhile, *Vibrio fischeri*, which occurs in extremely low numbers in sea water, has to adapt specifically to two completely different ecological niches: the open ocean and the light organ of the squid.

Bacterioplankton referes to all bacteria drifting freely in the sea and moved by currents. They can occur singly or collectively.

The squid is not alone: most (if not all) other sea creatures are also colonized by a myriad of microorganisms that carry out useful functions for their hosts. In exchange, the host provides them with a suitable living environment.

Marine worms, for example, are brimming with of bacteria that are never found in such high densities in the open sea. The worms have developed complex mechanisms to retain their bacteria from one generation to the next. Why? *Olavius algarvensis* for example, a marine oligochaete (meaning "with few bristles") living in the sandy seabed off the Mediterranean island of Elba, has not only radically reduced its digestive system – it has neither mouth, stomach nor intestines – but also possesses no kidney-like excretory organs.

Energy supply and waste disposal have been "subcontracted" to microbial partners. Nicole Dubilier and her colleagues at the Max Planck Institute in Bremen have spent years researching this wonderful example of "outsourcing" and, using metagenomic analysis techniques, they have been able to show that two sulfur bacteria and two sulfate reducers coexist in the worm. The sulfate reducers produce reduced sulfur compounds that can be used by the sulfur oxidizers as a source of energy. In addition, all four symbionts can fix carbon dioxide the way plants do. In other words, what this worm possesses is nothing short of an endosymbiotic power plant, which, through the coordinated interaction of its microbial community, enables it to use limited resources efficiently in a very confined space.



As most symbiotic microorganisms cannot be grown in culture in isolation, studying such a complex metaorganism with its close-knit interactions in detail presents enormous challenges. The task has been made easier by the recently developed technique of metagenomic analysis. The term "metagenomics" derives from a combination of the concepts meta-analysis (a process in statistics that enables quantitative comparison of the findings of different studies) and genomics (analysis of an organism's complete hereditary information). The metagenome is the sum total of all genomic information for a habitat at a given point in time.

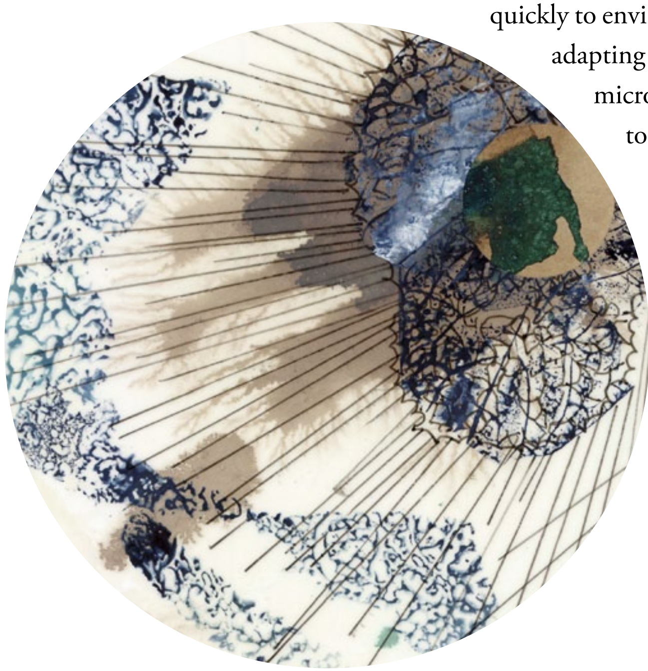
The composition of bacterioplankton in the world's oceans has been under investigation for more than fifty years. But only as a result of developments in the areas of **sequencing**, bioinformatics and robotics has it become possible to capture all the genetic information for a habitat or metaorganism and hence to study the diversity, function and interactions of marine organisms.

Sequencing technology:
Technology used to decode and characterize the genome. The technology has become so powerful in recent years that the genomes of many species have now been unraveled.

Biological individuals: a fallacy

Animals, plants and humans, too, can only function in diversity, in a metaorganism composed of countless billions of different organisms. The metaorganism, rather than the biological individual, seems to be the unit that is subject to selection. The Israeli researcher Eugene Rosenberg and his wife Ilana Zilber-Rosenberg give three reasons for this: First, all animals and plants maintain **symbiotic associations** with micro-organisms. Symbiont microorganisms are carried over from one generation to the next. Second, the interactions between host and symbionts affect the fitness of the meta-organism. And third, the symbiont community can change relatively quickly, for example by horizontal gene transfer, rapid multiplication or a change in the species set. Micro-organisms respond very quickly to environmental changes (oxygen, CO_2, temperature) by adapting their metabolism. Changes in the community of microorganisms can therefore result in major alterations to the host's biochemistry, and much more quickly than would be possible in a single individual by way of sexual recombination and natural selection. Geneticists estimate that it takes at least 50,000 years as a rule – in other words about 2,000 generations – before a DNA mutation becomes established. Genetic changes therefore require a great deal of time – too long to keep pace with current environmental changes. The exchange of components in a metaorganism, on the other hand, is much quicker.

Symbiotic associations: Symbionts are organisms of different species which build associations from which both partners benefit.



My vision for the oceans in 2100 is that we should not forget our countless partners in the sea. Marine organisms would not be able to live without them. We need to gain a molecular-level understanding of the organizational principles of metaorganisms, not least because this will enhance our understanding of the diseases that result from disruptions in host-microbe interactions. But at present we only know a few of these microbes. Most of them, especially the rarer species, live and carry out their functions unseen. If environmental conditions change, however, they could become vitally important as components of the metaorganism. Prophylactic use of antibiotics in fish-breeding facilities (aquaculture) thus has unpredictable consequences, not only as regards the development of resistant strains, but also in terms of maintaining vital microbial diversity. Let us make sure that even the less common of our marine microbial partners are also able to survive.

"Many science fiction stories of the past are now reality."

KATRIN KNICKMEIER AND FRIEDERIKE BALZEREIT

Put the kids in power: How knowledge changes our view of the ocean

KATRIN KNICKMEIER
AND FRIEDERIKE BALZEREIT

Dr. Katrin Knickmeier *is a marine biologist at the CAU, and heads the school programs of the Cluster of Excellence "The Future Ocean". She organizes the Kids' and Students' University, which presents marine and other scientific topics to students in an easily understandable manner. Her interest is passing on marine science knowledge to schoolchildren and students.*

Friederike Balzereit *is head of public outreach in the Cluster of Excellence "The Future Ocean". Balzereit communicates the Cluster's research results through exhibitions, public events and the internet, and informs the public on current research themes and activities.*

"Grandpa, is it true that you once helped to save the fish in the ocean?" Niko sits next to his grandfather on the beach. Together they look at the waves and the foaming white crests. Nothing matters more to Niko than the ocean. He may be just ten, but he already knows a huge amount about the sea and its creatures.

"Yes, not all that long ago there were almost no food fish left in the world's oceans," says Niko's grandfather. He was a small boy, about the age his grandson is now. The television and newspapers were full of reports on the imminent collapse of the world's oceans. Nearly all the food fish in the North and Baltic Seas and in the Atlantic were endangered or extinct. But that was not the only problem. Deep sea mining had just begun. There was oil spill after oil spill. Whole islands vanished beneath the sea. And in many other ways, the future of the blue planet no longer had such a turquoise sheen. "So how did you do that?" Niko persists, and his grandfather tells him the story:

"It began in the year 2012, a time when we were flooded with more information than ever before. Not only were we bombarded with news by newspapers, magazines and television, but via our mobile phones and computers, information from the internet washed over us in gigantic waves. The daily volume of information was 200 times greater than just 50 years earlier. We ten year olds knew so much about the world, and yet so little. But that was about to change. A group of ocean researchers from Kiel in Germany wanted to understand the ocean – the very sea we're looking at now. They said that our future depended on how we humans treated the world's oceans. And we still had time to embark on the right course to save the biosphere for the sake of all the children on Earth. The Kiel researchers joined forces with many other international oceanographers, and together they looked for solutions.

In our school we talked about it a great deal, and so did school children all over the world. Soon afterwards we founded a global initiative called "Kids save our ocean". To begin with, it was slow to take off. But little by little, many children found out about it through their online networks and from apps and magazines. They discovered there were researchers who were getting involved, lending their support and passing on their knowledge. Our teachers backed us up, too, and turned the ocean into a school topic. Suddenly, all that mattered to us was the state of the oceans. And we weren't alone; the same happened in all the countries of the world. The media in the whole world were reporting on the world's oceans. And that is how our concern forced government representatives all over the globe to pay attention. A few months after that, it was just a small step to launch the "Ocean Recovery" policy program, with considerable support from international corporations. You can see the result in front of you. Now stocks of fish are back up to strength, the **vortex of plastic waste** in the Pacific is very much smaller, and we now live without nuclear power plants."

Plastic vortex:
At the center of major ocean vortices, plastic debris and its decomposition products accumulate due to their longevity, forming large concentrations.

Could all this come true one day? Or is it just so much science fiction? One thing is certain: the ocean researchers in Kiel really exist. They want to understand the ocean and pass on their knowledge in order to shape our future. But the rest is nothing more than a dream for the future. A look at school curricula and textbooks shows that the largest, most fascinating and most astonishing habitat on our Earth, the ocean, is barely touched upon in schools. Try asking your child what he or she has learned at school about the ocean and its inhabitants. If you love the sea and know how important it is to human beings, you'll be disappointed in the answer.

When asked, children and young people say that they have little opportunity to gain a close familiarity with the ocean in school. In some of Germany's states, the topic of the world's oceans is dealt with in tenth grade geography, for just six weeks and perhaps no more than twelve lessons. For such complex and fascinating topics as deep sea raw materials, or the sea as one of our most valuable food sources, this is barely adequate. And little or no mention is made of the ocean's role as a carbon dioxide sink, or of ocean acidification, sea level rise, or medicines from the sea.

Why are dogs, cats or pigs always given as examples of the features of a mammal, rather than a whale? Why are **ocean currents** not used to explain certain laws of physics? There are so many fascinating topics in the ocean sciences – and there is always a crossover with other subjects. If school children study the ocean sciences, they learn interdisciplinary thinking.

Ocean currents are horizontal as well as vertical flows of marine water masses. Tidal currents, which alternate their direction within relatively short time periods, are distinguished from the continuous motion of global water masses such as the Gulf Stream.

What sends a scientist into rapture can be very difficult to explain to the general public. But in exhibitions by the Cluster of Excellence "The Future Ocean", a simple relief globe showing the mid-oceanic ridge and numerous mountains under the sea always elicits attention and astonishment. Research and measuring devices, properly displayed, stimulate all manner of questions and growing interest. And we frequently hear the words, "I never thought of it in that way," or "I didn't know that."

The sea does not reveal its secrets easily. Scientists must employ vast technical resources and staggering efforts to probe the depths of the ocean. Nevertheless, there are still huge areas and numerous species that we may never get to know. At worst, people are in the process of destroying parts of the ocean. Knowledge transfer – that is one key to saving the world's oceans. Every researcher who has ever given a talk to a really interested but uninformed public will have sensed their interest in the ocean. When the conversation moves on to subjects like deep sea glider craft for ocean monitoring, it is not just the children's eyes that light up. How do tsunamis start, and what are black smokers? Those are all examples of how proper scientific explanations can enthuse and inspire more people about our environment than many scientists themselves would have believed possible.

On our way to the year 2100, we therefore hope that the ocean, its beauty and its meaning have made an impression on people's hearts and minds. Today, the forest is a familiar habitat, but the sea and its creatures should be a subject that every school child, not just coastal children, can talk about with equal understanding and excitement. In the education system and in teacher-training establishments, research and presentations on "ocean literacy" have been taking place in parallel with "**scientific literacy**" for quite a long time. In a few countries, like the USA, it is already a reality today.

"Scientific literacy" is a term from education research and means basic scientific education.

In our vision of the future, every child will grow up well-informed about the ocean from preschool onwards. The ocean and the marine sciences have found a niche in schools, the curriculum and teacher training. And enthusiastic teachers and scientists can spark the same fascination among the children. Their passion helps to mold these well-prepared youngsters into the next generation of marine scientists. And every school has a relief globe and effectively presented teaching materials.

Apps, games and experimental kits are available on many topics in marine science, for children and adults at all levels of education. Exhibitions give hands-on experience of the ocean. New media can be used to look into the ocean, and the visions of scientists give rise to new forms in art. Respectful treatment of the sea and its resources has become established. Working side by side with the teachers and educators of the future are real scientists, who share part of their research time and knowledge with the public. In the year 2100, scientists from all disciplines will devote one day per month to the public, explaining their research projects and responding to people's questions and suggestions. The **portfolio** of every marine research institute will include experimental science courses for all. Social commitment and knowledge transfer are promoted, not just by the institutes but also by local and national governments.

Working side by side with the teachers and educators of the future are real scientists, who share part of their research time and knowledge with the public.

Utopian? Perhaps, but many science fiction stories of the past are now reality. Wireless phones and computers already exist. Why not children who save the ocean habitat – and naturally move on to become scientists or teachers and pass on their knowledge to others?

ILLUSTRATIONS *Kiel-based artists Corinna Kraus-Naujeck and Kerstin Mempel have worked together in the Blauschimmer artist group since 2008.*
Blauschimmer, which translates as "blue shimmer", serves the artists' desire to network, provide mutual assistance and engage in exchange in their work and communication. The name implies, among other things, working and living near the sea, observing and comprehending the immediate surroundings and translating this into the multi-dimensionality of art. Perception as the basis of drawing, the drawings as a foundation of the resulting works, mostly combined with painting techniques and the use of transparent materials.
www.leckerkunst.de // www.kunst-kiel.de

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