future ocean
KIEL MARINE SCIENCES

FUTURE OCEAN RESEARCH

INTEGRATING MARINE SCIENCE FROM OCEAN DISCOVERY TO SUSTAINABLE DEVELOPMENT

The **MISSION OF THE FUTURE OCEAN** is to use the results of multidisciplinary scientific research on the past and present ocean to predict the future of the Earth's marine environment. This involves understanding changes to the ocean as well as the interaction between society and the ocean with regards to marine resources, services and risks. This Mission carries with it an obligation to develop and assess scientifically-based global and regional ocean governance options, taking their legal, economic and ethical aspects into account.

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Dear Reader,

Welcome to this Highlight Report. It covers more than a decade of Kiel-based discovery, understanding and prediction of the ocean system and its importance for humanity.

More than 70% of our planet's surface is covered by a globally connected ocean. Kiel-based science contributes to our exploration of this ocean system by combining academic expertise from all faculties of Kiel University with the work of researchers from institutes such as the GEOMAR Helmholtz Centre for Ocean Research Kiel, the Leibniz Institute for the World Economy and the Muthesius University of Fine Arts and Design. Some of our research addresses well-known priority areas such as climate change, ocean pollution or overfishing. But it has also resulted in unexpected findings and assessments, showing for example that invasive species may not always be a bad thing.

Ocean research is "big science". It requires costly, high-tech infrastructure to carry out in-situ observations. This involves large research vessels as well as observing robots such as moored buoys, lander systems, autonomous underwater vehicles, and other expensive and complex equipment. Ocean science calls for investment onshore as well as at sea. Kiel's ocean scientists use high-performance computer systems to simulate the dynamic ocean, its past changes and its likely future development. Our advanced analytical facilities enable detailed analysis of water samples, sediments, and the unique functioning of ecosystems, and the organisms they contain.

As we show in this report, such investment in large-scale ocean science is essential. It is a prerequisite for generating new knowledge about the ocean system, which in turn is needed to improve our planning for the future and to seek solutions to the most pressing questions: How can the ocean's resources meet today's and future human needs while at the same time ensuring planetary sustainability?

Kiel's marine scientists work together in a virtual institute encompassing a broad range of academic disciplines and fields of expertise. They include oceanographers, geophysicists and geochemists, biologists, ecologists, lawyers, economists, political scientists, philosophers, and experts on the coastal zone as well as the deep sea and the open ocean. Many of the institute's members work on cross-cutting themes and are located between conventional faculties, for example in research on the environmental ethics of aquaculture. Our 'Future Ocean' cluster attracts students and researchers from around the world, including those from our strategic partners: Columbia University in the US, Dalhousie University in Halifax, Canada, the Ocean University in Qingdao, China and the Cape Verde Islands.

Over the years, the emphasis of Kiel's ocean research has evolved from the multidisciplinary understanding of the ocean's response to global changes and its potential resources for humanity, and towards science and knowledge generation, in consultation with societal actors such as governments, the private sector, civil society, or citizens at large. Our twin emphasis on excellent research and on academic knowledge in the context of societal challenges means that our work can inform decisions of politicians, public servants and policy makers, businesses, non-governmental bodies; and of individuals. It can also help scientists themselves to see their work in its full scientific and social context.

A more recent priority for Kiel marine research is to engage more actively with policy makers, the private sector and the public about how we can interact with the ocean more sustainably. We contributed to the inclusion of the ocean as a discrete issue in the list of the 17 Sustainable Development Goals (SDGs) on the UN 2030 Agenda on Sustainable Development. Much of our past and future work can be seen as a contribution to SDG14, which is specifically concerned with ocean sustainability [page 80].

One major concern for sustainable ocean use is to end today's massive overfishing. To understand the reality of sustainable fisheries, we have combined marine biology and ecology with the legal and economic aspects of regional and global fisheries. This approach has allowed us to develop the new concepts and ways of thinking that are needed to arrive at more sustainable fisheries [page 56]. They include the development of improved governance models, which requires the perspectives of international law, economics and other areas within the social sciences and humanities.

An example of the complexity of ocean governance is that different legal rules apply within the limits of each individual nation's economic zone (about 300 km out from land) than in the high seas beyond that boundary. We need a new political consensus on legal frameworks that would allow protected areas in the high seas to be established and managed effectively, preventing illegal and unreported fishing. The same applies to early plans to mine the deep sea bed for minerals and other resources across the world [page 62], some of which may be implemented during the coming decade.

Another set of issues is raised by climate change-induced sea level rise. In the future, storm surges will result in more flooding, while a rising sea level will make coastal communities more vulnerable to damaging tsunamis caused by earthquakes and subsea landslides. Our Cluster's programme of work includes a focus on the coastal zone [page 44], the region where risk management issues are especially significant. This involves communicating with the public about risk, and providing them with the information they need to implement actions that increase resilience even under a changing climate. The same applies to ocean pollution, such as plastics, and to the contribution of increased nutrient loads to the spread of oxygen-free dead zones in the ocean [see page 29]. People need to understand that the oceans are not an infinite dump site, and that benign neglect can have serious consequences. Kiel scientists argue for ocean spatial planning, adapted to the different uses and interests affecting the deep ocean as well as coastal areas, and guided by sustainability.

Some of our research focuses on the discovery of new ocean resources for food, materials and chemical compounds. This involves screening unknown biochemical products [page 68] and testing them once they are discovered. Some might have the potential to become revolutionary new drugs, cultured algae for food, or novel organic cosmetics. In this work we cooperate extensively with the private sector in and beyond Germany.

Achieving the goals set by the UN Agenda 2030 will call for a concentrated programme of research, societal engagement, public communication and awareness. Scientific and social issues that are complex and interlinked will need to be understood and acted upon. We believe that the Kiel Cluster of Excellence offers guidance towards a way ahead in this complex terrain, and are looking forward to reporting back in future years on our accomplishments.

Martin Visbeck | Nele Matz-Lück | Ralph Schneider

Joint speakers for the Cluster of Excellence "The Future Ocean"

The true delight is in the finding out rather than in the knowing.

Isaac Asimov

ABOUT THE CLUSTER

The Future Ocean

4 Partners*

* Kiel University (CAU)
GEOMAR Helmholtz Centre for Ocean Research Kiel
Institute for the World Economy (IfW)
Muthesius University of Fine Arts and Design (MKH)

8 Faculties*

* Faculty of Arts and Humanities
Faculty of Theology
Faculty of Law
Faculty of Engineering
Faculty of Business Economics and Social Sciences
Faculty of Medicine
Faculty of Mathematics and Natural Sciences
Faculty of Agricultural and Nutritional Sciences

323 Members*

*Count Autumn 2017

- 171 Associate
- 35% Women
- 30% non-German Members

€80 Million Funding*

*2006-2017 (including Overhead)

- 80% Spent on Personnel

55 PIs*

*Count 2012-2017

- 16 Female
- 14 International

~120 Full-Time Employees*

*including Technical and Administrative Personnel

- 56% Female Employees

Integrated Research Questions

Combining expertise through every faculty of Kiel University

During its long history of more than 350 years, Christian-Albrechts-Universität zu Kiel (CAU) has been closely linked to marine research. Even today, the study of the local waters of the North and Baltic Seas and their coasts, as well as international research on ocean and climate, form an important pillar of the research profile at Kiel University.

The Cluster of Excellence "The Future Ocean" plays a special role here. It combines the excellent expertise of scientists from all eight faculties of Kiel University and shines a beacon on the close cooperation of the university and non-university partners. Together with the GEOMAR Helmholtz Centre for Ocean Research Kiel, the Institute for the World Economy (IfW) and the Muthesius Academy of Fine Arts and Design, the researchers examine the great, socially relevant topic of "ocean and climate change" in an interdisciplinary and transdisciplinary manner. Thus the Cluster perfectly reflects the leitmotif of Kiel University as a university of cutting-edge research for and in society.

For many years, Kiel University has seen itself as a university of dynamically interacting scientific cultures which views the dialogue of disciplines and methods as an indispensable prerequisite to understanding and solving the complex problems of our time. In order to consolidate this aspiration, the university's Executive Board has established four cross-faculty research priorities in recent years. One of them is Kiel Marine Science (KMS), which is characterized by practiced interdisciplinarity, intensive research activity and high-ranking publications. KMS is and will remain the overarching structure for leading university research in the marine sciences in Kiel, and will be the driving force behind the successful acquisition of third-party funding at the federal level and within the framework of European research programmes.

As a state university, Kiel University assumes a special responsibility not only for its researchers, its students and teachers, but especially for the early education of school students. The Cluster of Excellence "The Future Ocean" has been able to set a decisive direction for the university with its programmes for school students. The Kieler Forschungswerkstatt, the school lab at the university, was born out of the school programmes of "The Future Ocean" in close cooperation with the Kiel-based Leibniz Institute for Science and Mathematics Education. This facility recently celebrated its fifth anniversary.

Kiel University also attaches great importance to the training and promotion of early career scientists. The Integrated School of Ocean Sciences (ISOS) of the Cluster of Excellence serves as a role model for teaching important scientific and social competences and for networking PhD students across faculty boundaries. Programs tested in ISOS have significantly influenced the Graduate Center at Kiel University. However, interdisciplinary teaching and research must not start with graduate education. Kiel University has therefore set itself the task of anchoring interdisciplinary teaching modules in bachelor's and master's programs. Here, too, the Cluster of Excellence "The Future Ocean" has provided important impulses for new ways of training students.

Facing the increasingly complex and, in essence, global challenges of our time, the close integration of scientific disciplines with their complementary methods, accompanied by an intensive exchange with society and its decision-makers from politics and business, is the basic requirement for commonly supported and societally accepted sustainable solutions.

With its many years of experience in transdisciplinary research in the Cluster of Excellence "The Future Ocean", Kiel University can make a valuable contribution here.

Prof. Dr. Lutz Kipp
President
Kiel University

C | A | U
Kiel University
Christian-Albrechts-Universität zu Kiel

Kiel University

Kiel University is Germany's northernmost State University and the scientific center of Schleswig-Holstein. At our institutes, more than 26,000 students learn their trade and about 2,000 scientists teach and do research in one of our eight faculties - Arts and Humanities, Theology, Law, Medicine, Mathematics and Natural Sciences, Business, Economics and Social Sciences, Engineering and Agricultural and Nutritional Sciences. They educate students in 185 degree programs and approximately 80 different areas ranging from Agricultural Science to Zoology. Throughout its 350 year history, the city of Kiel and the University have formed tight bonds. With its clinic, the University is one of the biggest employers in the region. It sees itself as a modern State University of interconnecting academic cultures.
www.uni-kiel.de

Investigating the ocean from a multidisciplinary perspective

Kiel has a long-standing tradition in ocean research – a history dating back to the late 17th century when Samuel Reyher, a mathematician and physicist at Kiel University, conducted the first recorded marine science experiment in Kiel to determine the salinity of the water in the Kiel Fjord. Ever since, there has been a strong focus on marine research and also the education of marine scientists at Kiel University and at marine research institutes in Kiel, including the GEOMAR Helmholtz Centre for Ocean Research Kiel and its predecessor.

The focus of Kiel marine research has for a long time been mainly on the natural sciences. However, during the last decades it has become more and more obvious that the Grand Challenges of marine research need an integrated cross-disciplinary and transdisciplinary approach to address the role of the oceans in climate change, the human impact on marine ecosystems, energy, mineral and biological resources, and plate tectonics and natural hazards. For this reason, GEOMAR is excited to team up with the Future Ocean Cluster and experts from many disciplines at Kiel University and at three local partner institutions ranging from the life sciences to environmental economics, international law, and philosophy, all dedicated to investigating the ocean from a multidisciplinary perspective.

This unique perspective of the Future Ocean has established a new benchmark in cooperation between scientific disciplines, for the first time connecting basic research on the ocean system with ocean prediction and sustainable ocean management and governance. Hence, Future Ocean research ideally complements the GEOMAR competencies and expertise and enables us to work together with our local partners on pressing marine research questions in a holistic manner and in key areas of integrative ocean science. The Cluster also deepened the traditionally strong cooperation between GEOMAR and Kiel University, for example with respect to the development of early career scientists. A unique framework for training, supervision and mentoring of young scientists has been established in Kiel with the institutional support of doctoral and postdoctoral researchers by the Integrated School of Ocean Sciences and the Integrated Marine Postdoc Network within the Future Ocean cluster.

Future Ocean has continuously promoted excellence in research and has also fostered the structural development of its partner institutions. It is a remarkable achievement that under the Cluster umbrella more than ten institutions with members of very diverse professional backgrounds, methodological approaches and expertise have become so strongly connected. Accordingly, the Future Ocean Cluster is well prepared to expand its intergrated research into the next phase. The global ocean will become increasingly important for the future of humankind, while ocean pressures also increase. Thus, Future Ocean must continue its unique interdisciplinary approach and further its goal of innovative, integrative, and solution-oriented ocean research.

GEOMAR
Helmholtz Centre for Ocean Research Kiel

Mankind vs humankind – your call

Prof. Dr. Peter M. Herzig
Director
GEOMAR Helmholtz Centre for Ocean Research Kiel

GEOMAR Helmholtz Centre for Ocean Research Kiel

GEOMAR Helmholtz Centre for Ocean Research Kiel is one of the world's leading institutes in the field of marine sciences. The institute investigates the chemical, physical, biological and geological processes of the seafloor, oceans and ocean margins and their interactions with the atmosphere. The institute has four major research divisions: Ocean Circulation and Climate Dynamics, Marine Biogeochemistry, Marine Ecology, and Dynamics of the Ocean Floor. With this broad spectrum GEOMAR is unique in Germany. Additionally, the centre has successfully bridged the gap between basic and applied science in a number of research areas. GEOMAR is a foundation under public law jointly funded by the federal (90%) and state (10%) governments. GEOMAR has a staff of 1,000 (on 31 March 2017) and a yearly budget of around €75 million.
www.geomar.de

Any sustainable ocean management approach requires a global perspective

The Kiel Institute for the World Economy, The Kiel Institute, was founded as Royal Institute for Maritime Transport and World Economics at Kiel University in 1914, and has focused on global problems and opportunities since its establishment. The ocean as a global common, connecting coastal and non-coastal societies on the planet, is obviously of great interest to the Kiel Institute. Any comprehensive and sustainable ocean management approach requires a global perspective. Yet, society is still confronted with an unsustainable consumption of oceanic resources and services, beyond rates at which these resources can reproduce, regrow, and regenerate. As a result, the pressures on our climate, ecosystems, habitats, and biodiversity are increasing.

A tipping or even turning point towards internationally coordinated sustainable policies could be the United Nations 2030 Agenda for Sustainable Development, which devotes a specific Sustainable Development Goal to the conservation and sustainable use of the oceans, seas, and marine resources. Because of the global dimension of the challenge and the level of international cooperation required to make progress, an integrated cross-disciplinary and transdisciplinary approach is essential. Accordingly, the Kiel Institute is very proud to be able to contribute to the Kiel Cluster of Excellence "The Future Ocean" with its expertise with respect to creating solutions to urgent problems in global economic affairs.

The mutual exchange between experts in science, international law, and ethics from the local partner institutions has allowed for significant progress to be made in modeling ocean carbon uptake in integrated assessment models and measuring sustainable oceanic development. With respect to the former, interdisciplinary teams of researchers from Kiel University, the GEOMAR Helmholtz Centre for Ocean Research Kiel, and the Kiel Institute analyze the potential of the ocean to generate negative emissions which are the key to compliance with the 2°C goal of the Paris Agreement. With respect to the latter, these teams show that it is essential to properly account for the social evaluation of ocean benefits and for the various risks and uncertainties involved in our interaction with the ocean in order to ensure precautionary and sustainable ocean governance. Policy assessment and advice based on approaches assuming unlimited substitution possibilities between ocean resources and services could result in certifying a human-ocean system of countries as healthy that in reality neglects important aspects of ocean health and in wrongly identifying certain development trajectories as sustainable, although this is actually not the case. Accordingly, the Kiel Institute is looking forward to continuing to be a part of this exciting integrated research cluster and to contribute to the challenge of achieving international cooperation and effective governance to protect the marine environment.

KIEL INSTITUTE FOR THE WORLD ECONOMY

Prof. Dennis Snower, PhD.
President
Institute for the World Economy Kiel

Kiel Institute for the World Economy (IFW)

The Kiel Institute is a major center for global economic research, economic policy advice, and economic education. The Institute's key focus is on researching innovative solutions to pressing problems affecting the global economy. Using this research as a basis, it advises decision-makers in the political, business, and societal arenas while also informing the general public about important economic issues. The Kiel Institute maintains an extensive network of national and international experts, whose work feeds directly or indirectly into the Institute's research and advisory activity. Another key area is training and education in economics, including the Institute's Advanced Studies Program in International Economic Policy Research. The Kiel Institute co-operates closely with the world's largest library in the economic and social sciences.

www.ifw-kiel.de

Put Your Heads Together!

ABOUT THE COOPERATION BETWEEN THE MUTHESIUS UNIVERSITY OF FINE ARTS AND DESIGN AND THE CLUSTER OF EXCELLENCE "THE FUTURE OCEAN"

The Muthesius University of Fine Arts and Design is the only art university nationwide which has been an active cooperation partner in two Clusters of Excellence for many years. The collaboration with "The Future Ocean" is a unique characteristic of both the art university and the Cluster of Excellence. Therefore, we are looking forward to continuing our participation in the Cluster of Excellence with the artistic research of our excellent study programs. We are looking forward to reciprocal gains in knowledge!

The artistic approach is reflected in the interaction with natural science as a seismograph, which creates a particular point of view of familiar considerations. Ultimately it is about the identity and the difference between science and art. This is where, the specific potential for insight of artistic productivity comes into effect: Art itself thinks, with their own tools. And so we think and ask questions in a new manner; questions which could not have been asked in this way in the natural sciences. Of course, research operates in different fields. Diverse disciplines are the basic elements of a successful collaboration; they just should not remain separated. Real collaboration must interweave adjacent elements into a network. Only then new thinking can arise. Soley in this manner the treasures of the sea can be uncovered. Thus (and with a small wink of the eye), our cooperation is dedicated to Friedrich Schiller's credo from his preface to the literary journal "Horen" (1795): "In this manner, one believes oneself to be contributing to the removal of the wall, which separates the beautiful world from that of the scholars to the disadvantage of both,

to introduce detailed thorough knowledge into societal life, and taste into science." Roland Barthes describes this in a similar way in his text to "Young Researchers" – and goes one step further: "The often addressed interdisciplinarity does not consist in contrasting already existing disciplines (of which, basically, none is willing to submit itself). If you want to pursue interdisciplinarity, it is not sufficient to take a 'topic' and to summon two or three sciences for this purpose. Interdisplinarity consists of creating a new object which does not belong to anyone." In short: Cooperation is the first virtue of the researcher with regard to such a complex question as the ocean. The present is no longer the time of the isolated researcher who descends into the basement and re-emerges with a Nobel Prize. We still need scholars and ingenious minds, but we have to put the heads together!

muthesius kunsthochschule

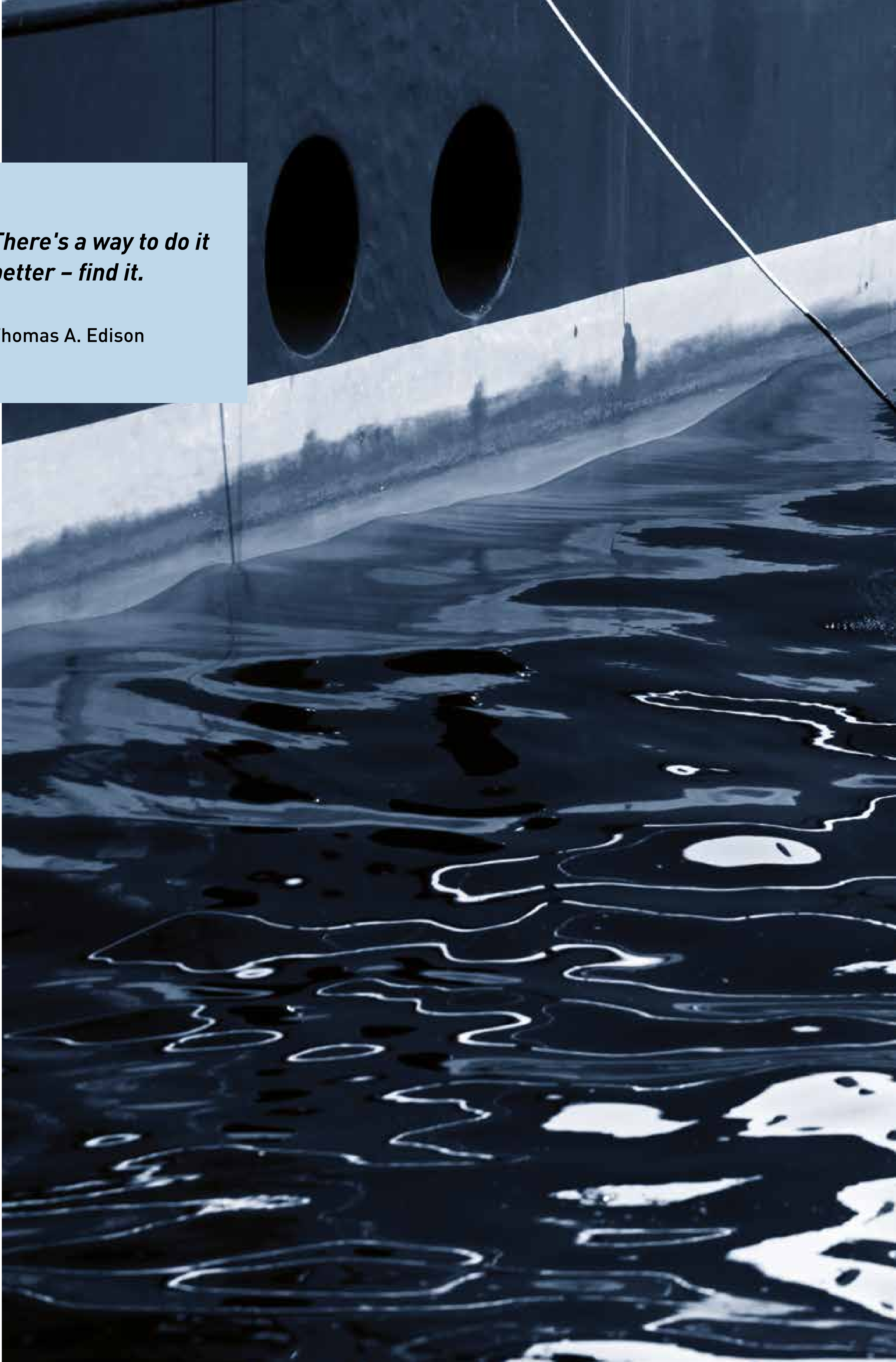
Dr. Arne Zerbst
President
Muthesius University of Fine Arts and Design

MUTHESIUS UNIVERSITY OF FINE ARTS AND DESIGN

Founded in 2005, the Muthesius University of Fine Arts and Design in Kiel is Germany's northernmost and youngest school of higher education devoted to the systematic study of art and design. The main goal of the Muthesius University in Kiel is to promote art, design and spatial strategies via research and development projects as a focal point for work and intellectual debates. As the only art university in the State of Schleswig-Holstein, the Muthesius is not only a place to develop culturally relevant biographies but with its project studies also a place of particular experimentation and realisation.

To a certain extent, the Muthesius Universities master's programme offers courses and development opportunities for students that are unique in Germany. Around 580 study places are spread across the study courses in Fine Arts, Fine Arts for Secondary School Teachers, Spatial Strategies, Communication Design and Industrial Design.

www.muthesius.de



There's a way to do it better – find it.

Thomas A. Edison

FUTURE OCEAN RESEARCH

Science facts

> 5000 Publications*

*2007-2017

- 35 Nature
- 14 Science
- 52 Nature Geoscience
- 24 Nature Communications
- 12 Nature Climate Change

- 3 ERC Grants
  - 1 Kovalevskaja Award
    - 3 Emmy Noether Awards
  - 1 Leibniz Award
- 10 Other Awards

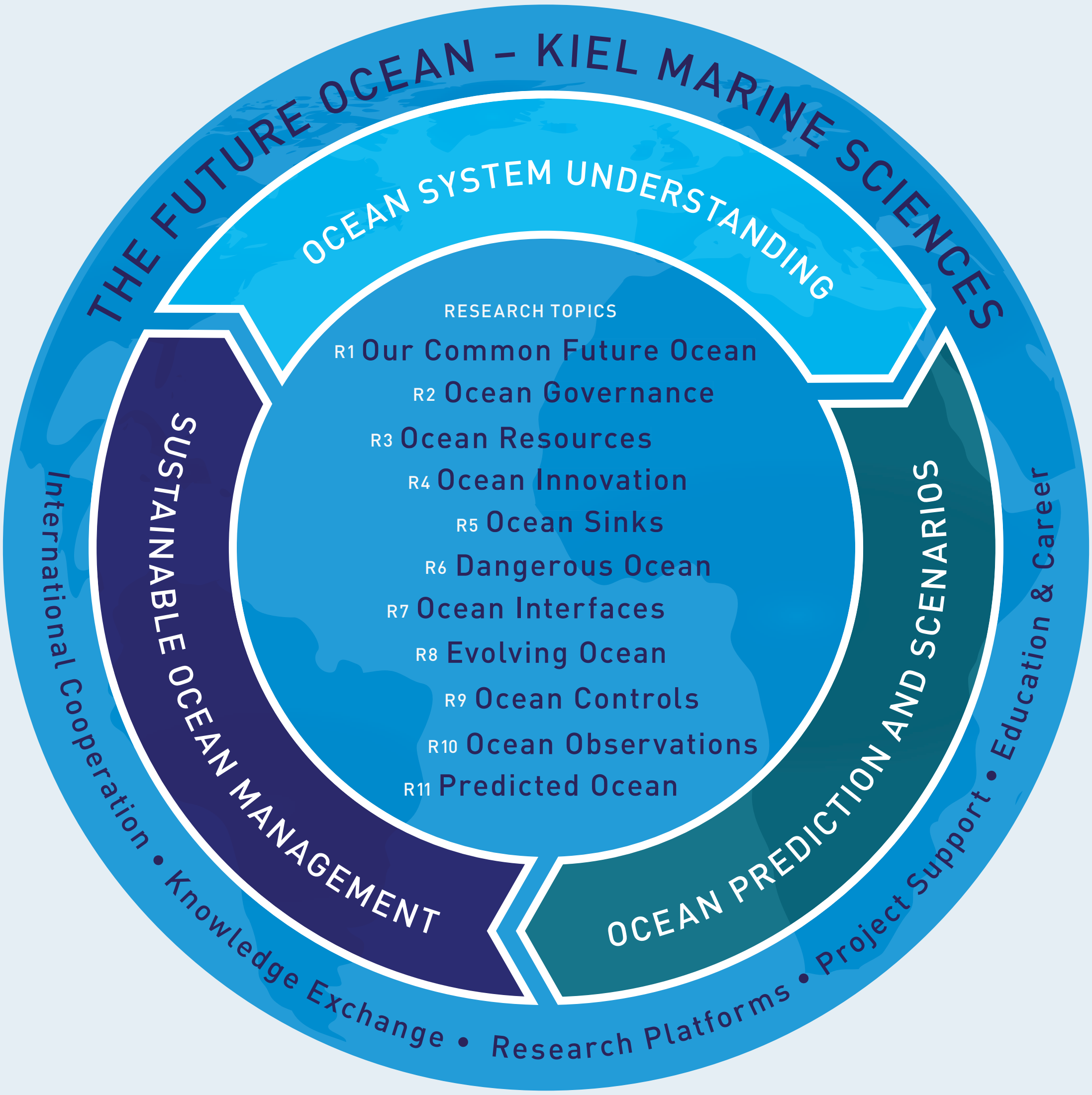
- 18 Proposal Calls Issued
  - Over 900 Proposals Received
- 287 Research Projects Funded*

*2007-2017, €32 Million in Total

- 48 Sabbatical Grants*
  - 115 Travel Grants*
- 32 Workshops and Conferences in Kiel*

* Funded by Future Ocean 2010-2017

The Cluster Concept



What future for ocean research?

Ralph Schneider and Nele Matz-Lück of Kiel University, and Martin Visbeck of the GEOMAR Helmholtz Centre for Ocean Research Kiel, are the speakers of the Cluster of Excellence "The Future Ocean" in Kiel. Here they explain why marine sciences in Kiel are unique.

What is Kiel's overall mission in the marine sciences in the 21st century?

MARTIN VISBECK Our interdisciplinary approach to ocean change, ocean risks and ocean opportunities has been ambitious and future-oriented. We have used the funds of the German Excellence Initiative to close the gaps between pockets of excellence in the Kiel research landscape. Thirteen research groups were established to investigate topics such as climate change, impacts on the ocean, ocean resources or legal and economic challenges. The virtual institute that we have created is the now world's most integrated setting for marine research. Before Future Ocean there were few economists or lawyers dealing with the new challenges of marine science. But their knowledge is essential to answering the key questions about the opportunities and challenges posed by the changing ocean.

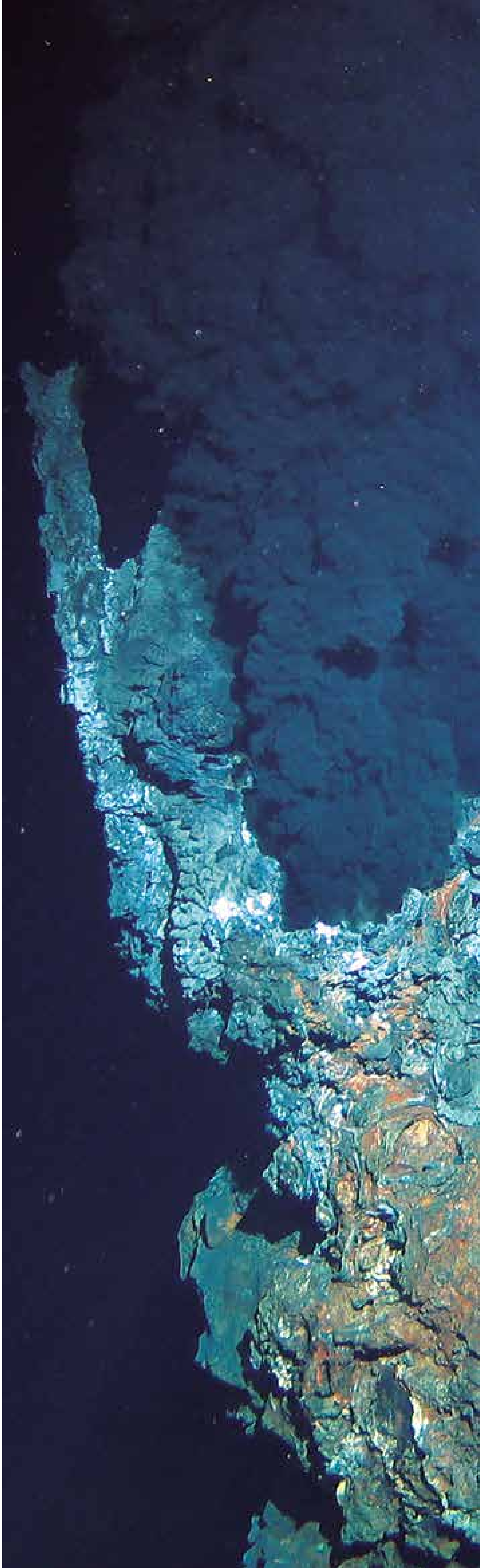
So it's not just about great research, but also about solving real problems?

VISBECK Alongside producing the best integrated science, the second phase of Future Ocean is designed to communicate and exchange knowledge with politicians, industry, NGOs and civil society. The overall aim is to put our innovation cycle into practice. The objective is for improved understanding, including scientifically-based predictions and scenarios, to provide crucial information to decision-makers.

MATZ-LÜCK Even in my own area of maritime law, interdisciplinary issues arise such as climate change and geoengineering, piracy, or the growing interest in Arctic resources. Working in an interdisciplinary way helps us to understand the pressures on the system more fully, and to point to ways of increasing resilience with more authority. We can discover and research the issues, assess their importance, and provide suggestions for regulating them. Industry is an important partner and we need to work with businesses to put money into the solutions we are suggesting, for example to plastics pollution. We need to strengthen those ties and work with industry on the co-design of future initiatives.

Do you have the right people for this big challenge?

SCHNEIDER A new focus for the Cluster is our strong support for young scientists and their careers. There has been a dramatic decrease in



Before Future Ocean there were few economists or lawyers dealing with the new challenges of marine science.

Co-Speaker
Nele Matz-Lück

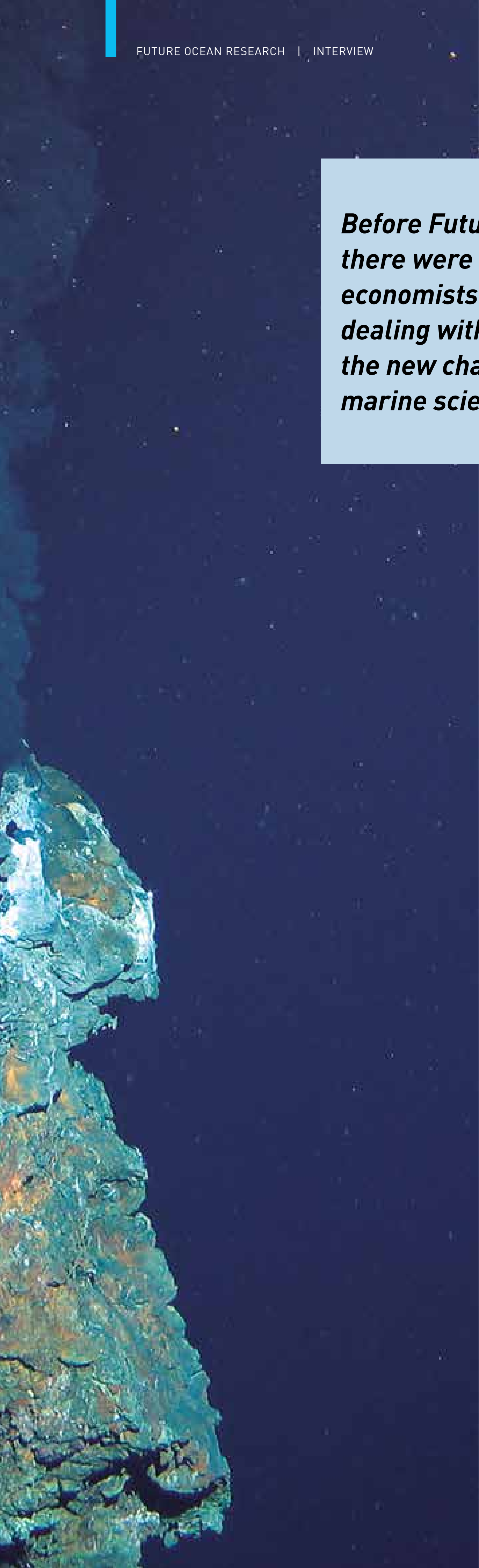
'Mittelbau' positions, people responsible for research, education and laboratories within a research group. This lack of career options might lead to a loss of next-generation scientists which would be felt at all levels of research and education. Within the Future Ocean Network we want to develop and implement a solid framework for career and personal development, including increased financial security for individuals and the institution.

Ambitious equal opportunity targets have been a feature of this work from the beginning. A continuous commitment to quantitative gender targets of 50% for junior research group leaders and postdoctoral research positions has led to a significant increase in the number of female professors and researchers in a number of departments at Kiel University, above all in the Faculty of Mathematics and Natural Sciences, the Faculty of Business, Economics and Social Sciences, and the Faculty of Law. We had six per cent female PIs in 2007 and 40 per cent in 2017. In the Future Ocean cluster, we have implemented the "via:mento ocean" program, a cluster-specific mentoring program for female postdoctoral researchers in marine science, offered in English in order to address international researchers equally. The cluster has provided a number of services such as a child care facility, child care during conferences and workshops, and a family commissioner that are available to all members with family duties, as part of its commitment to family-friendliness.

How do you connect Future Ocean research to possible user communities and research partners?

SCHNEIDER As a state body within Schleswig-Holstein, the university is well aware of the local and regional importance of its work. With interdisciplinary research, we can start to provide solutions to a full range of issues from basic to applied science. Some of our projects have industrial application, while others lead to better, knowledge-based political decisions or policies. The better we understand the key research questions and the approaches of other disciplines, the more relevant the conclusions from our own research can be. During the second phase of Future Ocean, it was particularly important to expand our disciplinary base into political science and environmental ethics.

At the same time, internationalisation is a key goal for Future Ocean. The Cluster is establishing premium, long-term relationships on an institutional basis with a handful of centres worldwide, while encouraging staff to



Research on Deep Sea Vents touches numerous disciplines, and involves discovering their nature, their influence on the surrounding ecosystem and their economic potential.

build their personal networks around the world. We envision easy exchange opportunities for students and researchers at all levels, and we will use our network to benchmark our scientific and organizational development.

MATZ-LÜCK We already work with ministries in Berlin and with bodies such as the Institute for Advanced Sustainability Studies in Potsdam. Our link to the State of Schleswig-Holstein gives us political influence locally and nationally.

Just how interdisciplinary is Kiel Marine Science?

SCHNEIDER Since autumn 2012, when the Kiel University Board founded Kiel Marine Science, it has integrated the expertise of more than 70 researchers, from every faculty of the University. Kiel has a long tradition in the marine sciences, in particular at the Institute for Geosciences which has several working groups in marine geochemistry and petrology, paleoclimate research and modelling, marine geophysics and coastal research. Over the past few years, we have emphasised interdisciplinary research across the full range of subjects. Our work enjoys high recognition across different subjects and faculties, and beyond national boundaries. One special asset has been our ability to recruit young scientists strategically, on an interdisciplinary basis that allows them to choose their own supervisors and work on their own projects.

MATZ-LÜCK The cluster has been very successful at creating platforms for interdisciplinary work to grow. In the past, I would never have been able to do a project proposal as a joint venture with an engineer.

We need to communicate the results of this approach to the public and to other academic institutions, and to make sure our strategy is understood. But there is also a task of internal communication. The Cluster has about 155 full members, over 300 if all our associate members are included.

How does this work feed our growing awareness of economic and environmental sustainability?

SCHNEIDER Kiel research helps develop strategies for using marine resources in a sustainable and responsible way. It also provides applied insights into marine hazards and risk factors, such as earthquakes and tsunamis. There is a strong emphasis on the economic, legal and ethical impacts of our use of the ocean, including the deep ocean as well as coastal and territorial waters. This knowledge has direct implications for human welfare.

Do other local organisations support and sustain this activity?

SCHNEIDER To achieve maximum impact for its work, Kiel has become a pioneer in knowledge presentation and transfer, from fundamental research

> ***Our ambition is to contribute the scientific basis for humans to live sustainably with the ocean.***

Speaker Future Ocean:
Martin Visbeck

to the development of models and the implementation of management concepts, for example in fisheries management. Here we are supported by partners including Research and Technology Centre West (FTZ) in Büsum, with its broad spectrum of research on the North German coast and internationally, the Kiel Institute for the World Economy (IfW), the University Hospital (UKSH) and the Society for Marine Aquaculture (GMA), also in Büsum.

What are your hopes for the next phase of Kiel Marine Science?

VISBECK The planned cluster will acknowledge the complexity of societal demands and the intricacy of society's interaction with the environment. Information exchange and engagement activities will add another dimension to our research. Our ambition is to contribute the scientific basis for humans to live sustainably with the ocean. We have confidence in the proposal because it is based on a decade of successful investment in integrated ocean research here in Kiel.

Is there a uniting theme for this very diverse range of activities?

VISBECK In terms of their human effects, we see the issues under three main headings.

'Ocean pressures' refers to the increasing variety of anthropogenic impacts on the ocean. These include climate change effects such as ocean warming, sea-level rise, marine carbon dioxide uptake, ocean acidification and ocean deoxygenation, and also the impact of waste dumping, increased noise levels, fossil fuel exploitation, the extraction of minerals and materials, coastal urbanisation, and carbon management activities. Our concept of 'ocean resilience' relates to the ability of human societies and marine ecosystems to endure and recover from

RV Maria S. Merian is one of Germany's four large Research Vessels.

Over the past few years, we have emphasised interdisciplinary research across the full range of subjects.

Co-Speaker Ralph Schneider

disasters, stress and other disturbances. Finally, our objective of achieving 'intergenerational ocean prosperity' will call for us to understand how to improve the overall, long-term wealth and well-being of humans.

What new institutions are needed within the Cluster to achieve these ambitions?

VISBECK Again, there seem to be three. Digital Ocean is our open science initiative, and will move the emphasis of ocean science in Kiel from 'publishing as soon as possible' and towards 'sharing knowledge as early as possible'. Ocean research benefits from improved sensors, more inclusive ocean system modelling, efficient data flows, and big data analytics and algorithmics, combined with long-lived open research software. We will combine methods from mathematics, computer science, signal and systems engineering, social science analytics and bioinformatics. Our Digital Ocean activities will also develop new methods and educational tools to support the full spectrum of marine science. The objective is to use these methods and techniques ourselves, and make them available for open ocean research around the world.

The Ocean Media Lab will ask how transdisciplinary data syntheses can be understood and interpreted. It will explore visual data in the context of marine science, including the visualisation of observation data, model simulations, and future ocean scenarios. Media artists and communications experts will be engaged at a high level, focusing on human-computer interactions, the role of media in the scientific discourse, and the broader societal impact of visually communicated knowledge.

The third part of the picture is the international Ocean Young Leaders Forum. It will bring early career researchers together with experienced academicians and non-academic stakeholders to address solution-oriented research into sustainable human dealings with the oceans.

Interview conducted by Science Journalist Martin Ince (UK).

How do we know what happens in the ocean?

We are living in the Information Age, and nowhere more so than in our growing knowledge of the oceans. Data and information are the key to using the oceans wisely, and to keeping them healthy for the future. To help do this, data are gathered by a range of global observation networks, where they are processed, stored and analysed by specialists.

There is global agreement on the importance of ocean data. In the 2016 Tsukuba Declaration on the future of science, technology and innovation, the G7 industrialized nations stated that "The health of the oceans has rightly been recognized as a crucial economic development issue." The Declaration detailed data priorities for the oceans, many of which are being pursued by researchers in Kiel. They are deeply involved in the collection, analysis, open publishing and sharing of ocean data, much of it gathered through interoperable observation systems.

The Argo programme (on page 28) has involved the creation of a global array of 3,800 free-drifting profiling floats that measure the temperature and salinity of the upper 2000m of the ocean. It is perhaps one of the greatest success stories in physical oceanography. Arne Körtzinger, a chemical oceanographer who has pioneered oxygen measurements from Argo floats, is a member of the scientific steering group of Biogeochemical Argo, which is pushing for a fully-fledged biogeochemical Argo programme. Argo working groups including Körtzinger's group in Kiel are already developing the next generation of these marine observation robots, which will be equipped with biogeochemical sensors measuring oxygen, pH, nitrate, chlorophyll and suspended particles in the water column. A global array of floats will greatly enhance our ocean database and our knowledge of ocean behaviour. It

GEOMAR's Autonomous Underwater Vehicle (AUV) Abyss returns after a successful deployment in the East Pacific Ocean.

How can we observe the oceans, the Earth's largest and most complex habitat? How does marine research in Kiel contribute to monitoring the ocean's temperature, salinity and other vital properties, and can we find out if they are changing?

will allow us to map these parameters on a global scale in real time, and detect even slight environmental change early on.

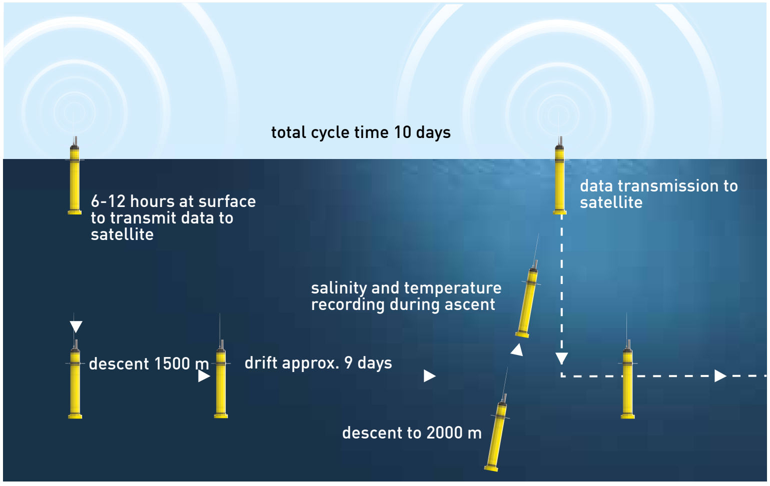
Other autonomous sensor platforms which are being employed and further extended by Körtzinger's group include Voluntary Observing Ships (VOS). These are usually merchant ships which sail stable routes across the ocean. They are equipped with sophisticated analytical instruments that measure carbon dioxide, oxygen, chlorophyll, and other parameters continuously along the same routes throughout the year.

Kiel scientists are also active in more static forms of data gathering. MoLab, a seabed ocean observatory which can be left in place for months at a time to gather data from sites of scientific interest, was developed to fill the need for a fixed ocean observing system (See picture on page 30). It was first used in 2012 off the North coast of Norway, to investigate the region's cold-water coral reefs 300m below the sea surface.

The Mo in MoLab means modular: different detectors can be placed at different locations across several kilometres of the sea floor, allowing a complete picture of the region to be built up. These subsystems communicate with each other by sound, so no cables need be laid on the seafloor. In the Norwegian experiment, MoLab was used to measure currents, tides, temperatures, salinity, nutrients and oxygen consumption, and the reef was observed continuously by MoLab's cameras. In this experiment, high resolution time series data and photographs from MoLab were analysed with machine learning techniques to determine the polyp activity patterns of cold-water corals [1]. The results showed that activity on the reef was governed by the strong tidal currents that prevail in that location. The coral was able to adapt to the large-scale patterns of water movement to optimize nutrient uptake.

Kiel Scientists are continuously measuring the state of the ocean on global and regional scales. They have discovered previously unknown-oxygen depleted zones within eddies in the Atlantic Ocean. These zones may play an important role in ocean productivity and biochemistry.

THE ARGO PROGRAM



The operational cycle of an Argo float.

The international Argo programme deploys thousands of Argo floats in the world's oceans. The term is misleading because the Argo floats are autonomous robots which only become interesting when they sink. They can descend to 2000m below the surface by pumping oil from a bladder to modify their buoyancy. Then they ascend to the surface at predetermined times, measuring pressure, temperature and salinity in the water as they do so. At the surface, they use satellite phone technology to transmit their position and measurements to the fast-growing Argo data centres in France and the US. The floats last about four years and send data on their deep ocean dives once every ten days. About 3800 floats are in use at any one time, averaging one per 300 km of the ocean. They produce 100,000 measurements of temperature, salinity and water velocity per year. These measurements are publicly available through the data centres. See more information on the Argo programme at www.argo.ucsd.edu.

An Ocean Tracer Injection System (OTIS) is deployed from a research vessel to conduct offshore tracer experiments.

While MoLab is designed as a flexible platform for studies lasting only a couple of months, Kiel's Baltic sea researchers, including Hermann Bange, take the long view. They have maintained the Boknis Eck station since the late 1950s. Monthly sampling there began on 30 April 1957, making Boknis Eck one of the world's oldest time series sites for marine data still in operation. In December 2016 a cabled underwater observatory was deployed close to the site. It sits in 14.5 m water depth and its sensors generate continuous in-situ data. It complements the established monthly sampling at Boknis Eck and allows short-term trends and events in the western Baltic Sea to be detected.

HOW MUCH CO_2?

Tobias Steinhoff is based at GEOMAR's chemical oceanography department. His research is concerned with carbon dioxide, the most important greenhouse gas, and how it moves between the ocean and the atmosphere. He is gathering CO_2 measurements from ships crossing the North Atlantic between Europe and North America, as this is one of the most important areas in which carbon dioxide enters the ocean and is stored. He is involved in a project that aggregates these flows of data into a consistent global data product, showing the potential for big data to revolutionise our understanding of the oceans.

Steinhoff is one of hundreds of scientists, based in institutions from New Zealand to Japan and Brazil, who have created SOCAT, the Surface Ocean CO_2 Atlas [2]. This massive global database unites updated, quality-controlled values for the carbon dioxide concentration of global surface oceans and coastal seas from a wide range of sources. Version 5 of SOCAT was released in 2017 and contains 21.5 million values from 3646 data sets from 1957 to 2017, three million more than the fourth edition. SOCAT has made more than one million observations per year for the last decade. Each data point comes with a quality flag, allowing users to gauge the reliability of data from different sensors and platforms.

SOCAT is used for vital scientific investigations, especially the quantification of the ocean sink for atmospheric carbon dioxide and its long-term variation. It also is an important input to the annually released global carbon budget [3], a key element in the compilation of the famous IPCC Climate Report.

THE ATLANTIC'S HIDDEN DEAD ZONE

The growing availability of data on the oceans has allowed Kiel researchers to find out about previously unknown dead zones of the Atlantic [4], working with colleagues in the Cape Verde Islands and elsewhere. A group involving Johannes Karstensen and Björn Fiedler discovered these oxygen-poor dead zones at the Cape Verde Ocean Observatory (CVOO) in the eastern tropical North Atlantic. They used data on dissolved oxygen in the oceans obtained from subsea gliders, moored measuring devices, research vessels, and the Argo floats mentioned above.

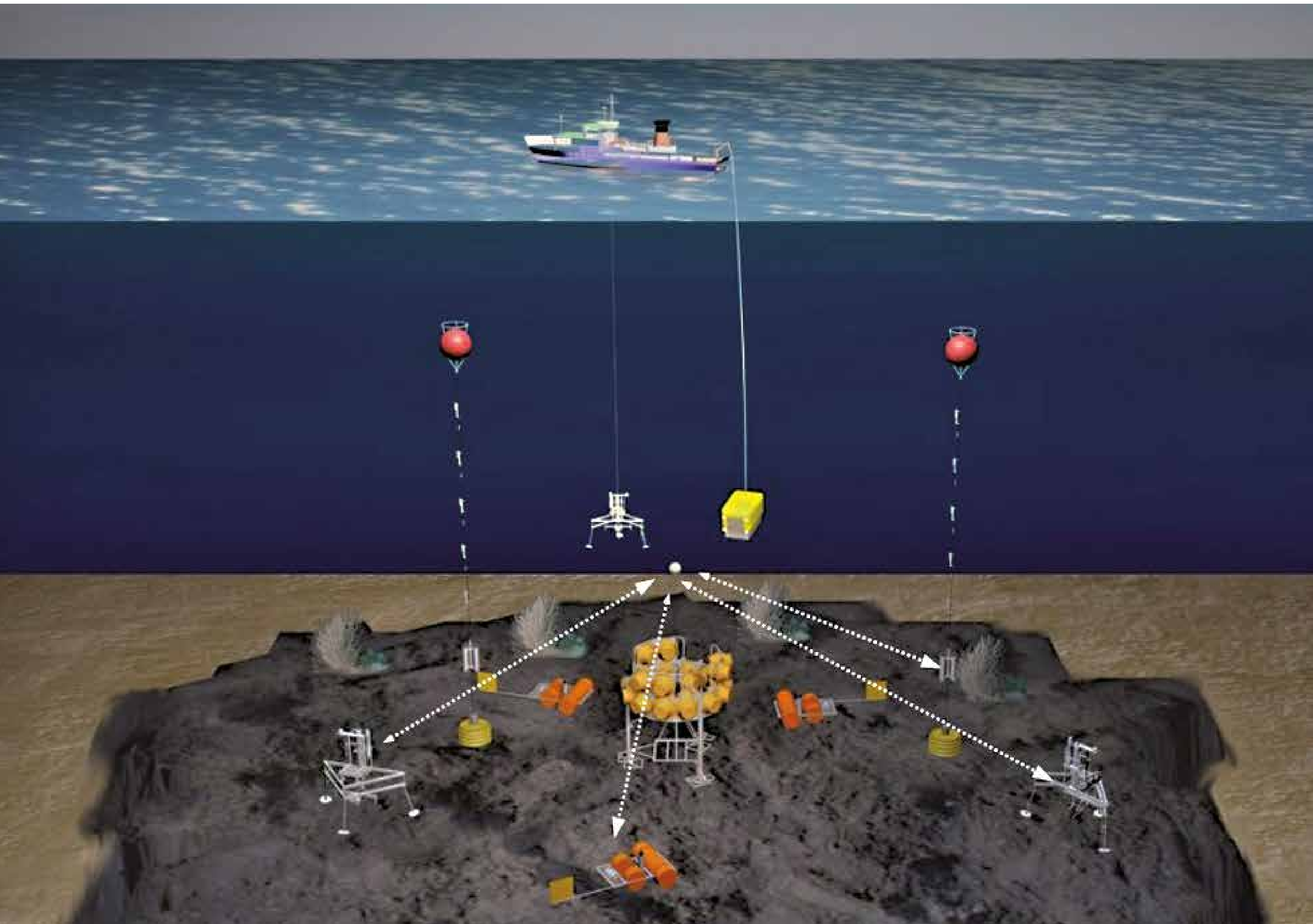
This novel dataset reveals that dead zones are common in the tropical Eastern Atlantic. They occur within eddies, swirling water bodies of more than 100 km in diameter. 27 have been observed so far in the available data. The lowest oxygen concentrations are found just below the surface, from 50 to 150 m depth, with consequences for the marine fauna.

It seems that these low-oxygen zones form because the swirling motion of the water isolates them from the rest of the ocean, while high levels of biological activity depress their oxygen content [5].

These results are important because we already know that climate change is likely to reduce the amount of oxygen in the oceans, and oxygen is important for almost all marine life. The scientists say: "In light of projected ocean deoxygenation, oxygen loss events like these eddies are already showing us how microbial communities and ecosystem structures will be altered in the future. There could be impacts on primary productivity and on biogeochemical processes in oceanic water bodies." This could have severe consequences for nations such as Cape Verde and the rest of West Africa, where national economies are heavily dependent upon fisheries.

New technology allows us to measure the oceans in greater detail than ever. Oceans can be monitored from the sea surface or from space, and by new devices moving autonomously within the water or sitting at the sea floor. Kiel scientists are leaders in ocean monitoring, a task which is becoming more and more of a global priority

MoLab, the modular multidisciplinary seafloor observatory, is able to measure biological, physical, chemical and geological parameters over a period of several months and across a wide area of the ocean floor. Graphic: MoLab-AG, GEOMAR



GEOMAR's remotely-operated vehicle Kiel 6000 can operate in water depths up to 6000 m.

THE LEGAL ASPECT OF SUBSEA ROBOTS

Subsea gliders and submersible buoys are effective at gathering data about the oceans. But many of them are drifting uncontrolled. What are the legal implications of these devices? Katharine Bork and colleagues from Kiel think they may not be well-defined.
In the journal Ocean Development and International Law, they point out that coastal states have full legal rights over what happens in their territorial waters, and this includes the use of these data-gathering devices. This applies even when they were launched into the ocean far away [6], but later drift into the territorial waters of a particular nation. In addition, using floats to gather routine weather and wave data might be regarded as survey activity rather than scientific research. This puts it under the remit of a different body of international law.
Bork and her co-authors say that "At the time of the negotiation of UNCLOS, the 1982 UN Law of the Sea convention that governs these activities, oceanographic surveying was not very advanced. The Argo Project, and other systematic programs, go beyond this understanding because the data collected is not for exclusive use, but is made available immediately without delay, in near real-time, to all kinds of users." But they add that "coastal states are not yet willing to modify the current legal regime on marine scientific research despite a clear need for the use of floating devices for the benefit of mankind, for example weather warnings, ship routing services, or the detection of climate change. It seems that, unlike floats and gliders themselves, their legal regime will remain firmly at anchor for the time being."

WHAT IS THE FUTURE FOR OCEAN MONITORING?

Sensors are improving rapidly, while Argo and other initiatives allow us to monitor large parts of the ocean on a regular basis. "The new parameters measured by the BioGeoChemical Argo will provide a breakthrough for marine biogeochemistry" predicts Arne Körtzinger.
However, gaps in our knowledge remain. Few of today's observatories target the deep sea, and even these are mostly temporary. The zone below 2000 m is only well-explored in small patches of specific interest, for instance where commercial exploration for oil or other minerals has taken place or where there are particular geological or ecological features. Most of the deep sea between the seafloor and the upper two km of water remains largely unexplored.

This problem is now being addressed. New infrastructure installed at the Ocean Science Centre Mindelo (OSCM) in the Cape Verde Islands provides a modern, multifunctional platform for deep ocean assessment. Its development follows what we term the 3-Spheres Approach. This addresses the sphere of international marine research, the sphere of locally-motivated research driven by socio-economic need, and the sphere of capacity-building in the West African region. Coherent and concerted activity in all three of these spheres is one of the foremost tasks for marine science in Kiel.

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The Ocean System: Do we really understand what is going on?

The oceans store large amounts of heat and greenhouse gases, and they each have a direct role in the Earth's climate. So it is essential to understand past and present ocean behaviour if we are to model the future ocean and atmosphere in an era of climate change. This understanding of how the different parameters that drive the oceans relate to each other is needed to feed the future ocean models described in the next chapter.

An important example of improved understanding gained within recent years concerns the topmost layer of the ocean. This is where it exchanges heat and matter with the atmosphere. Contrary to appearances, the ocean often has a very thin layer of organic material at its surface. But how stable is it? And is it present in remote ocean areas, where there may not be a source of organic matter to maintain it? Researchers from Kiel have shown that a thin, gelatinous layer may form on Arctic sea surfaces from organic compounds produced by microbes on the sea ice [1].

Kiel researchers have shown that plastic litter does not degrade within a reasonable period of time. Instead it accumulates in sediments, and will probably influence our environment increasingly over the long-term future.

We know that microbial life in the top layer of water has a big influence on the amount of greenhouse gases and other chemicals that are emitted to the atmosphere from the ocean. Microscopic organisms there both use and generate gases that include methane, carbon dioxide, nitrous oxide, and many halogenated hydrocarbons. In recent years we have realised its vital importance to our understanding of present and future climates. Researchers in Kiel are now refining this knowledge.

One important aspect they are tackling is the chemistry that goes on at this interface. Gernot Friedrichs is a physical chemist by training. His studies involve the development and use of optical laser spectrometers. This has involved the development of ultrasensitive trace gas sensors which can be used on board research ships, despite being advanced pieces of lab equipment not normally found at sea. A team of Kiel researchers has demonstrated the reliability of these instruments on cruises with the research vessel Polarstern across the Atlantic ocean [2]. Their success means that more and more research groups worldwide now count on equipment based on cavity-enhanced spectroscopy, the principle that underlies this innovation.

But Friederichs also researches other aspects of the ocean environment. One involves the use of a technique called non-linear surface-sensitive sum-frequency generation (SFG) spectroscopy to analyse water samples. It has allowed Kristian Lass and Gernot Friedrichs to establish a completely new view of the water-air interface [3]. Friedrichs says: "We now have the technology to detect organic matter in the nanolayer, the top few molecular layers of the ocean surface." This nanolayer forms part of the ocean's surface organic microlayer, which influences the roughness of the water surface by inhibiting the formation of capillary waves.

At present it is generally believed that high concentrations of organic matter in surface water, which often result from natural algal blooms, are directly correlated with the abundance of the organic microlayer. But the SFG measurements have shown that there can be algae in the water but no organic material in the nanolayer, putting the current paradigm in question. This finding implies that microbial processing

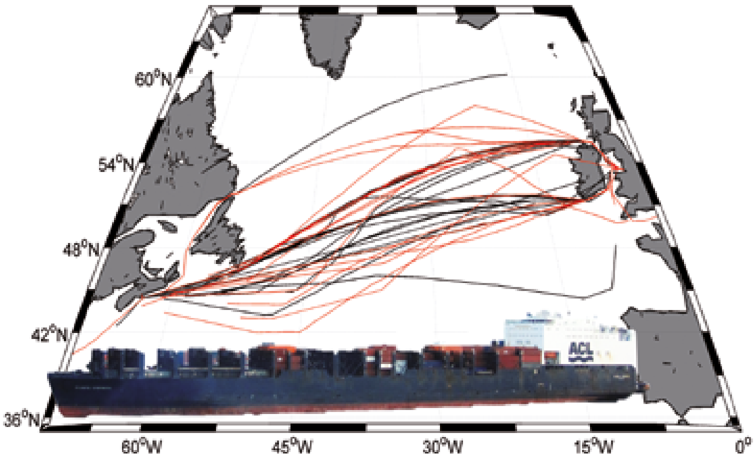
How do the oceans, the atmosphere and the solid Earth interact? How do the interfaces between them affect rising temperatures, and are there important feedbacks between them? How can we understand the chemistry, biology and physics that keep the Earth well-balanced and habitable? Do humans influence that system?

of organic precursor compounds may have an important role in shaping the microlayer [4]. They also suggest that satellite measurements of the colour of the ocean, the standard way of detecting chlorophyll and with it algal blooms remotely, may not tell us the whole story about what happens at the ocean surface and its role in modulating the exchange of trace gasses. Friedrichs says: "This work, including the fieldwork and the interpretation of the results, is completely interdisciplinary. It strongly links chemistry, my own subject, with biology, including microbiology, and involves working with optical engineers and other technologists to develop the equipment we need."

For instance, a group involving Anja Engel from GEOMAR recently studied how environmental change induces bacterial degradation in the Arctic Ocean. The results suggest that an assessment of the potential for climate change to alter biogenic carbon and energy fluxes in marine systems will need to consider many complex interactive effects [5]. Motivated by this and other studies, internationally leading scientists gathered at a workshop at Kiel University in July 2015 to discuss unexplored aspects of microlayer research. The resulting perspectives paper "The Ocean's Vital Skin: Toward an Integrated Understanding of the Sea Surface Microlayer" paves the way for future international research [6]. It will involve the detailed simulation of transport processes using computational molecular dynamics techniques, as well as the development of remote sensors for the measurement of surfactant distributions on a global scale, to identify, quantify, and predict global biogeochemical feedbacks.

Marine litter, in particular plastic litter, has become a serious problem on many of the world's coasts. See page 36

OBSERVATION STATIONS ON COMMERCIAL VESSELS



Cruise tracks of M/V *Atlantic Companion*. While underway it measures carbon dioxide (black and red) and carbon isotopes (red).

Science is in urgent need of routine, sustained global information on the marine environment which can meet society's need to describe, understand and forecast variability and long-term change. Arne Körtzinger, one of the leading scientists in this field, stresses that: "This information is only accessible through a dedicated 'observing system of systems', in which the components are synergistically linked." He adds: "The Marine ICOS observation network is such an observation system, one that provides more the 90 per cent of all surface ocean CO_2 measurements." These data represent the backbone of the "Surface Ocean CO_2 Atlas"[14] which, among other important uses, routinely informs the high-profile Global Carbon Budget.

The North Atlantic is an area with high biological productivity and distinct seasonality. But for several biogeochemical parameters such as the stable carbon isotope ratio, this seasonal cycle is still underdetermined. An experiment designed to fill this gap has been inspired by the success of an interdisciplinary collaboration between the Körtzinger and Friedrichs groups[2]. It involved installing a commercial CRDS (Cavity Ringdown Spectroscopy) analyser on a Voluntary Observing Ship that sails the North Atlantic between Europe and North America. In total more than two years of isotope ratio data were collected from the *Atlantic Companion* during the course of this project. This dataset provides a good look at the seasonal variations of the carbon-13 budget of the North Atlantic Ocean. This allows researchers to make new estimates of the carbon flux between ocean and atmosphere by taking into account biological matter and the mixing of underlying water masses.

A German research vessel at work in the Mediterranean Sea off Sicily. In the background, Mount Etna emits large amounts of carbon dioxide and other chemicals into the atmosphere.

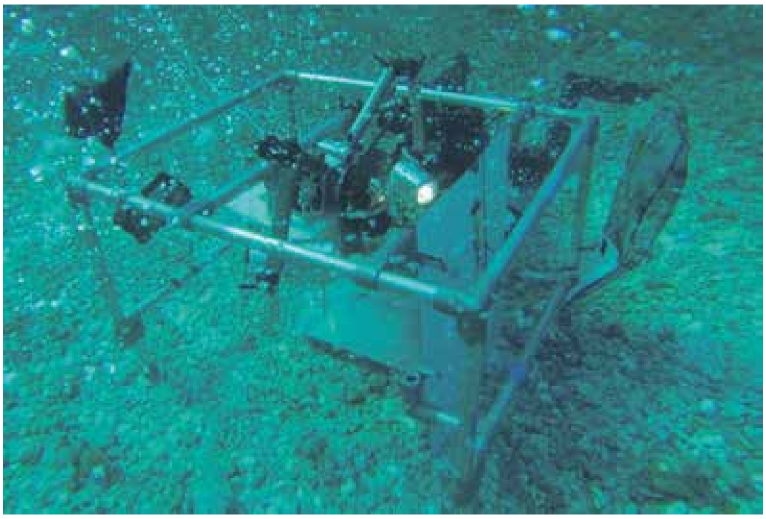
The surface of the ocean is a place where heat, matter and living organisms move across boundaries between air and water. We are now finding out what these transfers mean for us and for the planetary environment.

THE OCEAN AS A SOURCE AND SINK OF ATMOSPHERIC TRACE GASES

Another natural system that needs to be understood is the role of nitrous oxide (N_2O). Nitrous oxide is a potent greenhouse gas as well as playing a key role in stratospheric ozone depletion. How much of this gas is produced in the ocean, and how does it propagate into the atmosphere? Damian Arévalo-Martínez and colleagues have measured its emissions off the coast of Peru, at one of the world's largest upwelling ecosystems [7]. In an innovative use of optical trace gas analysers, they continuously measured nitrous oxide, carbon monoxide and carbon dioxide concentrations using an off-axis integrated cavity output spectrometer in combination with a non-dispersive infrared detection system (NDIR). They showed that the coastal upwelling areas can emit massive amounts of nitrous oxide to the atmosphere, and that these emissions are considerably higher than previously known, in fact being the largest ever reported. One important outcome of this study is that the regional and global budgets of this climate-relevant gas might need to be revisited.

Many opportunities are open to Kiel scientists studying ocean chemistry. Christa Marandino notes: "Direct flux measurement techniques are powerful tools for investigating the physical forcing of gas exchange. With the eddy correlation technique, we can examine the role of the surface microlayer and bubbles on gas exchange directly. It allows us to measure the flux of trace gases alongside indicators of physical forcing, such as the slope of capillary waves, white caps, and wave fields." Arévalo -Martinez and Bange agree, saying: "This technique will improve our understanding of the global distribution and magnitude of trace gas fluxes across the sea surface".

But other developments will drive this field as well. New sensors and platforms will allow more precise and automated monitoring of the sea surface. For example, Friedrichs envisions the use of frequency-comb laser light sources for the simultaneous detection of many trace gases. The development of this technology led to the award of the Nobel Prize for Physics in 2005. So there are plenty of ways to add to the wish list for in-depth ocean understanding.

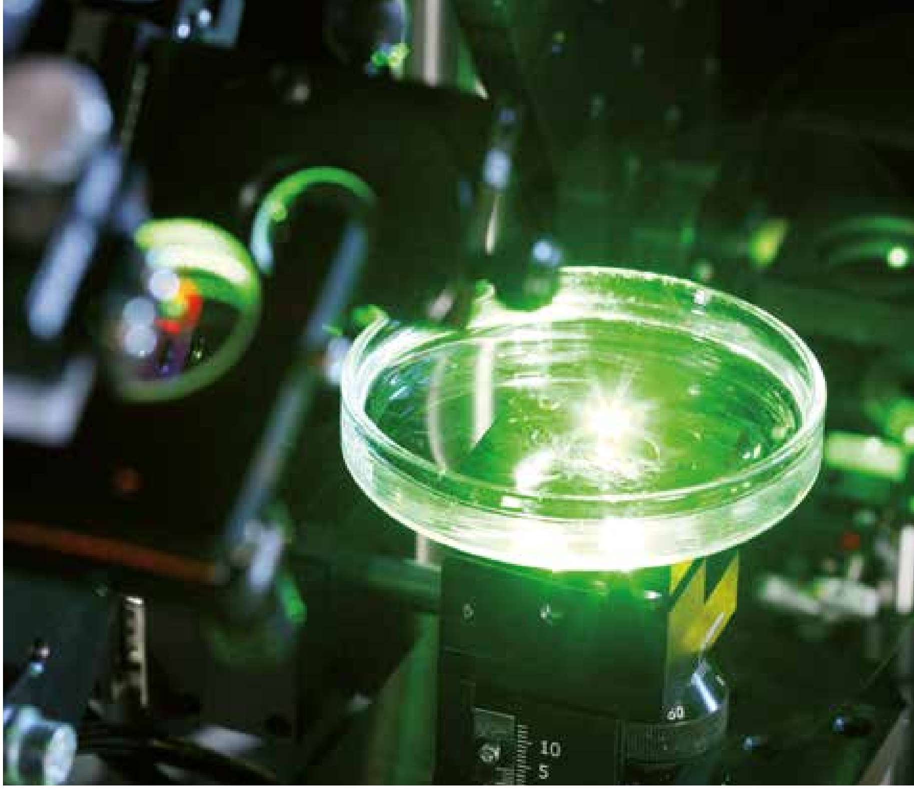


This "bubble box" is equipped with a high-resolution camera to measure the initial size range of bubbles from a natural seepage at the ocean floor, how fast individual gas bubbles shrink, and how quickly they rise towards the surface.

METHANE EMISSIONS

Part of Kiel's systematic research on understanding the ocean system involves work on the occurrence of methane seeps at the sea floor. These seeps have often been observed at active continental margins, for example off Costa Rica, Chile, and the Pacific coast of the US. But the mechanisms controlling these emissions are poorly understood. To their surprise, a group including Jacob Geersen, Peter Linke and Mark Schmidt observed a high methane flux off the coast of central Chile seven months after the strong 2010 earthquakes in that region [8]. This led to the development of a conceptual model explaining the mechanisms behind the high methane flux, which is amplified by the strong earthquakes which occur every 100-150 years in that area. They concluded that recurring strong earthquakes at a continental margin generate strain which in turn produces geological faulting. These earthquake-generated faults allow fluids such as methane to rise from deeper strata to the seafloor and emerge into the water column.

Kiel scientists are also investigating what happens to methane once it gets to the water column. Here, the size and activity of methanotrophic (methane-eating) communities determine the amount of methane that is consumed in the water column before entering the atmosphere. In the past, the supply of nutrients and the local water chemistry were thought to be the main influence on these communities. But we also need to understand how the physical properties of the



A green laser is directed onto a water sample during a cavity ringdown measurement to detect the composition of the surface nanolayer.

ocean influence these emissions. A group including Lea Steinle, Tina Treude, Arne Biastoch and others from Kiel has investigated methane emissions off Svalbard to address this issue [9].

They found that ocean currents can have a major impact on aerobic methane oxidation in the water column, and therefore on the amount of methane emitted to the atmosphere. Most methane seeps are located along continental margins, where bottom water currents are often strong and fluctuating. These currents can displace local waters, which harbour efficient methanotrophic communities, and make the water column more "leaky" for methane. The study suggests that this effect is a global determinant of the distribution and abundance of methane-degrading life, and therefore on the efficiency of methane oxidation above point sources.

Further investigations by Johanna Maltby and Tina Treude, involving organic-rich sediments from the Baltic Sea and in the Peruvian Upwelling system, revealed that microbial methane production is not limited to the deeper sulphate-free zone where it is usually expected. It was found too in sulphate-rich surface sediments, which means that it could directly add to methane emissions from the seafloor [10].

OCEAN-EARTH INTERACTION

As well as interacting with the atmosphere via its surface layers, the ocean interacts with the solid Earth through the sea floor. Understanding the influence of the deep Earth on the ocean is as important as understanding the ocean itself. Research in this area forms part of a broader Kiel programme on marine earthquake hazards. Recent Tsunami disasters in the Pacific emphasise the need to understand this risk.

Work by Jacob Geersen and colleagues has shown that the size of a strong earthquake, such as the 2014 Iquique quake off Chile, can be much reduced if there is a rocky obstacle which prevents the seismic rupture caused by the quake extending over a wide area. They found that the presence nearby of extinct volcanoes called Seamounts limited the surface scale of the Iquique earthquake and the damage that resulted [11].

Kiel scientists are now active in southern Italy, one of the most complex areas of Europe for natural hazards. Felix Gross and colleagues have conducted detailed seismic mapping on the Eastern slope of Etna, Europe's biggest volcano. The data indicates that continental spreading, which is occurring offshore in this region, needs to be taken into account to improve stability models for the area [12].

The Kiel researchers working in Sicily include social scientists as well as geologists and seismologists. They are using an approach termed Multi-Hazard Analysis to look at the threats to this well-populated region in a connected way, and are assessing the linked hazards from faulting on land adjacent to unstable submarine slopes. Their analysis is becoming more complete as new data becomes available. This means that people in the coastal regions of the Mediterranean, including Southern Italy, can hope for more accurate and timely hazard warnings. This will let them take more appropriate short and long-term measures to protect themselves and their livelihoods.

HOW DOES PLASTIC DEGRADE IN THE OCEAN?

Understanding these natural phenomena is only one side of the coin. Human activity is the other side of research into the marine system. The clearest example is an unwelcome human addition to the sea: litter.

Plastic litter is a big problem for the whole ocean. How long does plastic last in these environments, and is biodegradable plastic a solution? Alice Nauendorf, Stefan Krause, Tina Treude and others have addressed this problem in an experiment with sediments from Kiel's Boknis Eck field station in the Baltic [13]. They found that biodegradable plastic bags were much more strongly colonised by microbial communities from the sediment than polyethylene bags. But more importantly, neither type of bag showed any sign of biodegradation during their 100-day study.

Tina Treude concludes that: "Plastic waste is likely to accumulate in marine sediment, which might ultimately act as a long-term plastic sink." Though other studies have found partial disintegration of biodegradable plastic products in the marine system, there are no reports yet of complete biological recycling. Nauendorf, Krause and Treude stress the need for new plastics that are fully degradable by natural marine microbial communities over short timescales. They are urgently needed to avoid more plastic waste accumulating in the ocean. Nele Matz-Lück, an international law expert within the Cluster, says that the Cluster's ability to address the problem of plastics pollution shows the benefits of an interdisciplinary link between the physical and life sciences and the humanities such as law. "If we have solution-oriented projects that we can talk about to politicians, it becomes easier to argue for stricter laws to prohibit certain practices, and it gets easier to implement technology to clear up the problem."

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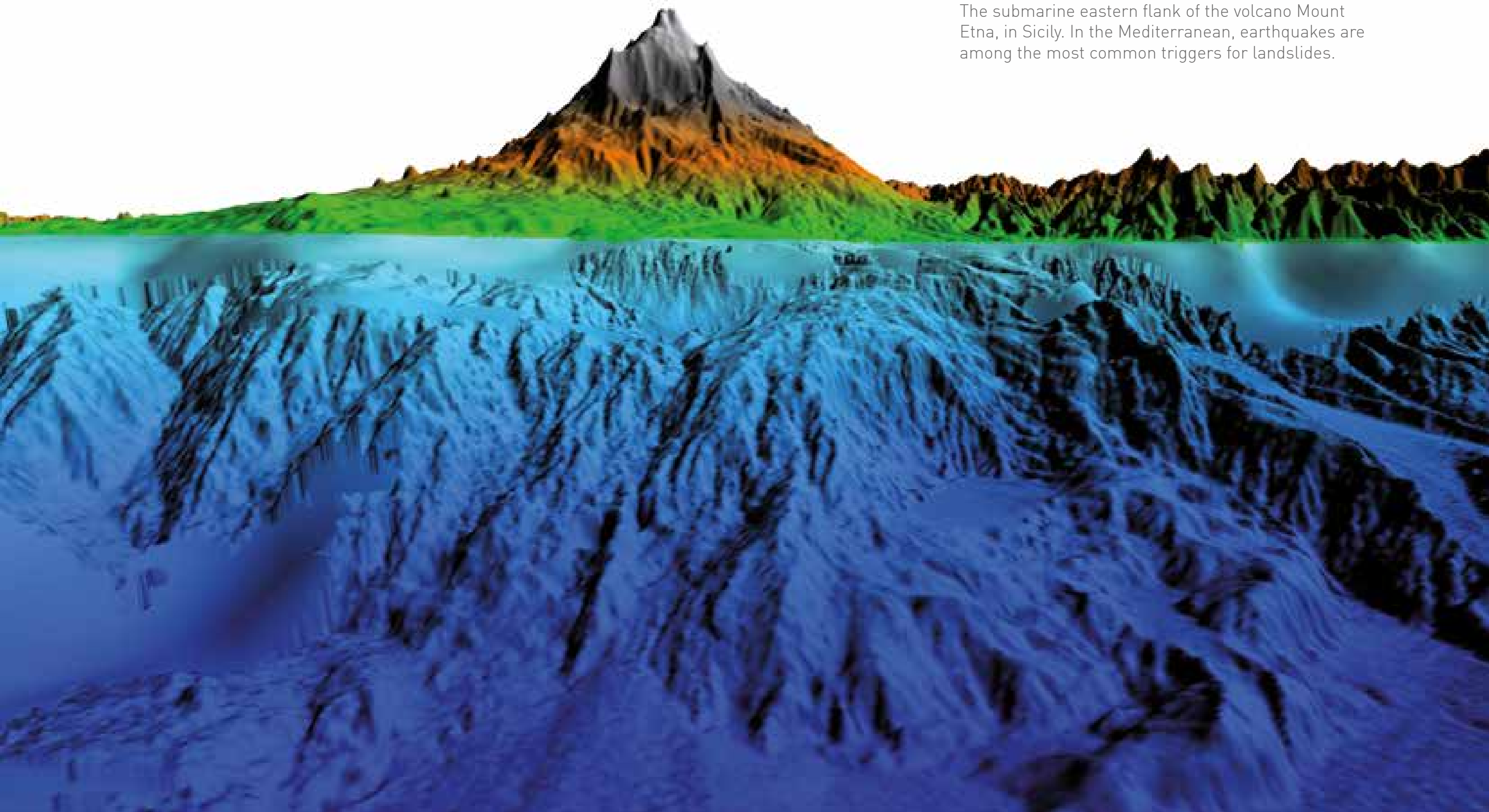


The submarine eastern flank of the volcano Mount Etna, in Sicily. In the Mediterranean, earthquakes are among the most common triggers for landslides.

What can models tell us about the future ocean?

In the era of climate change, the ability to model and predict the future ocean is essential for policy making and to inform business decisions. Kiel's marine scientists, including mathematicians, computer modellers and oceanographers, play a key role in this vital interdisciplinary project. The Kiel Climate Model is their unique tool for calculating interactions between the ocean, the atmosphere, sea ice, and ocean biology and chemistry.

While its work is global, Kiel marine research has traditionally been strong in improving climate models for the North Atlantic area, and has created improved simulations of the ocean current regime in this important ocean region. In 2016, a group of three Kiel researchers led by Mojib Latif published the solution to a long-standing problem with models of the North Atlantic [1]. Sea-surface temperatures predicted by previous models were inaccurate, because they did not have good information on the salinity of the topmost layers of the ocean. These models had used values that were too low for key areas of the northern North Atlantic and the Arctic Ocean. So they have not incorporated as much mixing of surface and deep waters as happens in reality. This leads to misleading results, like predictions of too much sea ice.

The Kiel scientists ran a number of different versions of the Kiel model to see what happens when the sea-surface salinity is corrected by the use of improved climatological data. This approach led to a more realistic model of the ocean's convection, which in turn led to better models of the sea's surface temperature. These better models will permit improved predictions of short and long-term climate variation in Europe, both natural and anthropogenic.

Can computer models help us to understand the ocean? How precisely can we reconstruct ocean currents and vertical mixing? Will ocean currents change in the future? Is it possible to run ocean models backwards?

GREENLAND LOSES ICE

Kiel research is also directly relevant to one of the most-discussed aspects of human-induced climate change, the possible destruction of Greenland's immense glaciers and its effect on the Atlantic meridional overturning circulation or AMOC. Oceanographers are very concerned with the effects of melting ice on ocean currents.

Working with colleagues from the UK, Kiel researchers including Claus Böning and Arne Biastoch (both GEOMAR) have modelled the impact on the ocean circulation of the growing mass loss from the ice sheets of Greenland, which has been observed since the 1990s [2]. Nearby regions of the Atlantic have been affected by a growing flux of fresh water. As this cold, fresh water reaches the Atlantic, it could concentrate in the upper reaches of the ocean and weaken ocean convection in the Labrador Sea and the Atlantic. Some bleak forecasts suggest that this effect could slow the AMOC and therefore the Gulf Stream's journey from the Gulf of Mexico to the north-East Atlantic, and drastically reduce winter temperatures in continental Europe.

The Kiel modellers have assessed the impact of these increased flows of fresh water, using a global ocean circulation model with a grid spacing fine enough to capture the small-scale, eddying transport processes in the subpolar North Atlantic. This modelling suggests that so far, the invasion of meltwater from the ice sheets of West Greenland has had only a limited effect in the Labrador Sea. The effect so far is smaller than the region's natural variability. However, big episodes of natural freshwater melting are known from 1970, the mid-1980s and the early 1990s. It seems that each of these events involved about 1700 cubic kilometres of fresh water making its

The melting of glaciers in the Arctic and Antarctic plays a huge role in shaping global climate.
It has to be taken into account when modelling future climate conditions.

As computational power increases and data-gathering improves, model calculations become better and better. Current ocean and climate models already help us to understand the scale of the influences on the Earth's climate. The example of the Agulhas Current proves that we can now refine our models to an unprecedented level of detail.

way from the Arctic to the North Atlantic. This is a massive amount, about equal to a cube of water measuring 12km on each side. The Kiel group says: "Our model simulation suggests that the accumulation of meltwater in the Labrador Sea is reaching half that magnitude."

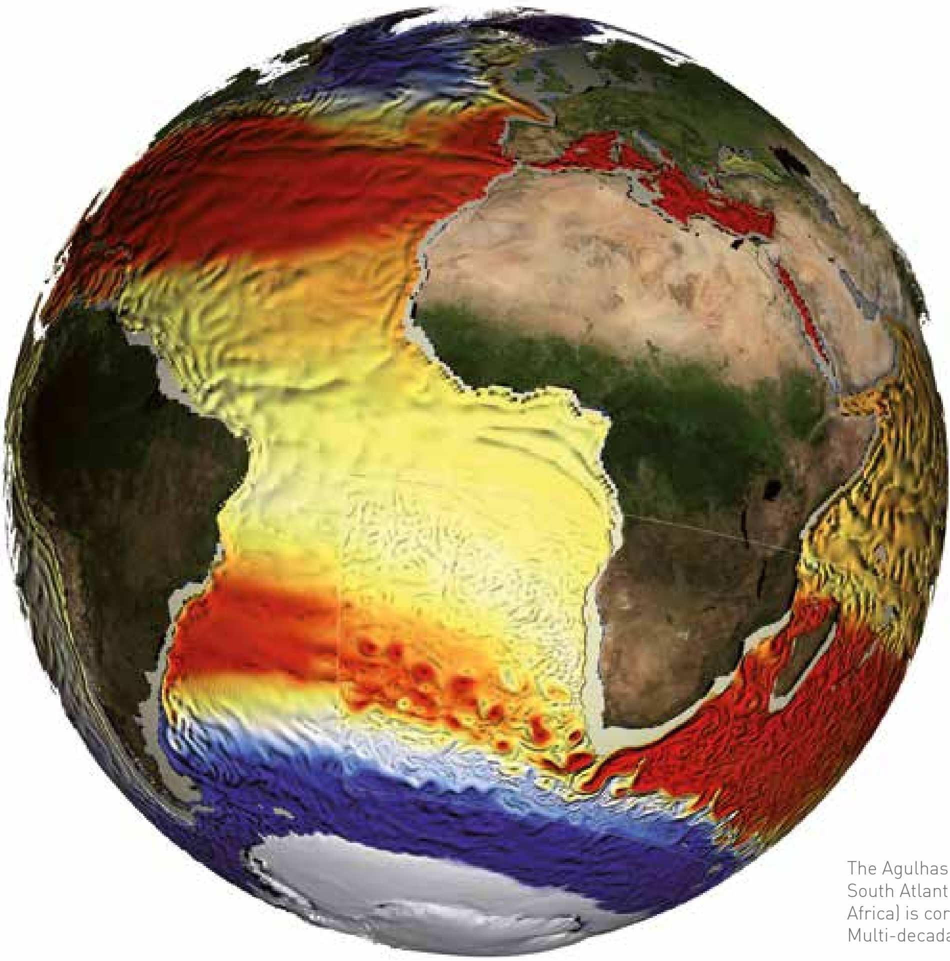
At the moment, they say, we are observing only minor repercussions of this increased runoff. Their models suggest the "first hint of a weak signal" in Atlantic currents and convection patterns. But they add that a much larger melting effect of 3,000 cubic kilometres per year would cause a rapid dilution of the surface waters, an end to deep convection of the ocean after six to eight years, and a rapid slowdown of the AMOC. They say: "Under a continuation of the actual observed trend, (an effect of this) magnitude would be reached around 2040." And they add that the normal variation in the behaviour of the Atlantic is so big that it could cancel and hide this trend until it was nearly upon us.

AGULHAS INFLUENCE

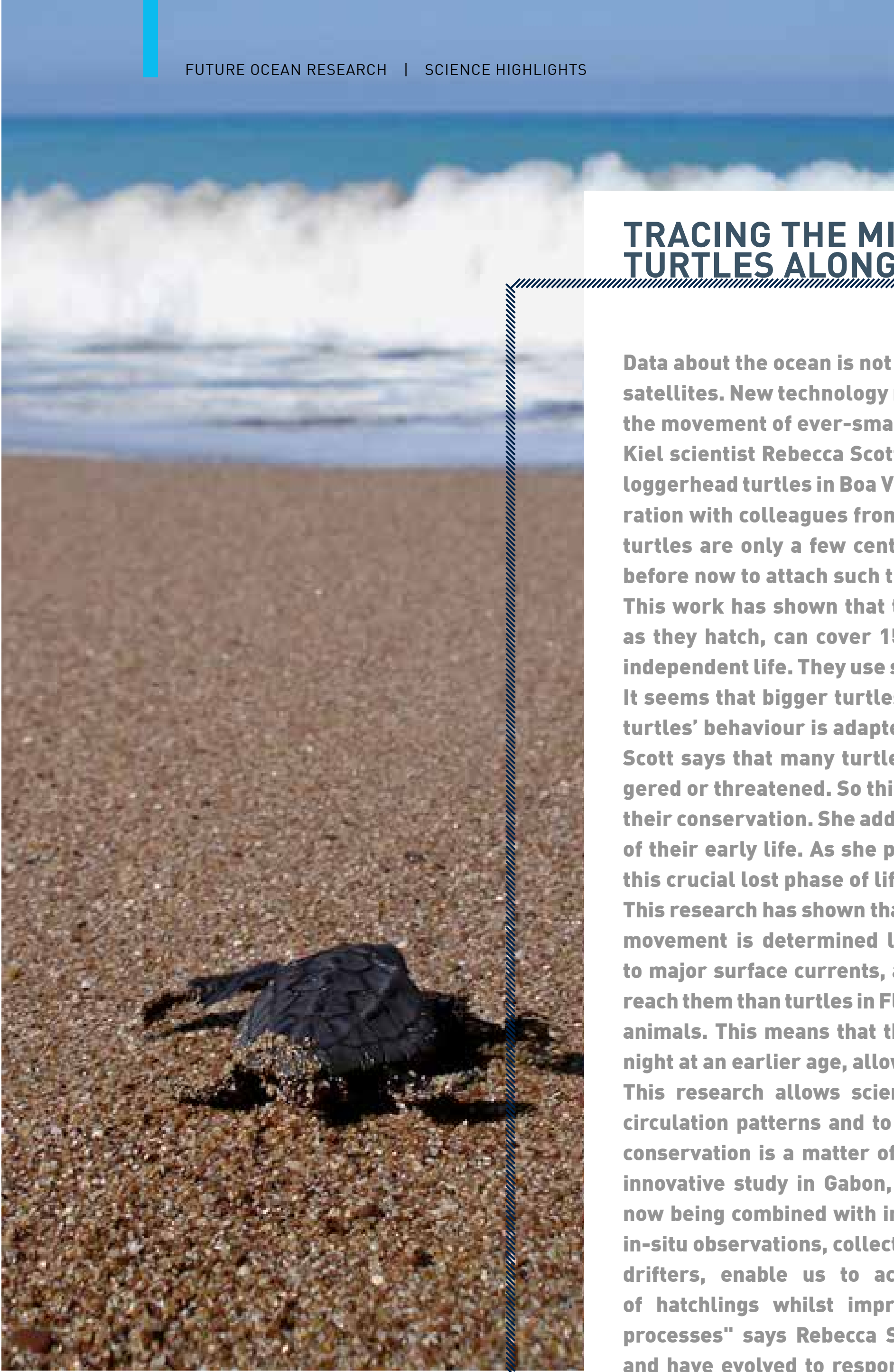
Kiel modellers are also unravelling the complex flows of water and heat at the other end of the Atlantic. Here warm, salty water is carried from the Indian Ocean to the Atlantic by the so-called Agulhas leakage, an extension of the Agulhas Current in the Indian Ocean around the southern tip of Africa. The water that Agulhas leakage brings to the Atlantic could not be more different from the cold, pure meltwater of Greenland. But it too could be an indicator of human-made climate change. Kiel modellers have worked on its possible future evolution, in a large international collaboration effort [5].

They find that the previously disregarded Agulhas leakage is "a crucial component of the climate system" and that "ongoing increases in leakage under anthropogenic warming could strengthen the Atlantic Overturning Circulation." While Kiel research on ice loss in Greenland suggests that this vital feature of global ocean circulation is threatened by the arrival of large volumes of cold water in the Arctic, it also indicates that injecting warm, salty water to the South would add to its strength.

This research is not all about the ocean. The Agulhas leakage is also influenced by prevailing winds. Current models suggest that the westerly winds observed in the region will move south under conditions of global warming. If so, they change Agulhas leakage and the amount of warm and salty Indian Ocean water entering the Atlantic from the south. The researchers say that it is already possible to observe a trend towards increasing Agulhas leakage consistent with the observed increasing intensity of the westerly winds over the past three decades. It is "projected to continue over the 21st century" as a result of anthropogenic climate change [6].



The Agulhas Current's leakage into the South Atlantic Ocean (shown just off South Africa) is correlated with the Atlantic Multi-decadal Oscillation.



TRACING THE MIGRATION PATHS OF JUVENILE TURTLES ALONG OCEAN CURRENTS

Data about the ocean is not gathered only from buoys, aircraft, ships and satellites. New technology means that we can learn about the ocean from the movement of ever-smaller animals.

Kiel scientist Rebecca Scott has been attaching "nanotags" to new-born loggerhead turtles in Boa Vista, one of the Cape Verde islands, in collaboration with colleagues from Cape Verde and London. The newly-hatched turtles are only a few centimetres in size, and it has not been feasible before now to attach such tracking devices to them.

This work has shown that the turtles, which hurry into the sea as soon as they hatch, can cover 15km of ocean during their first few hours of independent life. They use sea currents to travel at up to 60m per minute. It seems that bigger turtles swim more than smaller ones, and that the turtles' behaviour is adapted to local ocean conditions.

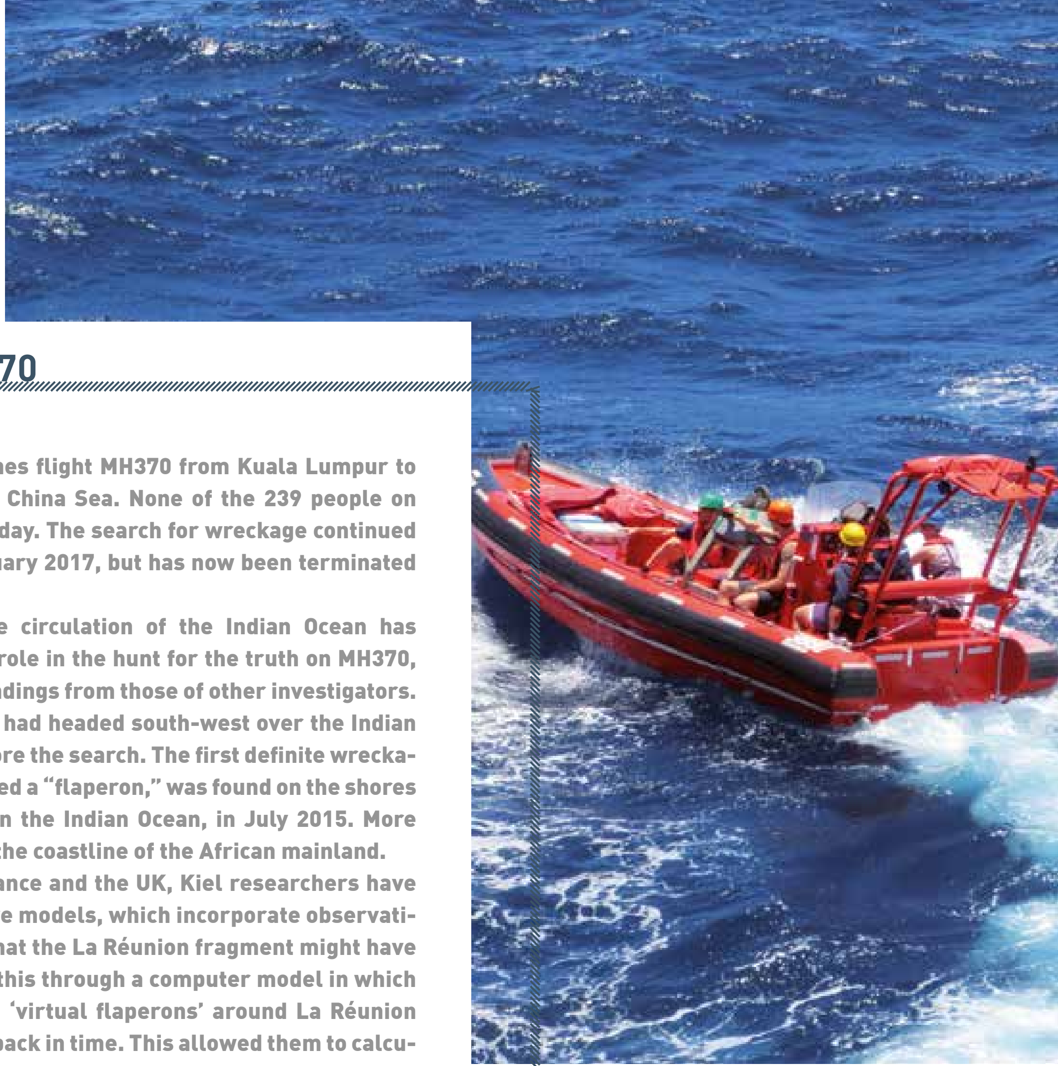
Scott says that many turtle species such as the loggerhead are endangered or threatened. So this research helps design the right strategy for their conservation. She adds that up to now, we have had little awareness of their early life. As she puts it: "Technology is now emerging to allow this crucial lost phase of life to be studied."

This research has shown that once they are at sea, the loggerhead turtles' movement is determined largely by ocean currents. Boa Vista is close to major surface currents, and the turtles there have less far to swim to reach them than turtles in Florida, also a major population centre for these animals. This means that the Cape Verde turtles can become inactive at night at an earlier age, allowing them to be less obvious to predators [3].

This research allows scientists to improve their knowledge of ocean circulation patterns and to learn about the behaviour of animals whose conservation is a matter of environmental concern. In a new and highly innovative study in Gabon, behavioural studies of hatchling turtles are now being combined with in-situ observations of ocean currents. "These in-situ observations, collected using novel turtle inspired surface oceanic drifters, enable us to accurately assess the swimming behaviours of hatchlings whilst improving our understanding of upper surface processes" says Rebecca Scott. "Hatchling turtles actually experience, and have evolved to respond, to very fine scale ocean variability, which models are too coarse to resolve." In-situ studies of this nature on young turtles can provide valuable new high-resolution ocean current data to test the robustness of ocean models.

A young loggerhead turtle rushes into the sea after hatching on the coast of Gabon.

Right:
Loggerhead turtle hatchlings are marked with trackable nano-tags.



THE HUNT FOR MH370

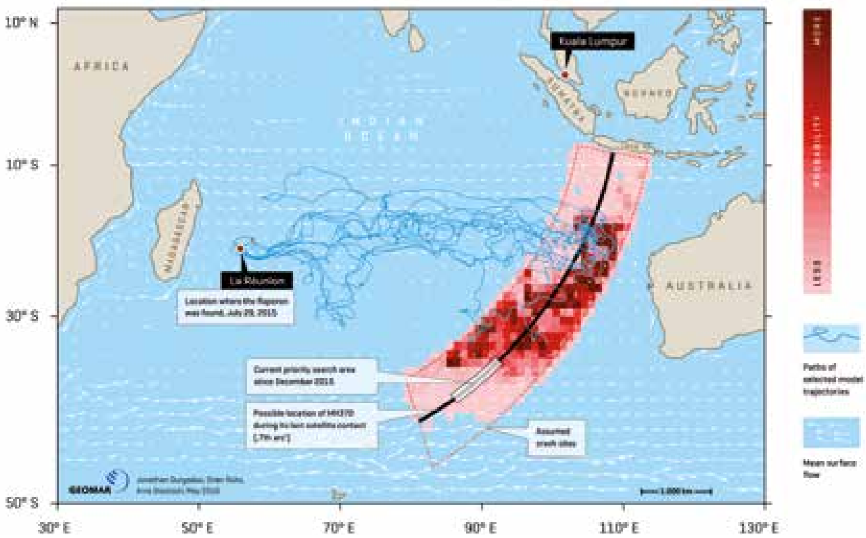
On 8 March 2014, Malaysia Airlines flight MH370 from Kuala Lumpur to Beijing vanished over the South China Sea. None of the 239 people on board have been seen since that day. The search for wreckage continued for almost three years until January 2017, but has now been terminated without a definite result.

However, our knowledge of the circulation of the Indian Ocean has allowed Kiel scientists to play a role in the hunt for the truth on MH370, and to draw radically different findings from those of other investigators. It seemed likely that the aircraft had headed south-west over the Indian ocean before it crashed even before the search. The first definite wreckage from MH370, a component called a "flaperon," was found on the shores of La Réunion, a French island in the Indian Ocean, in July 2015. More pieces have since been found on the coastline of the African mainland.

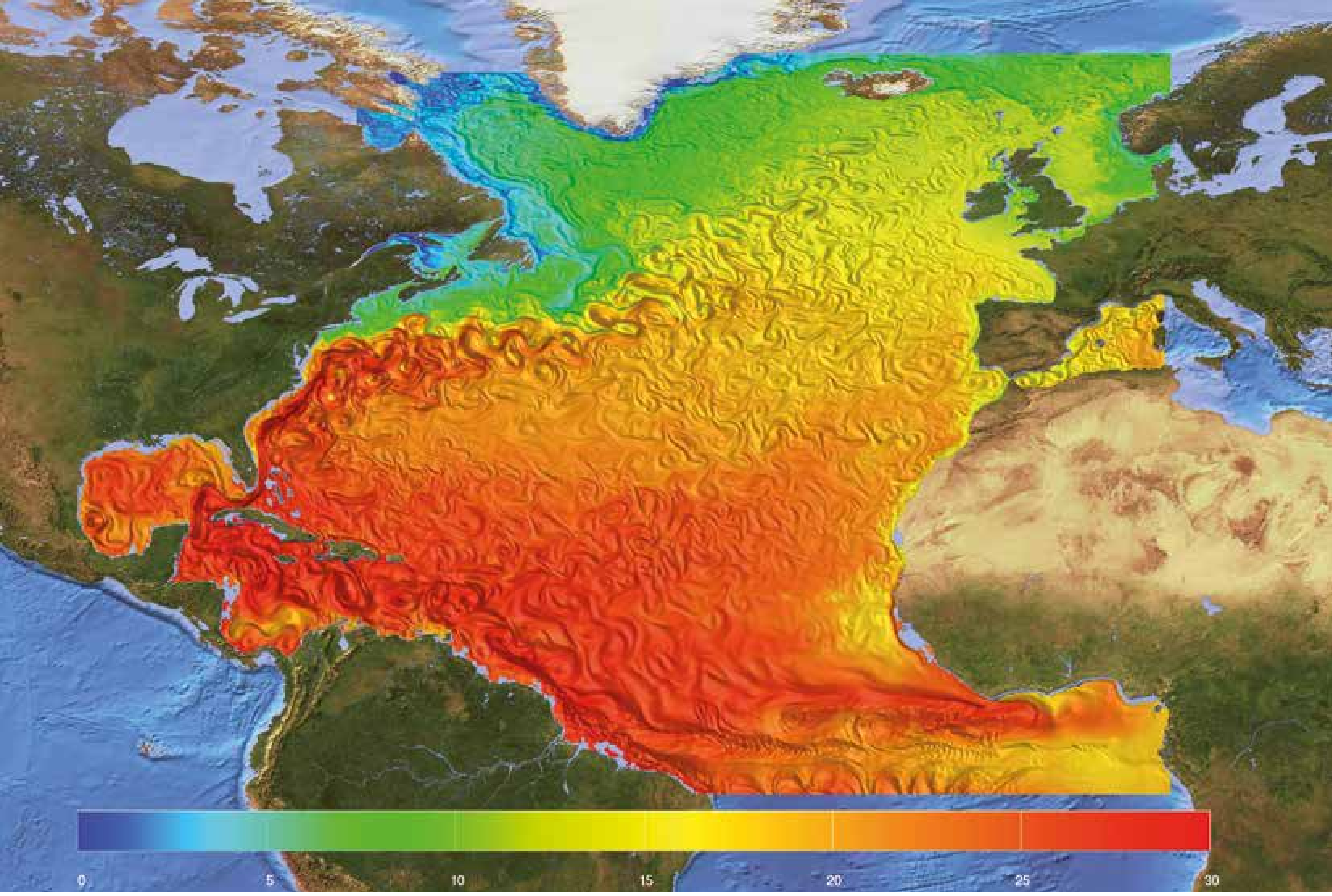
Working with scientists from France and the UK, Kiel researchers have used results from ocean and wave models, which incorporate observational data, to analyse the route that the La Réunion fragment might have taken whilst afloat [4]. They did this through a computer model in which they released about five million 'virtual flaperons' around La Réunion and computed their trajectories back in time. This allowed them to calculate the probable point of origin of the flaperon at the time when MH370 vanished even before the search. The calculations have also been refined by the addition of physical processes which simulate movement at sea more realistically, such as drift induced by wind-generated ocean waves. Jonathan Durgadoo of Kiel says that this study shows that the flaperon probably entered the ocean "in a region north of the main search area for 2016."

His colleague Arne Biastoch (GEOMAR) adds that this finding has been strengthened by the discovery of further debris at other locations in the southwestern Indian Ocean. "The ocean currents through the Mozambique Channel and along the South African coast are extensions of the route that passes by Réunion," he says. The Australian authorities leading the search for MH370 were made aware of the group's findings before the decision to terminate the search was made.

Right:
Sea surface temperatures and ocean currents in a high-resolution model of the North Atlantic Ocean.



Map showing the most probable area of origin for debris from the missing Malaysia airlines flight MH370. These probabilities were derived by backward modelling the possible paths of parts of the aircraft which were found on Réunion in 2015 [3].



MULTIDISCIPLINARY ENDEAVOUR

Kiel's unique strength in climate research is its ability to work in a multidisciplinary way in which findings from a wide range of intellectual approaches support each other. For example, detailed weather records date back only a few centuries. Geological approaches, for example making use of carbon isotope measurements of fossil shells, have the potential to extend this record. These different ways of measuring past temperatures provide valuable inputs to climate models and to our understanding of possible future climates. A good example is Kiel research on ENSO, the El Niño Southern Oscillation. This well-known climate variation in the Pacific is of global importance. Its behaviour over the past 150 years is being mapped at Kiel by measuring the atomic composition of mollusc shells. This work has explained the variability of ENSO over time, including its seasonal and longer-term variation [7].

The more we learn about the ocean system, the better our educated guess on the future will be. Our improved understanding of natural phenomena, and refined environmental data, allow better calculations of the effects of climate change. The ocean's current system will most likely change in the future. The latest computing technology is required if we are to model change in a way that is valuable to human society.

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How can we assess the risks of sea level rise?

Research in Kiel looks at human impacts on the coast, and at possible measures to protect its populations and assets. Integrated models point to vulnerable spots, and suggest solutions for adaptation to a changing environment.

The coast is where human activity meets the ocean. Events there show us whether this encounter is sustainable and healthy. It typically falls into one of four categories: the exploitation of coastal resources, the installation of commercial infrastructure, the maintenance of coastal settlements, and recreation. These four have overlapping effects.

An example of the relationship between people and the ocean breaking down is the Baltic "stone fishery," a now defunct industry which gathered big boulders from the seafloor for construction and other uses. Removing them speeded up the erosion of the seafloor, and deprived species such as mussels of the firm surface they need to grow on.

Partly because of the stone fishery, the Baltic coast is now eroding and the seafloor is being abraded away to reveal new stones. Kiel researchers including Klaus Schwarzer, a coastal geologist, are mapping them as they appear and in the process, finding out about the effect of storms on the seabed below [1].

The scope for these offshore surveys to produce new knowledge has been expanded by the growing capability of detector technology. In the past, sonar has been used mainly to determine water depth and to map seafloor topography. Now its return signals, called backscatter, can be analysed to tell the difference between rock, algae, shells or seagrass at the ocean floor. This innovation removes the need for expensive and damaging grab-sampling of the seafloor. Kiel researchers including Karl Stattegger are also looking at coastal erosion, now a topical concern because of sea-level rise. Work carried out in Europe and Brazil suggests that "beach nourishment" with fresh sand works better to slow erosion than attempts to stop the sea with massive concrete structures.

Coastlines around the world are the place where people and ocean meet. They provide sought-after places to live or to do business, and are home to vital infrastructure. Researchers at Kiel are looking at the future of the coast in an era of climate change, sea-level rise and population growth.

On Sylt island in the North Sea, 1.7 million cubic metres of sand are used for beach nourishment each year. Kiel research points to improved ways

of managing this investment. They have found that it might work better to put a large amount of sand on the beach every 20 years instead of small amounts annually. This would allow local benthic life, organisms living in or close to the seabed to reinvigorate itself over a longer period, instead of being swamped by new sand every 12 months.
At the same time, even this apparently green form of sea defence can have undesirable environmental effects. The sand is usually obtained offshore. There is now evidence that the pits left in the seafloor where this extraction occurs can be long-lived.
This finding suggests the need for a policy rethink on coastal erosion. There is a long history in Germany of protecting or reclaiming coastal land. But as sea level rises and removes coastal material, those rocks and sediments have to go somewhere. A cliff that vanishes into the sea can turn into a new area of low-lying or swampy land. This effect can be seen at work in the Baltic islands, some of which have grown in size as their cliffs have been lost. Schwarzer says: "This proves the need to look at these sites case by case. The Baltic is very different from the North Sea. It has its own tidal regime and geology."
Researchers from Kiel are also looking at the condition of Europe's seas to help implement EU guidelines for "Healthy and Productive Seas and Ocean." This involves charting the habitats and environments of the North Sea and the Baltic at less than 1km resolution, the current standard for mapping the sea in these regions.

The history of sea-level and environmental changes is recorded in sediment cores.

What problems arise where people and ocean meet? How do the coasts develop and react to human impact? Can we learn from past sea level rise? What risks does the ocean pose to communities in coastal areas?

SEA-LEVEL CHANGE AND HUMAN INTERVENTION IN VIETNAM

Kiel scientists are valued around the world for their advice on coastal zone issues. A special focus is Vietnam. They are working in the Mekong Delta, a large land area which is mostly less than 2m above sea level. While this low elevation already poses problems, things may well get worse, and not only because of sea-level rise [4].
Here and in other Asian megacities, Kiel researchers find that groundwater extraction increases the rate at which the land subsides, adding to the problem of rising sea levels. Areas of the delta are subsiding at different rates as the sediment below them compacts. At the same time, the massive dams that have been built on Asia's major rivers catch sediment that would previously have found its way to the delta and helped reinforce it, and this encourages further subsidence. Klaus Schwarzer, a marine and coastal geologist at Kiel, says that 90 per cent of the sediment that once travelled down the Yellow River in China is now trapped in this way. As he sees it, "Sea-level rise is not a simple issue. It is to do with the response of the coast to human intervention." If the Mekong delta becomes uninhabitable, millions of people will be displaced and valuable farmland will be lost. Because flooding by seawater pollutes the land with salt, the delta is already becoming less productive for agriculture.

Some areas of the Chao Phraya Delta (Vietnam) are flooded every 14 days during spring tide.

Coastal Erosion in Ponta Negra (NE-Brazil) during a typical high-tide event in 2013.

The information generated from this research will have economic as well as environmental uses. It will be needed to plan offshore wind farms and other renewable energy installations, to regulate fishing, and to conserve natural resources. Because of its high practical value, this work is being carried out in collaboration with federal environment agencies and the Alfred Wegener Institute, a German centre for polar and ocean research. The programme has started with a look at the seabed and the sediments that underlie it, and will focus next on benthic organisms.

SEA LEVEL RISE AND COASTAL RISKS

But what do we know about the effects of sea level rise? One way to learn more is by examining the most recent major rise in sea level, which took place at the end of the last Ice Age. It happened from about 20,000 years ago onwards, but we know that it was not a smooth process. It involved several short time intervals of strongly accelerated sea-level rise caused by so-called meltwater pulses, which indicate increased melting of the polar ice caps of Greenland and the Antarctic. A well-documented meltwater pulse occurred between 14,800 and 14,200 years before the present. But a similar event between 9000 and 8200 years ago remains controversial. Knowledge of these meltwater pulses is important for predicting future sea level rise as a consequence of global warming.

Karl Stattegger's research shows that this last meltwater pulse, which involved a sea level rise of more than 20 metres, is well documented along the coast of Vietnam in Southeast Asia. He says there was "extremely fast flooding of the South Vietnam shelf region between 9000 and 8200 years ago, which caused a shoreline migration of up to 300km," He adds: "Better understanding of these regional sea-level records can help to improve our models of glacio-isostatic adjustment, the process by which the land adapts as the ice is removed. This improves our predictions of the flood risk to coastal regions." The same researchers are now examining the western Baltic Sea region for clearer traces of these rapid meltwater events.

ENDANGERED ASSETS

Stattegger's colleague Athanasios Vafeidis says that sea-level rise will lead to more frequent flooding and erosion, strongly affecting people and economic activity. He has been involved in developing predictions of sea level rise impacts to 2100 for the European Environment Agency, and in sea-level research for the World Bank and the United Nations. His work shows that the impact of losing lowland areas or wetlands will depend on how many people live nearby and on the industrial or commercial assets they contain [2].

The big message, says Vafeidis, is that "people do not sit there and wait to be flooded." Instead they take action, and the form of action they take will vary from place to place [3]. This means that every adaptation to sea-level rise has to be considered in its own right. Dykes to keep the sea out are often economically viable, but would be harmful if they prevent access to a popular tourist beach. While parts of the coastline consist of towns and other valuable assets that are worth protecting at almost any price, other options need to be considered for other areas. There need to be viable policies on what to protect and how.

Kiel researchers provide policy-makers with flexible options for situations like this. In Africa, a piece of coastal land which has low economic value by the standards of the developed world may also have a population for which it is not ethically or politically desirable to shift. So a dyke to keep the water out

could produce a social saving that a strict economic analysis would miss.

Kiel researchers support policy thinking by means of a global sea-level model that can be interpreted at a local level for specific cases. The model Vafeidis runs uses assessment data from the Intergovernmental Panel on Climate Change, the world authority on global warming trends. This data is combined with information on future populations and economic activity, and on physical processes such as tides and storms, to generate policy insight. It might for example point to the benefits of expanded wetland regions, which can soak up water in a more flexible way than big fixed structures [5]. It may also highlight problems for coastal assets such as oil refineries or nuclear power stations, showing the need to go beyond the safety margins built into current engineering practice. If a big storm that used to be expected once a century happens every ten years instead, how will these massive investments stay safe and effective?

This field is advancing fast, with new models and data under continuous development. But it will never be possible for models to produce complete certainty. Economic development cannot be predicted, and nor can human behaviour. While people often want to live in the coastal zone, future approaches to governance could make living there less attractive and reduce the demand for space there. This sort of risk is best explored by scenario planning, not by forecasting and prediction.

The Kiel scientists expect tools developed in the Future Ocean initiative to help communities shape the sustainable coast they need over a timescale of 50 or more years. They are now carrying out a review of Mediterranean coastal regions which will allow them to refine their understanding and learn from colleagues there. As Vafeidis says, this work is being done "in the spirit of mutual learning, and not by telling other countries how to run their own coastlines."

IMPROVING RISK AWARENESS

Kiel researchers believe that new technology may allow the driving forces behind marine natural disasters to be quantified for the first time. Improved imaging techniques now generate an extremely detailed view of structures on and beneath the seafloor, often by the use of remotely operated or autonomous subsea vehicles, or by the new technique of 3D P-cable seismology.

Kiel research shows that integrated assessments are needed to evaluate the consequences of rising sea levels. And it points to possible solutions which take account of human and economic reality.

This new technology means that the science of geodesy, the exact measurement of the Earth, can be extended from the land to the ocean for the first time, and allows geodetic measurements from onshore and offshore to be combined. Submarine geodesy is a completely new field. Among other uses, its development will make it possible to map earthquake-related tension at the bottom of the sea. Undersea drones are another new technology. They will allow researchers to examine volcanic hazards much more precisely than before. Added together, these advances will allow natural science to improve the risk assessment studies conducted in Kiel for public benefit worldwide.

In the past, research on natural hazards has usually focused on individual risks, such as earthquakes, submarine avalanches or volcanic eruptions. Methodological innovations such as novel time-series analysis, and technological developments like seafloor geodesy, make it possible to take an integrated approach to investigating multiple oceanic hazards in a specific region or place. The working groups in Kiel have a unique ability to use these new techniques for shoreline-crossing research on oceanic hazards, and on the underlying processes which threaten coastal communities.

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The Kiel Vibrocorer, a novel device for sampling the ocean floor, on research vessel *Alkor* during an equipment test.

Will climate change alter the future biosphere?

Martin Wahl is deeply concerned about the rapid physical, chemical and biological changes now taking place in the ocean. He sees little chance of preserving its present condition, or of reconstituting some former and purer state of nature there. Instead, the challenge as Wahl sees it is to mitigate the impact of global pressures like warming by reducing more local stresses, including fishing and excess nutrient input. His role as a conservation ecologist is to investigate ways of maintaining ocean function and diversity.

How does life in the ocean cope with changing environmental conditions? Might sea life run out of oxygen? Can corals learn to live in hot water?

As a promising start to this challenging endeavour, the Kiel Excellence Cluster has catalysed research across disciplines over the past decade. Only collaborative research involving the natural sciences, the social and economic sciences, maritime law, political science and environmental ethics will produce the fundamental understanding which is needed to produce viable solutions in this complex arena.

The Cluster's previous research on ocean acidification and warming is a case in point. As humans burn fossil fuels, the Earth gets warmer. But at the same time, some of the carbon dioxide produced by burning them is dissolved in seawater, making it less alkaline and more acidic.

If seawater becomes more acidic, mussels should find it more difficult to grow their shells. But things are not quite that simple. Biological activity in a natural community causes acidity to vary throughout the day, and mussels are expert at calcifying their shells at the best time. This typically happens during the hours of daylight, when acidity is at its lowest. Wahl adds that scientists often fail to recognise natural fluctuations on different scales, including the seasons. "If the seas are a little warmer, some species may benefit during the winter months, making them more able to resist heat stress in summer. Most fieldwork tends to happen in summer, so this aspect of global change gets missed." To overcome this bias, Wahl, Ulf Riebesell and colleagues conduct large-scale, year-round mesocosm experiments in different areas of the world (see boxes) [1].

The researchers are also investigating hypoxia, reduced levels of dissolved oxygen in ocean water. This is a natural phenomenon in enclosed bays or

Predictions say that environmental conditions will change in the coming centuries. Who are the winners and losers from that change? Experiments on evolution under natural conditions, conducted in Kiel, can shed light on how species react to different kinds of environmental stress, like the rise of temperature or ocean acidification, and how ecosystems might change.

Three of the ten Kiel KOSMOS mesocosms – developed at GEOMAR – at Gullmar Fjord, Sweden.

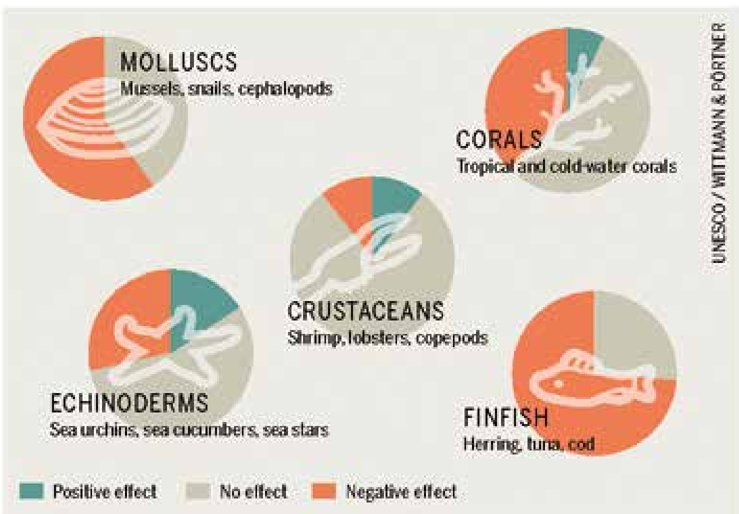
seas, but is less familiar in the open ocean. Ocean warming combined with nutrient enrichment favours the development of large masses of algae. When the light, nutrients and other resources they need to grow start to decline, these masses of algae die off, and their microbial degradation may lead to hypoxic conditions which create dead zones in deeper waters. If this lifeless water wells up in shallow areas, there can be economic as well as ecological harm. These waters are used intensely for fishing, leisure and other purposes.

On a more cheerful note, recent findings suggest that bioinvasions by novel species, while undoubtedly a major ecological risk, may have a positive side. A substantial number of native species will disappear. But if their role can be taken over by more robust invaders, there may be times when the ecosystem benefits.

Kiel research, carried out in collaboration with valued colleagues around the world, is showing us more about bioinvasion pathways. In addition to known routes such as ballast water, aquaculture and hull-fouling, new findings suggest that that potential invaders may arrive as hitch-hikers in the guts of migratory fish and sea birds. Evaluating the risks and benefits of bioinvasions, and the importance of man-made versus natural vectors, calls for an innovative combination of fieldwork, modelling and the expertise of lawyers, economists and other social scientists. International cooperation in marine ecology with all the Baltic nations and with Israel, France, Portugal, Iran, Cape Verde and other maritime countries around the world renders our insights more robust.

This research may also help to ease our biggest worries about the future of the ocean. It suggests that many oceanic species have enough genetic diversity to cope with rapid climate change. Within a period of three months, diatoms in the mesocosm experiment (see box) can adapt the way they use their genes to cope with increased ocean acidity. This is known as “sorting” their genetic diversity to adapt to changed conditions.

This adaptability is the subject of several projects conducted within Future Ocean on marine life and its ability to adapt to high levels of stress. As well as temperature, it is looking at stresses such as increased salinity and acidity to see how rapidly species and whole ecosystems can adapt. It has already shown that species in the Baltic often have more resistance to acidification than their close relatives in the North Sea. One variable is the



Increasing Ocean Acidification:
many species will suffer, but few can benefit.
(Ocean Atlas, Boell Foundation)

Divers map the occurrence of Eel gras along the Baltic Sea coast.

EXPERIMENTAL EVOLUTION

As the ocean gets more acidic, calcifying organisms might be expected to find it harder to grow their scales, shells or skeletons. But Kiel marine research suggests that this short-term view may not be the full story.

Groups led by Ulf Riebesell and Thorsten Reusch from GEOMAR have looked at the ability of the world's "most important calcifying organism," the coccolithophore *Emiliania huxleyi*, to respond to ocean acidification. Most research in this area has been short-term, but this project involved several experiments, the longest of which lasted for four and a half years and almost 2000 generations. It revealed that experimental populations exposed to higher levels of carbon dioxide initially grew more slowly than those experiencing current levels, but that they could fully restore their initial growth rates after long-term evolution [2]. However after four years, all of the cultures exposed to extra carbon dioxide had reduced coccolith (scale) growth. So long-term adaptation reduced the capacity for coccolithophores to produce calcite. The authors therefore have a mixed message: while growth rates are restored by adaptive evolution, calcification is switched off under high concentrations of CO_2. On a more positive note, another series of experiments revealed even faster adaptation to warming, which played out independently of simultaneous adaptation to acidification

To bridge the gap between long-term laboratory experimentation and more realistic field conditions, Kiel researchers have worked with colleagues from the UK, the US, Finland and Sweden on mesocosm experiments which show that marine microbes are surprisingly robust when it comes to coping with climate change. They say in their report that: "(Their) large population sizes and rapid cell division rates (mean that) marine microbes have, or can generate, ample variation to fuel evolution over a few weeks or months, (giving them) the potential to evolve in response to global change."[3] By exposing a natural plankton community to higher or lower levels of carbon dioxide, they found that genotypes of the marine diatom *Skeletonema marinoi* were sorted within three months. Over that short period, this important species could evolve in response to carbon dioxide enrichment to the point where its population growth rate increased by 30 per cent [4]. Future Kiel research will emphasise this genetic response to climate change.

The importance of this Kiel research was recognised in 2011 by the award of Germany's most highly endowed research prize to Ulf Riebesell. He was honoured with the Leibniz Prize of the German Research Foundation, a €2.5 million award bestowed for his research on the effects of global change on marine ecosystems, and especially the effects of climate change and ocean acidification on calcifying marine organisms. The research which led to the award was carried out both in the laboratory and in the field, using freely-drifting experimental tanks developed in Kiel. His mesocosm experiments were carried out in the Baltic Sea, in Norwegian and Swedish Fjords and in Arctic waters, and in the Pacific Ocean off Hawaii.

KIEL´S OUTDOOR BENTHOCOSMS

The Kiel Outdoor Benthocosms (KOB) is an array of 12 water tanks connected to the Baltic on the Kiel seafront. Kiel scientists use it to investigate the possible effects of global warming on the marine environment under near-natural conditions.
The tanks are designed to improve upon earlier mesocosm systems, which provide a constant setting for marine life. Instead, they allow researchers to simulate future conditions while respecting natural fluctuations. If climate modelling or extrapolations from time series suggest changing salinity, carbon dioxide concentration, hypoxia or the availability of nutrients, those conditions can be simulated here for multispecies communities. It is also possible to examine extreme events, for instance by introducing a heatwave or a wave of cold into the temperature regime. The tanks contain over 100 sensors to track and control environmental variables.
This approach is generating more realistic insights into the ecological consequences of global change. One important finding concerns the seasonal variation of global change impact. In a warmer sea, organisms may grow more in winter if resources are available, increasing their stamina for surviving the heat stress of summer. In contrast, high metabolism in a warmer winter may be stressful when resources such as light are lacking. Better or worse winter performance may affect the rate and timing of spring reproduction.
Shifting environmental conditions affect different plants and animals in different ways. For example, ecologically important and long-lived seaweeds suffer more from temperature stress in summer than do the short-lived filamentous algae which compete with them. These algae, in turn, are kept under control by small crabs which graze on them. But if the water temperature exceeds 21°, these crabs disappear. So warmer conditions can lead to a complete takeover by new species of small algae, with different and less valuable ecological functions.
Thus Kiel marine research takes place on all possible scales, from the laboratory bench to the semi-closed mesocosms and on to the open ocean. Future experiments will allow more realistic and longer investigations. including the ability to test the effects of more variable environmental factors, more biotic interaction, and new components such as parasites and pathogens.

Benthocosms in the city of Kiel, at the Pier in the Kiel Fjord.

Sea butterflies, *Limacina helicina*, play an important role in the Arctic food web but are affected by ocean acidification.

prevalence of parasites. Under rapid stress, host species could lose all their parasites, which might be a good result, or we could get tougher, invasive parasites replacing the present ones. Wahl stresses that the project is not all about biology. "It needs ethical thinking to decide how we make use of these findings."

Coral reefs are another well-publicised example of a marine environment at risk, especially the Great Barrier Reef in Australia. As seawater gets warmer, the corals there are vulnerable to death by a process called coral bleaching. But corals in the Persian Gulf can live at 40°, much higher than the temperatures found off Australia. It might be possible to use these corals for a form of controlled species invasion. Or it could be feasible to train Australian corals in the warm waters of the Gulf and reintroduce them to the Great Barrier Reef. Kiel research will certainly contribute to such efforts.

What is to come in this field of research? Thorsten Reusch at Kiel suggests that: "The next stage is to take findings from our long-term evolution experiments, which are carried out in deliberately simple conditions, and apply them in the outdoors. We are currently expanding our work to have simple multi-species communities in long-term evolution, in order to see how they evolve under competition." This may mean including pathogens or even human consumers into the experimental environment. It might well involve working with a range of microbe species rather than with single ones, for example by looking at the association between bacteria and phytoplankton.

The ocean changes all the time. But the exceptionally fast pace of today's anthropogenic global change poses a substantial risk to ocean habitats. Multidisciplinary research in Kiel is investigating ocean change, its societal consequences, and possible mitigation measures.

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Can fisheries survive in a potentially depleted ocean?

Thirty years from now, will we still be fishing the ocean for bulk supplies of food fish? Researchers in Kiel are going beyond traditional concerns with overfishing and ecosystem stability to answer this question, with a focus on technology, economics and human demand. They work in interdisciplinary teams which include biologists and fisheries experts, economists, physical oceanographers and even lawyers with knowledge of international maritime agreements. They have shown that economic factors have a bigger influence on the future of fishing than climate change or ocean acidification.

Will we still be eating fish from the sea tomorrow? Who owns the fish in the ocean? How does climate change affect commercial fish stocks? Can the right management ensure that today's depleted fish stocks recover and yield maximum revenue?

Cod, salmon, tuna and sea bass are the most important food fish. Salmon and sea bass are now produced in bulk by fish farming, but cod and tuna are not. While investment in fish farming is set to grow,

To achieve sustainable fisheries, it is necessary to consider the full economic picture. The concept of shadow interest combines fisheries biology and economy, and may lead to an economic model that takes account of the nature of fish stocks as a renewable resource.

Martin Quaas from Kiel University and colleagues in Kiel and in Finland have shown that the expected growth in aquaculture will not satisfy the world's demand for fish [1]. Instead, improvements in fishing technology will make fishing more productive and add to pressure on fish stocks. At the same time, population growth and increasing incomes will mean more demand for fish.

This research shows that at least one of the globally-traded big four, most likely Bluefin tuna, will fall below 10 per cent of its original population before 2048. This is the level regarded by ecologists as critically low.

The authors find only limited scope for policy change to affect this picture. Aquaculture has been growing at up to 9 per cent a year. But to fill the demand gap completely, it would have to expand at an unrealistic 24 per cent each year. There are probably too few good sites for fish farms for this to be feasible. Aquaculture also creates environmental impacts that limit its growth.

Fish at local market in the Cape Verde Islands.

CLEVERER FISHING REGULATION

The other alternative is to manage large-scale commercial fishing more effectively. Regulation will have to be smarter than in the past. It must take account of growing demand and improved fishing technology, and will need to foster compliance. This will mean limiting total catches. And other measures might also be needed to set the right incentives. These may include regulations on fishing gear, new management structures, or rules to prevent new participants from entering the industry. As spending on fish increases and large-scale fishing technology gets more effective, the industry becomes more profitable and more attractive to new participants. This means, according to Quaas, that "management improvement is the key to sustaining wild fish stocks until 2048 and beyond."

This research raises the question of what future fishing regulations ought to look like. The classic way of restricting fish catches is by limiting the raw tonnage of a particular fish species that can be removed from the sea. This is known as a biomass-based management tool.

There are many problems with this comparatively crude approach. In particular, it does not distinguish between overfishing that takes fish out of the sea at too young an age from overfishing older fish, which are responsible for the reproduction of fish stocks.

Research at Kiel points to more sophisticated ways of regulating fish catches. The key is to develop "age-structured" fishery limits that distinguish between fish of different age and size [2]. This approach is sympathetic to the way the fishing industry works, as it is already standard practice to sort fish by size for auction.

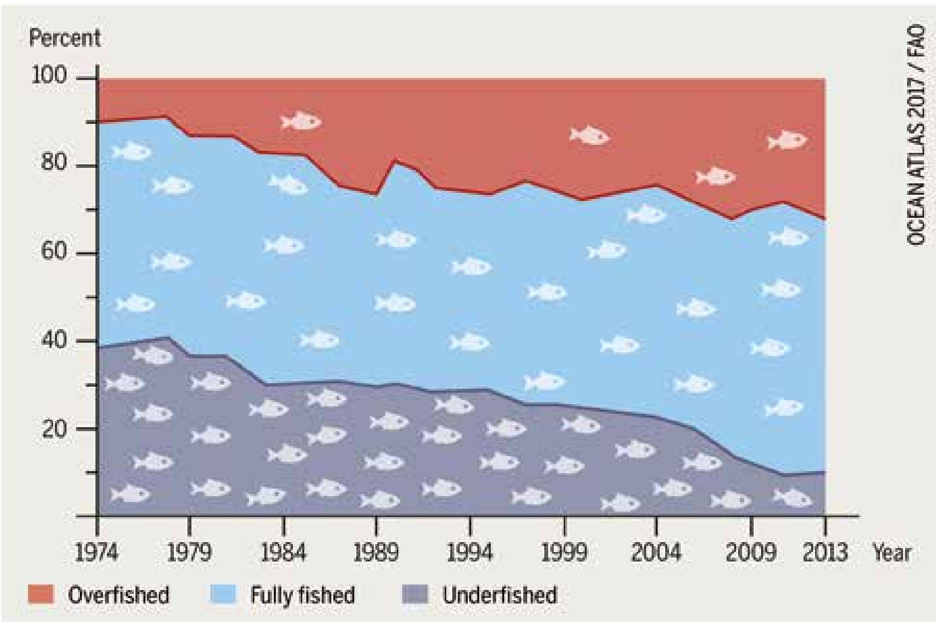
For example, there could be fishing permits which are set in fish numbers, instead of by weight. This simple idea could solve the problem of overfishing, and, as a nice bonus, make gear restrictions obsolete. The researchers point out that fishing vessels are increasingly likely to have cameras on board, making it hard for fishermen to cheat by throwing smaller fish back into the sea.

Making age-structured regulation work would require a detailed analysis of each fishery. The Kiel researchers took the Eastern Baltic cod fishery as an example, showing that age-structured fishing regulations could lead to a yearly harvest "substantially higher" than today's.

New research will allow this idea to be developed yet further. Baltic cod feeds on sprat and herring, while the sprats in turn feed on cod eggs and larvae. So it is important to introduce catch limits that take account of these interactions. This, say the researchers, would "allow for the development of an integrated policy that would regulate several commercial species simultaneously. Such an approach could also consider a fair distribution of profits between interest groups, be it different fishermen or nations." [3,4]

GLOBAL REACH

While much of Kiel's fisheries research concentrates on the Baltic and the North-East Atlantic, scientists there have a keen interest in fisheries on a global scale. They are well aware that fish is the world's most internationally-traded form of food.

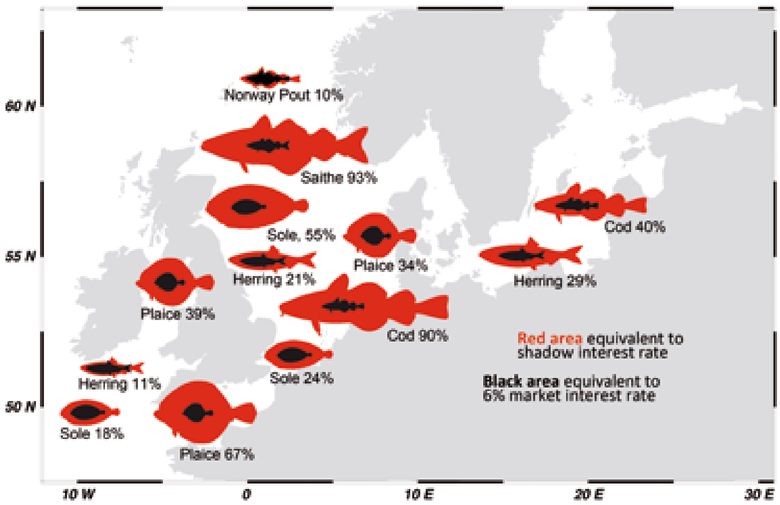


Overfishing on the rise: 58% of all fish stocks are at their maximum fishing capacity, 31% are already overfished, and only 10% are not yet fully exploited.

Fishing vessels in a harbour on the Cape Verde Islands.

SHADOW INTEREST

Some conservationists may regard the science of economics with suspicion. But Martin Quaas and his colleagues think that its methods contain useful insights about the natural world and the way mankind uses it. In a recent paper, they look at fishing as a form of borrowing from the ocean, and draw policy conclusions from the "interest rate" we pay on this loan. As Martin Quaas sees it: "These shadow interest rates can be thought of as the price that fishermen pay for this year's catch through reduced future catches. A catch reduction today is an investment in future fish stocks, and we know that these returns can be large. Recent catch limits for North Sea herring have shown that it is feasible for the fishing industry to realise these returns through temporary reductions in fish catches. Our figures suggest that it would be wise to set much lower catch rates in most European fisheries to allow a temporary rebuilding period."
Taking fish out of the sea reduces the size of future catches. Quaas and his co-authors have looked in detail at data for 13 species of fish caught off Europe, from Ireland to the Baltic, and have worked out the shadow interest rate which these lost fish imply for commercial fishing [6]. It turns out to range from 220 per cent a year for Saithe caught in the North Sea to 16 per cent for Norway pout. The figure is 199 per cent for cod, the most significant species. These credit card-type figures apply even where sustainable fishing is carried out. The shadow interest rate is lower – but still approaching 100 per cent for cod and Saithe - when fishing is carried out in a manner that maintains constant yields of fish. These big numbers are another way of saying that reduced fish catches, despite being politically controversial, could return significant profits to the fishing industry in just a few years.



Shadow interest rate for 13 species. The higher the percentage, the more overfished the stock. More investments benefit both, the fishing industry and the fish stocks.

TOWARDS SUSTAINABLE AQUACULTURE

Aquaculture and fisheries are essential to global food security, and will help provide protein for a future world population of 9 billion people. Success here will involve innovative, integrated and multidisciplinary science and technology.

Biniam Samuel-Fitwi from GMA in Büsum, an aquaculture research company part-owned by Kiel University, says: "This challenge will require a holistic approach to socio-economic, health and technological development, and will call for new assessment tools and technologies for the sustainable use of bioresources."

Sustainable aquaculture systems now under development use Recirculating Aquaculture, Integrated Multi-Trophic Aquaculture and feed optimisation to increase the efficiency and sustainability of aquaculture across a range of fish species [7].

But a comprehensive concept of sustainability also includes animal welfare. There is broad societal concern about the treatment of animals, going beyond traditional animal ethics and into new concepts such as "zoozentrism," the idea that animal welfare is of uniquely high moral value. The environmental and sustainability implications of aquaculture innovation can be gauged by the use of new tools such as life cycle assessment.

New aquaculture technologies might combat water pollution and the other problems of traditional aquaculture by farming fish, filter feeders such as mussels, and algae all together. Little research has been carried out on these systems in marine conditions.

Kiel researchers working on integrated multi-trophic aquaculture, which may become an important part of the sustainable use of ocean resources.

Kiel researchers investigate the effects of mankind's economic decisions for the future ocean. A key part of their work involves assessing the prospects for fisheries in Europe and around the world.

We now have detailed knowledge of environmental conditions in all the world's oceans, especially their temperature and salinity. This has allowed scientists in Kiel to map where marine species, both familiar and obscure, are able to live [5]. Rainer Froese has been involved in mapping the possible distribution of 7,000 types of fish, as well as many bird species and all sea mammals and reptiles.

This work shows the areas of the ocean which are most important for sustaining endangered species. It also helps us to understand where invasive species might find it easiest to populate new sea areas. An example is a map showing which of the world's waters are most friendly to the spread of Mnemiopsisleidyi, otherwise known as the warty comb jelly. This species is now spreading to European seas from its original home on Latin America's Atlantic seaboard.

These maps show how ocean warming influences what species can live in which sea areas. Froese says that his work reveals "far more losers than winners." Using data for 324 fish species on which we have good information, he foresees a 6 per cent average loss in their possible habitat between 1999 and 2050.

By depleting fish stocks and degrading habitats, overfishing and intensive aquaculture exert major pressures on the ocean's ecosystems. They lead to pollution of the marine environment, and alter the species composition of the ocean, the balance of different types of fish and other animals.

New research and innovation suggest that aquaculture can in principle turn into an ecologically sensitive and sustainable form of food production. However, the increasing shift towards industrialised aquaculture has damaged both ecosystems and the livelihoods of small-scale fish farmers. Improved approaches to fisheries management that reestablish and maintain the productivity of wild fish stocks will be required if marine food production is to continue making a significant contribution to human prosperity, alongside new and more sustainable forms of marine aquaculture. For example, small-scale and artisanal fisheries and aquaculture production provide food while generating employment and income for millions of people. Sustainable aquatic food production is therefore of prime scientific importance, and has immense economic and social value.

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Deep sea mineral resources: Hype or future?

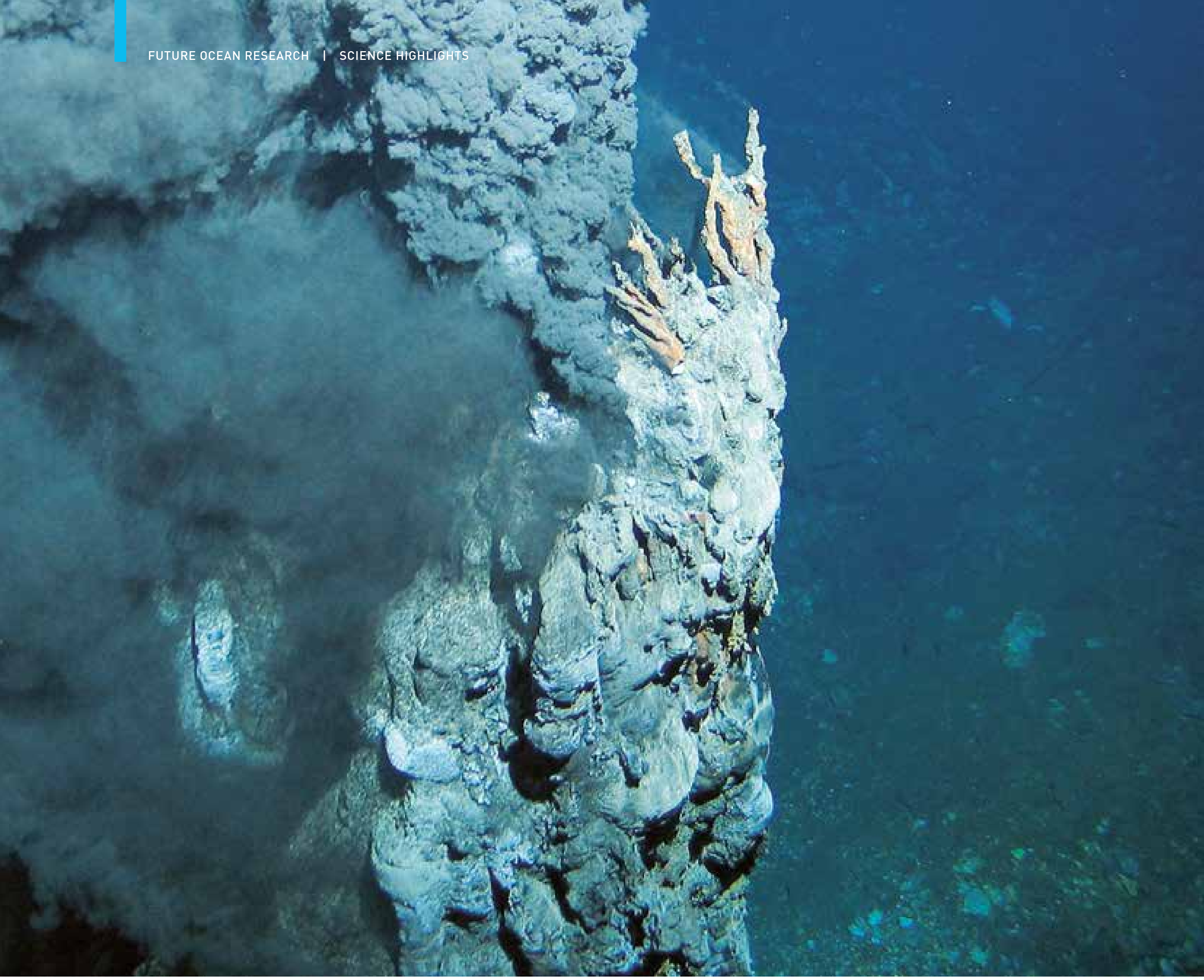
Most of the Earth's surface is ocean, but the metals we use are almost all mined on dry land. There are abundant minerals on the sea floor, but is it practical to use them? Major environmental and ethical questions arise from exploiting areas whose ecological resilience has not been explored. An interdisciplinary approach is needed to reach valid solutions.

The floor of the deep ocean is a dark and mostly slow-changing environment. But scientists led by Kiel marine researcher Sven Petersen point out that over geological time scales of millions of years, this makes it the perfect site to mine rich mineral deposits.

Several deep-sea minerals have been identified that might prove economically viable to extract [1]. The best-known example are manganese nodules that form on the muddy abyssal plains over millions of years. The nodules are found in old, stable regions of the ocean floor, especially in the Pacific, and typically in water depths of 3000-6000m. Because they form so slowly, they do not occur in geologically active areas where the seafloor is continuously being replaced by new lava. The Kiel experts estimate that manganese nodules might be found in economically viable amounts across more than 50 million square kilometres of the deep ocean. Most of these areas lie beyond areas of national jurisdiction, the so-called Exclusive Economic Zones (EEZ), of any nation. The greatest concentrations of metal-rich nodules occur in the Clarion-Clipperton Zone (CCZ) of the eastern Pacific Ocean, which extends from the west coast of Mexico to Hawaii.

Can the ocean supply raw materials for future generations?
As land-based mineral resources become increasingly difficult and expensive to acquire, the potential for mining them from the deep sea floor has become more widely discussed and debated. However, the quantity and quality of these seafloor resources are uncertain, as are the risks to deep-sea ecosystems.

While they consist largely of iron and manganese compounds, these nodules are referred to as "polymetallic" as they host other elements of economic interest such as nickel, copper, cobalt, lithium, and the so-called rare earth elements. Copper and nickel are among the most important metals for today's human society, especially copper for its pivotal role in electrical equipment. Lithium and cobalt are needed in today's batteries, while the rare earths are widely used in electronic devices and in renewable energy technology, especially in wind turbines.



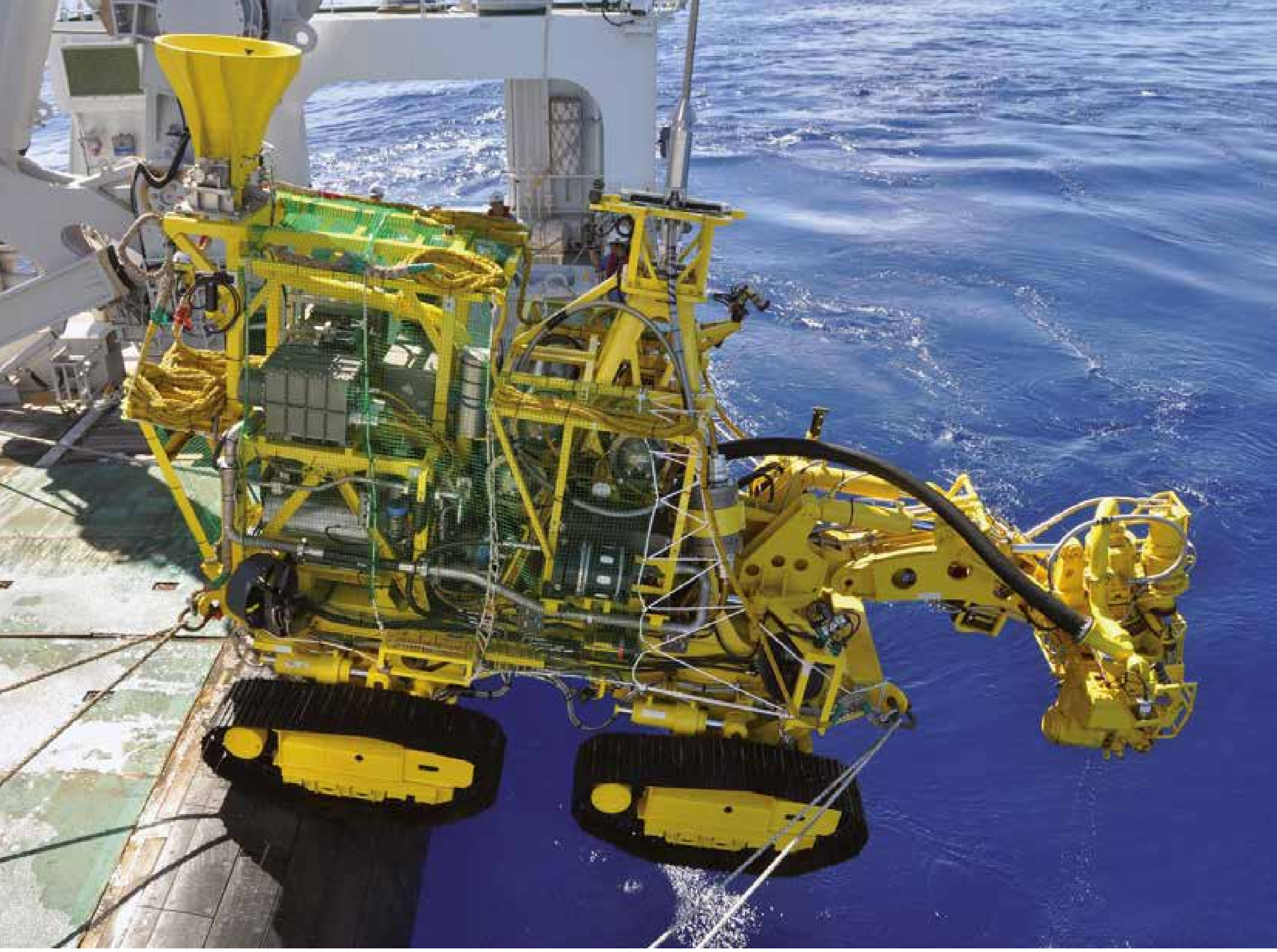
Black smokers emit large amounts of hot water. These fluids precipitate minerals which may contain valuable metallic elements.

Research in Kiel is contributing to assessments of the volume and metal content of deep sea ores, and of the environmental and legal consequences of their exploitation. This is an exceptional form of interdisciplinary research spanning basic natural sciences, economic models and legal questions.

In theory, the nodules hold vast reserves of accessible metal. The nodules from the CCZ alone are thought to contain three times as much nickel and five times as much cobalt as the current reserves known on land.

In addition, the mining of cobalt-rich manganese crusts that form on the flanks of old volcanic seamounts also seems viable. The most promising region for this kind of deposit lies in the western Pacific. Like the nodules, these crusts contain mainly iron and manganese. But they hold large quantities of cobalt, tellurium and the rare earth element yttrium that far exceed land-based reserves.

Petersen and his co-authors have also examined mineral deposits in the neighbourhood of "black



Ore-collecting test machine launched from the deck of a Japanese vessel
Copyright: Ministry of Economy, Trade and Industry of Japan.

smokers," hot subsea vents in volcanically active regions of the ocean floor. These deposits are rich in copper, zinc, and in some cases gold and silver. Some occurrences contain other valuable elements such as selenium and cadmium, but may also contain abundant toxic metals such as mercury or arsenic. It is much harder to assess the commercial potential of black smoker deposits. Unlike manganese nodules and crusts, their deposits are three-dimensional, and information on their depth and therefore their size is lacking. The biggest deposits of this kind host a few million tons of ore, which is small compared to land-based deposits.

But further Kiel research suggests that we may be underestimating the scale of these deposits. Jörg Hasenclever and colleagues from GEOMAR, the UK and Norway have examined the basic science of so-called "hydrothermal" zones in the ocean [2]. They find that these regions are the sites of hot-water circulation which can lift metallic elements from deep inside the Earth to an accessible location. Their calculations show that the amounts of metal that could be mobilized by hydrothermal flow are far greater than current estimates based on the deposits we know of today. It is still unclear where these missing metals are.

CHANCE TO DO IT RIGHT

Although the decades-long debate about the technological and economic challenges of nodule mining continues, the International Seabed Authority (ISA) has issued 17 licences to allow the exploration of these resources in recent years. Most are for the Clarion-Clipperton Zone in the Pacific. In addition, the Cook Islands have issued licences for nodule exploration in their own waters and covering 100,000 square kilometres of seabed in its EEZ. France, Korea and Japan also have EEZ areas that may be suitable for marine mineral mining in the Pacific, in France's case via its overseas territories.

Petersen and his fellow experts from Kiel and the United States point out that extracting these resources means significant disturbance of seafloor areas of which we have incomplete knowledge. Mining a million tonnes of metal in the form of manganese nodules would involve disturbing about 75 square kilometres of the seabed. They add that

> **Deep-sea mining forms part of the debate on the United Nations Sustainable Development Goals. We need to address the economic, scientific, legal and diplomatic challenges that arise from the possible use of these resources.**

while a typical nodule is 1-5cm in size, the cobalt-rich crusts can be 4-10cm or more in thickness. This means that they can be exploited across smaller areas, perhaps 12 square kilometres for every million tonnes mined.

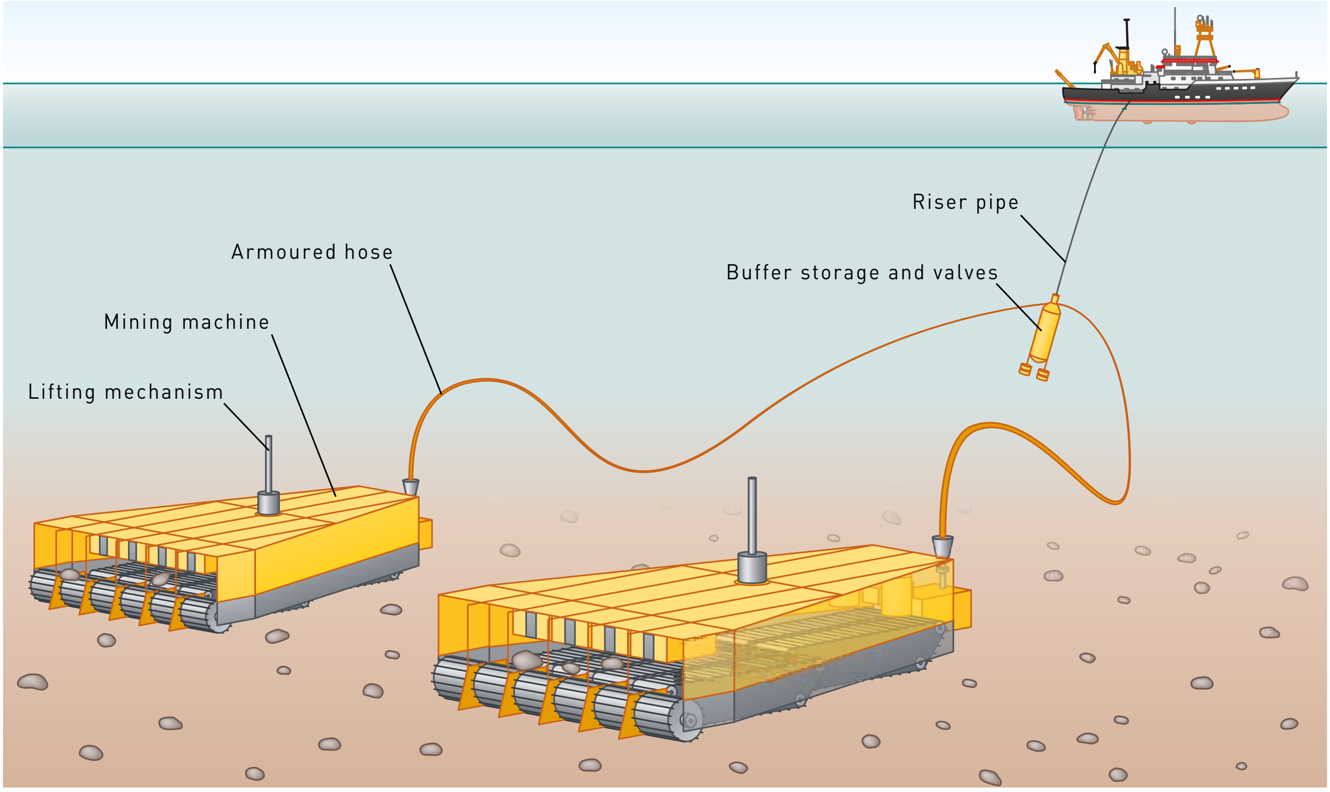
Nodule mining would involve massive dredges sweeping over huge areas of the deep ocean floor. If this happens, say Petersen and colleagues, "ecosystems in the deep ocean plains may never recover to the original species richness and distribution, due to the substantial loss of hard substrate."

While the resources available at black smokers have yet to be fully defined, it is possible that they would recover more effectively, since they are located in a fast-changing volcanic environment that is renewed far more often than the deep ocean floor.

The authors add that because deep-sea mining has not yet developed, there is a chance to get the legal and environmental regulations right before mining starts. The ISA is responsible for producing the rules that govern this possible future activity, which means that there is space for academics, NGOs and other stakeholders to influence their final form. Nine nodule-rich areas of the seafloor have already been declared Areas of Particular Environmental interest (APEIs) by ISA and are out of bounds for future mining activities. These APEI cover 400x 400km each, totalling 1,440,000 square kilometres of the Pacific. Two additional areas are being considered for this status.

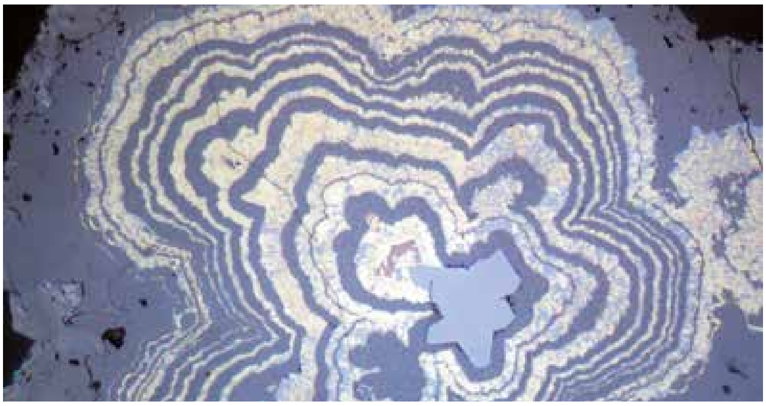
WHAT DO WE NEED TO LEARN?

The overall resource potential of deep sea minerals seems immense. But the question of how mankind's need for energy and metals can be met in the future, and whether deep sea resources will play a significant role, cannot be answered at present, due to the lack of information on their distribution and metal content. It is important, however, to provide basic geological information as a basis for political, economic and societal discussions of the prospects for deep-sea mining [3].



Future deep-sea mineral harvester robots may crawl the seafloor collecting manganese nodules.

Manganese nodules on the seafloor in the Clarion-Clipperton Zone. The picture was taken by ROV KIEL 6000 in April 2015.



These microscopic structures in massive sulfide deposits are caused by contact with hydrothermal fluids.

The possibility of deep-sea mining implies that exploratory work needs to be carried out in vast areas of the global ocean floor that have never been investigated in detail. This research will need to be complemented by improved frameworks for assessing the societal and environmental impact of marine resource exploitation. The benefits of this new technology depend on the trade-off between the market value of these resources and the risks of their exploitation.

At present it is impossible to assess this trade-off. We lack fundamental knowledge of the implications for biology and oceanography. So we cannot envisage how the value of a marine mineral deposit compares to the risks of mining it. This issue must be addressed by combining different research disciplines, linking natural science with economic studies, legal assessments and the discussion of ethical questions.

It is also important to realise that many geological resources exist close to the shoreline in submerged areas of the continental shelf [4]. Mark Hannington and colleagues suggest that it may be feasible to mine these deposits from a base on land. This approach could minimise environmental risk to seafloor ecosystems while helping to meet global resource demands.

Nele Matz-Lück, a specialist on the international law of the sea and Cluster speaker, says: "It is not yet clear how the law will develop as our knowledge of the deep ocean improves. The international legislation on its exploitation is so far only in draft form and needs to be reassessed as science finds out more. The law needs to be able to deal with uncertain impacts from this new technology, and will have to change in the light of new evidence".

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GAS HYDRATES IN A WARMING ENVIRONMENT

The gas you probably burn to cook your dinner is methane, produced alongside oil from deep wells running thousands of metres into the Earth's crust. But there is another type of methane trapped inside the Earth, and Kiel scientists have been looking at the hazards and benefits that go with it. Called Methane Hydrates, these deposits are a mixture of methane and water found in cold conditions at shallow depths in the Earth, often in lakes or on continental margins.

Because they are only stable in cool conditions, it is possible that warmer ocean temperatures will cause some of these hydrates to decompose. When this occurs, the methane is released into the water above, and potentially into the atmosphere. It seems that this happened during a global warming episode at the start of the Eocene epoch, 56 million years ago. Methane is a greenhouse gas, so releasing it into the atmosphere in large amounts poses the risk of further global warming.

Kerstin Kretschmer and colleagues at Kiel have shown that over 1.1 trillion tonnes of methane are trapped in these hydrates [5]. However, predictions for ocean bottom temperatures over the next century are reassuring. They imply that less than 500 million tonnes of methane will be released, mainly from deposits less than 700m below sea level. This, they say, is "negligible compared to the current anthropogenic releases of methane and other greenhouse gases." Substantial amounts of methane are also locked up on land, including large volumes in perma-frost in the Arctic. The possible release of this methane is a further global warming hazard.

But these findings do not mean that we can forget about methane hydrates. Methane leaks and gas flares have already been observed that are probably caused by these hydrates decomposing.

In addition, they are a usable source of hydrocarbons and can in theory be exploited. Work by Lena-Katharina Doepke and Till Requate at Kiel has pointed out that this exploitation could lead to unintended methane leakage, as well as to extra carbon dioxide emissions when the methane is burned [6]. Both of these would contribute to climate change. More intri-guingly, removing these deposits would destabilise geological structures at the continental margins, and so increase the risk of submarine slides.

Doepke and Requate say that new policies are needed to manage this risk. They call for global agreement on a tax regime which would compensate for the pollution due to using methane from hydrates, and for the potential damage due to increased risks of submarine mass wasting. More research is needed to define how big and how frequent these slides would be.

Gas Hydrates form on continental slopes in sediments at 400-1600 m of water depth. They disintegrate quickly after being brought to the surface, releasing methane gas and water.

How can marine Genes help human wellbeing?

Like inland mineral waters, seawater has long been credited with miraculous curative powers. Kiel researchers are putting this belief onto a scientific footing.

Ocean life has the same basic components as life on land. Creatures there have immune systems, they digest food and they fight disease. But the unique nature of the marine environment means that it contains chemicals that are unknown on land, and which can be used to relieve pain or fight disease.

While about 30,000 of these marine natural substances are known to science, the process of getting to an effective and safe compound that solves an actual human problem is a long one. Kiel researchers are working to ensure that these active ingredients are used to best advantage to meet human need for medicine, food and other essentials.

Life began in the ocean and has been evolving there for billions of years. Kiel Research indicates that marine species may become the source of drugs against pain, infection, and diseases including cancer.

How are marine species connected to human well-being? What can we learn from the immune systems of simple marine organisms? Can substances produced by marine animals or microbes cure illness? How do microbes communicate, and what happens if we disturb their communication? What genes can be found in sea life and used by humans?

Examples include two compounds termed nucleosides, chemical relatives of RNA and DNA. They are derived from a sponge found in the Caribbean, and are the first marine metabolites to be developed into an anticancer drug derived from the ocean. They are also the first ocean chemicals to serve as the scaffold for the development of drugs against diseases, from Herpes simplex to HIV. Other medicines that originate from marine organisms have been obtained from ascidians, molluscs and bryozoans, invertebrate animals that live in mossy-looking colonies.

One problem with this research is that a chemical compound with a novel effect can seem to come from some large invertebrate, when it is in fact made by a much smaller organism living symbiotically in or on its host organism. Discovering exactly where a compound comes from and how it works requires both fieldwork and laboratory science.

While a specific nation owns any living marine resource within its jurisdiction, those found beyond territorial waters are regarded as freely available

Coral reefs are marine environments with a large number of species and genetic variety.

WHY WE NEED MICROFLORA

Philip Rosenstiel is a medical doctor. He works on interactions between the environment and mucous membranes in the human intestine. And his research depends on ocean resources.

Any natural environment contains hostile pathogens. Skin and other tissues form biological barriers against them. But in addition, these surfaces are the ecological niche for microflora that carry out essential physiological functions for the host. In humans, these barrier organs can be affected by chronic inflammatory disorders including asthma, inflammatory bowel disease and psoriasis.

"When we study intestinal inflammation, the human host and its associated gut microbiome must be regarded as a single functional unit. Disease mechanisms can only be described if we take both sides of this 'metaorganism' into account," says Rosenstiel. "To answer our research questions, we try to understand regulatory events and bacterial responses in model systems." And these model systems are marine organisms. They are used in a translational approach to understanding the general principles of human health related to immunology and the maintenance of resident microbial diversity.

Rosenstiel has investigated how these interactions between host and symbiont take place, and how the hosts are colonised [2]. He looks at the symbiosis between the bioluminescent bacterium *Vibrio fischeri* and its squid host. The squid's cells regulate enzyme levels to support colonisation by the bacteria. As few as three to five V. fischeri cells (named after Bernhard Fischer, a professor at Kiel in the 19th century) are sufficient to induce a genetic signal within thousands of cells in the squid's light-organ tissues.

Learning how these interactions between animals and their symbionts work, and how deeply these different species depend upon each other, will help us to understand the inflammatory diseases which result from an imbalanced microbial system within the human body.

SEARCH FOR NEW DRUGS – A COMBINED EFFORT

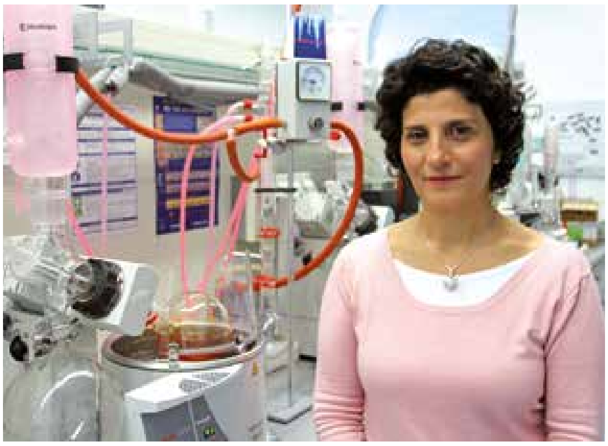
A significant new drug would be the most impactful result of Kiel's work on the ocean's genetic resources. But only seven major drugs have been developed from ocean resources in 40 years of intensive drug discovery efforts around the world. The process of isolating a few milligrams of the compound to be scaled up to enter clinical trials, and then patenting and licensing it for medical use, is an exceptionally expensive, risky and time-consuming one, involving a minimum of 10-15 years of effort.

However, there are other product areas in which specifications are less demanding and legislative requirements are simpler to satisfy. Kiel marine science is active in many of them. They include foods for people and for animals, agrochemicals, fuels and cosmetics. In some cases, it may not even be necessary to extract the active ingredient from the source organism. It is possible to add marine microorganism to soil in order to kill soil-borne crop pathogens.

Another possible product is what Tasdemir terms "probiotics for fish." At the moment, fish farms have a big impact on the coastal marine environment, because of the large amounts of antibiotics they use to keep fish healthy. Kiel research (page 56) has shown that this limits the growth of the aquaculture industry. New and more natural probiotics are being developed which would strengthen the immune systems of the farmed fish and keep them free from infection, while reducing impacts on other marine life.

This work is being carried out through the mentoring of a Latvian company, Baltic Probiotics, under the umbrella of the Baltic Blue Biotechnology Alliance project, led by Tasdemir [3]. This grouping of over 25 businesses and research organisations aims to exploit the massive potential of the Baltic Sea to supply novel, sustainable biotechnology products for the benefit of the region and the rest of the world.

Tasdemir says: "We are using this initiative to develop awareness in industry, and among the public and politicians, of the potential of marine biotechnology. We approach small enterprises, or even academics with business minds, and find out their problems in product development, all the way from research to business plan. How do they identify business needs and get the expertise they need? At Kiel, we plan to build a database of experts and expertise that can help. If it works, this approach can be replicated in other regions."



Prof. Deniz Tasdemir, Director of the GEOMAR Biotech Institute, researches active substances in her lab.

for use. But Nele Matz-Lück, a maritime law specialist who is speaker for the Kiel Cluster, points out that new proposals being prepared for consideration by the UN General Assembly may alter all this. She says: "The law could change so that these resources are regarded as the 'Common Heritage of Mankind.' That could mean creating a licensing scheme for access to genetic resources in areas beyond national jurisdiction, and an accompanying benefit-sharing mechanism."

Kiel researchers are working with business, government and non-profit bodies to ensure that their discoveries turn into useful drugs and into other types of innovative compound.

MARINE DRUGS?

Most people would find the view from Deniz Tasdemir's office all too distracting. From a building near the mouth of the Kiel Canal, she has a constant prospect of ocean-going ships making their way through the world's busiest inland waterway.

But Tasdemir is not diverted by this prospect. Her focus is on the ocean not as a highway, but as a source of new chemical compounds of benefit to the human race. Her focus is on marine biodiscovery, the main pillar of marine biotechnology. It involves the hunt for exotic chemicals developed by marine organisms through millions of years of evolution in the seas and oceans. And she explains that the implications are massive. Most obvious is the potential for new drugs and medical treatments to emerge from her research, mainly anticancer agents and antibiotics. But in addition, there could be new "nutraceuticals," foods with added health properties, chemicals for the bioremediation of polluted land and water, and even new cosmetics. Marine-derived antifouling agents might be created as a natural and less polluting way of preventing organisms encrusting ship hulls. This would mean replacing today's toxic and less effective antifouling agents with natural molecules coming from the sea. Other marine products include an analgesic 1,000 times more powerful than morphine. This small peptide is derived from a snail which uses it to paralyse fish which it then eats.

Tasdemir points out that most medicines, including familiar ones such as aspirin, come from nature. They may be natural products, or synthetic ones derived from them. She adds: "So far, most drugs have been derived from terrestrial plants. But life began in the sea and has longer to evolve there." [1] In addition, the ocean contains many extreme environments. To survive there, organisms need to innovate. Tasdemir says: "In the deep ocean or the polar regions it is cold and dark. There are low nutrient levels and extreme pressures. So anything living there needs a good strategy to survive. The biosynthesis of unusual chemical compounds for adaptation and survival is a known mechanism in extreme environments. This means that many exotic compounds can be isolated from so-called extremophilic organisms."

While drug discovery normally involves small molecules, larger ones such as cold- or heat-adapted enzymes are of interest to the food industry and for other applications. The texture of some well-known ice-creams depends upon the way they do not freeze solid even below zero degrees Celsius. This is because they contain a natural antifreeze derived from a deep-ocean fish.

However, most of the compounds studied in Tasdemir's laboratory are derived not from these advanced animals but from microbes. One millilitre of seawater contains a million microbes, while the same amount of sediment contains a billion. These latter are of interest because most of the antibiotics we use today come from sediment bacteria. At the same time many larger sea animals, such as sponges, contain a complex array of symbiotic bacteria and fungi that produce food or other useful chemicals for the host. Sponges do not have any internal organs. Instead, about half their body weight is made up of microbes with their own special functions and a highly evolved genetic structure. "Most of the molecules we obtain from marine animals are in fact produced by these microbes," she says.

From ocean mud to coral reefs, the seas are full of chemicals with the potential to cure disease, improve food production and clean the environment.

WAR ZONE

Tasdemir says that once microorganisms are isolated from sediment or from their animal hosts, it is important not to let them get too comfortable. If you put them in a Petri dish and feed them with artificial nutrients, they have no need to produce novel chemical compounds. In nature, all these microorganisms are in harsh competition for nutrients or other resources. Some produce interesting molecules to communicate, fight and deal with environmental stresses or cues. In the lab environment, microbes are subject to none of these stimuli. So she is now putting two or more microbe species from the same environment together.

Tasdemir says: "If you put rival species together, you get competition. They switch on chemical pathways that produce compounds that have a role in attack or defence. That cell-to-cell communication creates a 'war zone' with a rich chemistry of toxins, and often creates antibiotic activity that we can exploit. Seeing these pathways in action can give the biotechnology industry the strategies it needs to produce novel compounds."

Despite their beauty, this competition is seen at its most savage in the world of the coral reef. Here creatures are forced to compete and interact in a tiny space. To do this, they create a vast range of defensive and offensive chemicals. These molecules are often toxic and can have biological properties such as anticancer activity. In addition, much of the action on a coral reef takes place in shallow water which receives a lot of sunlight. So the animals here have evolved their own sun protection strategy. One commercial sunblock cream makes use of a natural compound evolved on the Great Barrier Reef in Australia.

And while the genetic diversity of reef creatures has long been recognised, we are now becoming more aware of the biological potential of the sea floor and the sediments that underlie it. This material can be harvested by remotely-operated vehicles or by coring machines.

But Tasdemir stresses that developing a useful product from a promising chemical in the ocean, or in a laboratory dish, is a long and complex process. The so-called supply issue is the main bottleneck. To avoid harming the natural ecosystem, we collect only small amounts of any organism. This means that only a few milligrams of the sought-after compound becomes available for all the chemistry and pharmacology work that is needed. And even then, she says: "The second hard part is to characterise the very complex structure of the compound and its mode of pharmacological action. After that, synthesising it is less of an issue." Fortunately, new technology is shortening timescales. "Computational chemistry is speeding up the process of determining the structure and action of these compounds. This is essential because industry is only interested in agents whose structure and action are known and which we are sure have low toxicity in humans." There is no point in a cure for cancer that kills the patient.

OUTLOOK

We now think that pathogenic microbes and parasites are important regulators of marine populations and biodiversity. This prompts the question: how many pathogens make up a healthy ocean, and what is their role in sustaining a functioning ecosystem? There is mounting evidence that the abundance of marine pathogens is increasing as a result of anthropogenic pressure.

The emergence of novel diseases from the marine realm is well-documented. Examples include the increased incidence of Vibrio species, bacteria that can cause infection in humans. Shellfish toxicity can be associated with harmful algal blooms, and viral diseases of marine origin may have the ability to attain epidemic proportions.

To date, only a minute fraction of the ocean's microbial richness has been studied. As we carry out a thorough assessment of the services provided for human well-being by ocean microbes, we expect important insights into infection biology to emerge. Kiel research into marine life will tell us more about the potential for harm from these species, so that the risks can be assessed and countermeasures developed.

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BIOFILMS

If you have had to clean that horrible black mess that builds up around the detergent tray in the washing machine, you already know about biofilms. These are masses of living cells attached to a natural or artificial surface, anything from the top layer of the ocean to the inside of the human body.

Biofilms are especially dangerous when they form on medical equipment or implants. The infectious cells they contain are impossible to destroy. The best approach is to stop them forming in the first place, and scientists from Kiel and Hamburg Universities are developing ways to do this. Professor Ruth Schmitz-Streit, from the Institute of General Microbiology, says that they are looking at this problem through the lens of basic science. In order to establish themselves on surfaces, the bacteria in a biofilm must communicate with each other via signal molecules. If this communication is disrupted, no biofilm can be formed. And this cell-to-cell communication can be disrupted by proteins which break down these signal molecules or make them ineffective [4].

The researchers have concentrated their search for these proteins on natural environments outside the laboratory. They took samples from seawater, from glaciers, from jellyfish, and indeed from the biofilm residue in a washing machine. They extracted DNA from the samples, and used it to identify proteins with the ability to break down the signal molecules or render them ineffective.

They found that the marine environment contains many proteins which can prevent cell-to-cell communication. "As the oldest ecosystem, the marine setting is incredibly rich in new, undiscovered substances. It offers huge potential for these biologically active proteins," says Schmitz-Streit. Particularly important was their discovery of the communication-disrupting protein QQ-2. This protein can prevent many different types of bacterial biofilms from forming. Its discovery may lead to the development of medications to fight the growth of disease-bearing biofilms in hospitals and other critical locations.

Prof. Ruth Schmitz-Streit researches biofilms in her microbiology lab in Kiel.

How do people see the future ocean?

Kiel marine research is not just about oceanography, chemistry and biology. It asks questions about the way we interact with the ocean. It comprises social sciences as well as the natural sciences, and is driven by insights from research in all the world's oceans and coastal regions.

Kiel researcher Barbara Neumann is looking at the interplay between people, and the oceans and coasts, and at the interactions between land and sea. Her work takes place in the context of sustainable development and global change. She says: "The existence of a Sustainable Development Goal (SDG) for the ocean and coasts within the UN'S 2030 Agenda for Sustainable Development means that we can develop a more normative idea of what development means in coastal regions. I am interested in the interconnectedness between different goals for sustainable development, and in their implications for the human and ecological systems of coastal regions. This involves social, cultural and economic considerations as well as environmental ones. And it requires consideration of which concept of sustainability is, or should be, applied by stakeholders or decision-makers." [1, 2, 3, 4]

Neumann and her colleagues have been examining how SDG 14, which is concerned with the sustainable development and conservation of the oceans, seas and marine resources, might interact with other SDGs. The ocean has a massive role in carbon sequestration, so there is a strong interaction between SDG 14 and the goals on climate action which make up SDG 13. Martin Visbeck, a physical oceanographer at the GEOMAR Helmholtz Centre for Ocean Research in Kiel , explains that SDG 14 exists because of the votes of small island states which feel threatened by climate change. Big, rich nations were less keen on the idea, and would have preferred fewer SDGs. [2, 11]

Neumann says: "It turns out that interactions

What do we want the ocean to be like? A natural space for people to relax, perhaps? But what consequences for the ocean are we willing to accept in return for cheap food and the benefits of the world trade, both of which mean more use and more pollution of the sea?

What role does the ocean play in human life? How do people think about the ocean? What part do maritime businesses play in shaping blue growth? What are the links between a healthy ocean and sustainable cities? What goals can society set for ocean management? And what do you smell when you go on holiday to the seaside? Does the aroma tempt you back, or does it force you to go somewhere else next year?

Society's interactions with the sea are complex. Researchers from Kiel have shown that marine businesses may be more sustainable than you think. But rebuilding agriculture to avoid polluting the ocean will be a complex social, economic and scientific task.

between land and sea are both positive and negative, and they run in both directions." One strong negative correlation has to do with marine pollution caused by agricultural fertiliser use. Reducing nitrate runoff into the ocean may mean reduced food production, unless agriculture is optimised in a new way to succeed with lower chemical inputs. But she adds that today's policy frameworks tend to produce more questions than solutions. "Systems of governance on land and at sea are very different," says Neumann. "There needs to be better integration of land and ocean governance. For example, pollution does not stay still once it is in the sea. This means that we need to connect maritime governance to the way things are done on land, and in the rest of the world. At the moment, policy work in this area tends to point up the issues clearly, but is still less good at solving them."

BETTER MEASURES

Neumann adds that we need better ways of monitoring sustainable development in terms of progress towards achieving the SDG goals and targets, including those for the oceans. She says: "It is vital to set the right indicators and benchmarks for monitoring progress. But it is also critical to decide which kind of monitoring framework, and what conceptual understanding of sustainability, is applied when weighing and balancing the measures we apply." She asks: "What are the topics we need

WHAT'S THAT SMELL?

Why did you choose to go back to the same seaside resort for the second year running? Kiel ecologist Florian Weinberger says that your decision might be driven by signals from your nose as much as from your eyes and ears. The animals, plants and microbes that live in the sea are affected by global warming, reduced oxygen levels in the water, and pollution from sources such as agriculture. But this pollution does not turn the seafloor into a wasteland. Instead it encourages new species to drive out older ones.

In an ongoing and highly transdisciplinary project, Weinberger and colleagues investigate the perception of beach wrack by beach users. Weinberger says: "This change can influence what a tourist from Bavaria thinks when he comes to the Baltic coast. Part of the way he decides if he is seeing a good beach or a bad beach is the smell. If small filament-type algae replace larger species that were there before, the smell will be different and far less acceptable." They also try to measure whether decomposing algae on the beach are more or less likely to deter tourists than litter or other deposits.

The hotel trade is interested in this research, as are tourist agencies and travel operators. And it is an obvious case of environmental change with big economic effects that can be explained to politicians. "It makes a clear link between agriculture and the health of the sea, in a way that affects people and business directly."

In this experiment researchers tested tourist´s reaction to the smell of different kind of algae on the beach was tested.

Macro algae are common on Baltic Sea beaches. How will the attractiveness of the beach change, if they are replaced as the dominant algae species by slimy, filament type, micro algae.

to consider in making the right assumptions about progress in sustainable development, and what makes a good benchmark?" She thinks that some current thinking in this area is over-ambitious. There are plans for integrated indicators which tell a full story about social and environmental issues, but in practice it is impossible to make them effective. She is more interested in how far we can look in practice, and which indicators describe good and bad impacts in a useful way.

HOW DO WE SEE THE SEA?

Ulrike Kronfeld-Goharani is an oceanographer turned political scientist. Her research has included work on maritime security and on the Soviet Union's dumping of nuclear submarines in the Barents Sea.

She analyses texts to examine just what we mean by sustainability at sea. Goharani has asked hundreds of maritime businesses how they define the term, and analysed over 80 sustainability reports from oil and gas companies, tourism operators and other marine enterprises.

Her work reveals a fascinating change in business thinking about the oceans. She says: "In the past, this document used to be called the Environment Report. Now it has turned into the Sustainability Report, which has a wider role and adds an environmental and social dimension to the traditional measures of profit, or of return on investment to the shareholder. I have found that maritime businesses are exposed to massive pressure to meet the expectation of their employees, customers, shareholders and other stakeholders that they will prevent harm to the environment, save resources, respect human rights and follow international regulation. Because they operate globally, large companies can transfer ideas, visions and technologies around the world. And because of their bigger financial resources, they can implement more ambitious sustainability goals than conservation NGOs." [7, 8]

However, Kronfeld-Goharani adds that the public themselves have only a faint impression of the size and significance of the oceans. "Ships move very rapidly through the sea, while containerisation means that the ocean is not regarded as part of the transport process any more. People do not see the ocean as a space in its own right and do not appreciate its dynamics, or the life and other resources it contains. Even on a cruise ship, the passengers are in their own space and have no connection to the ocean."

As a solution, Kronfeld-Goharani calls for more stress on the literary and artistic aspects of the ocean. She has been involved in creating Kiel's newly-published Ocean Atlas (see page 86) to tell people about the oceans, with an emphasis on how we use and change them.

Better knowledge of the ocean, she thinks, may create public demand for it to be treated better. Responses might include changes in the law of the sea to allow marine protected areas to be created in the high seas. We now know that the deep oceans are subject to serious pollution, from many sources ranging from plastic waste to excessive noise. This means that we need a framework for ocean governance that protects the oceans as well as guaranteeing the freedom to use them.

WHO WORRIES ABOUT THE DEEP OCEANS?

Kiel researcher Erik van Doorn's special concern is with fish that live mainly in international waters. These waters fall legally under the freedom of the high seas. This can result in an offshore version of the well-known "tragedy of the commons."

He says that one solution is for the principles that govern the exploitation of minerals on the deep sea floor (see page 62) to be extended to the ocean's living resources [9].

For example, he says, states should use the Law of the Sea Convention to define maximum sustainable yields for each fish species in their exclusive economic zone. Licences could be sold to allow this amount of fish to be caught, yielding financial benefits for states, for businesses and for people.

Van Doorn adds that his idea of "marine fish as the common heritage of humankind" is unlikely to catch on soon. "State sovereignty is still the utmost important pillar of international law." But he also thinks that if statehood declines in importance and economic factors gain momentum, the idea might become more important. For this to happen, the victims of today's overfishing system would have to speak out, along with intergovernmental and non-governmental organisations, as well as states that are willing to pay for a fairer solution.

FACING THE CONSEQUENCES OF OUR OCEAN ACTIVITY

Marine research at Kiel has a uniting theme. It shows that today's human activities have consequences for the physical and biological environment, and for people themselves, that demand new ecological, economic and personal choices.

We can all agree that it is good to be kind to nature, but there is less agreement on the right economic and philosophical approach to big environmental challenges. So Konrad Ott and his colleagues at Kiel are developing a new normative framework that they term "Strong Sustainability." The idea, explains Ott, is to ensure that the amount of "natural capital" in any environmental system remains constant, be it an ocean or a forest [10]. By natural capital, he means any property of the system that contributes to human welfare. Animals, plants and clean water are obvious examples, but pleasing landscapes or relaxing surroundings would also count. To maintain this natural capital, it is necessary to invest in order to get damaged environments back into their original condition.

Ott says that decisions on Strong Sustainability call for qualitative judgements. For example, it might be right to devote special effort to restoring rare environments because of their contribution to natural diversity. It rejects the strictly economic calculations involved in the ecosystem services approach, which sets monetary values on green assets and takes account of intergenerational equity by trying to leave adequate natural capital for future generations.

Ott and Neumann are researching how this concept relates to SDG 14 and the sustainable use of oceans, seas, marine resources and coastal areas, which are mentioned in two of the targets within SDG 14. They argue that the SDG process might be regarded as an opportunity to address ocean and coastal challenges on a range of scales. But this requires a clear account of the underlying approaches, principles, and objectives. They say: "Since most of the SDGs refer to humanitarian aspirations, there are reasons to ground SDG 14, as one of the environmental SDGs, in a concept of sustainability that does not allow for ongoing substitution of natural capital, but provides for restoration, rehabilitation, and conservation." [4]

Martin Visbeck points out that major ocean issues can only be solved by international agreement. And this is where things get complicated, because there is no single human view of the oceans. "In the Christian view, the ocean is given to mankind for use. It was regarded as human property and as being indefinitely large and impossible to ruin. Only more recently have we realised that the ocean is finite and that we can damage it." In Asian culture, he adds, there is more emphasis on living in harmony with the ocean, and less on human ownership of it. So when these two cultures meet, it is not surprising that they often have trouble seeing each other's standpoint.

Kiel research cannot of itself dispel these global cultural differences. But it can provide the scientific evidence for future action, alongside an analysis of the legal, economic, social and ethical issues that are inherent to our thinking on the future ocean.

The Future Ocean initiative involves many types of research, from the natural to the social sciences, and all with a strong focus on ethics. The result is a deep understanding of how the sea affects our thinking and our everyday lives, from climate change to our summer holidays, and how we in turn affect the oceans. Kiel marine research looks at the impacts of human action, and at how to govern human activity to ensure the sustainable use and development of oceans and coasts.

The Kiel Canal is sited near the home base of The Future Ocean, running between the North Sea and the Baltic, and is one of the most important artificial seaways in the world. Shipping puts significant stress on the environment through engine emissions and essential port activity, and by the release of oil and litter to the ocean.

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Toward sustainable (ocean) development

Kiel research aims to suggest solutions which allow technical and economic development while protecting the environment through the sustainable use of resources.

It is impossible to imagine a sustainable Earth without a sustainable ocean. Kiel research is pointing the way to both.

Kiel scientists carry out research in all the world's ocean basins, and are expert in understanding their past and present as well as in modelling their possible future states. Experts from the Kiel Cluster combine insights from physics, chemistry and biology with social, economic, legal, and ethical assessments. Their work is a world-leading example of trans- and interdisciplinary research informing current and future ocean use.

Scientific findings are increasing our awareness of the risks posed by our current use of the ocean. Kiel scientists investigate how future needs for marine food production can be met sustainably, either by means of fisheries or through aquaculture. They increase our understanding of the long-term risks resulting from ocean acidification. They are also investigating and assessing proposals for deep-sea mining of metal nodules, taking into account how intrusive and devastating this new technology might be. And they are looking at the case for and against marine climate intervention, the possible deployment of ocean-related technologies intended to counteract climate change. All of these examples involve value judgements, and these are addressed in Kiel by ethical reflection on underlying values and principles.

Integrated marine research in Kiel works on assessments and solutions for the sustainable use of the ocean. And it is improving ocean literacy through publications like the World Ocean Review and the Ocean Atlas.

Kiel research produces proposed solutions which are intended for consideration and use. They will help societies, and in particular coastal communities, to become more sustainable, resilient and even prosperous, and they encourage people to become more aware of the issues. Kiel researchers carry out a broad range of educational outreach, making use of novel digital resources. Through our own work and our collaboration with noted artists, we are able to bring the unimaginable world of the deep ocean to life for a wide range of audiences.

Kiel's research is increasingly engaging with individuals, businesses, non-governmental organisations and policy makers of all kinds. It maintains contacts with coastal communities in many parts of the world and works with them to reflect on solutions to see if they are ethically and legally sound as well as being scientifically and technically feasible.

What is the link between sustainable development and living in harmony with the ocean? What problems do we need to solve if we are to achieve a sustainable ocean? Can new technology improve the way we use the ocean? How can art and other imaginative forms of communication help tell ocean stories? What governance systems might make our use of the ocean more sustainable?

Left: Raising awareness: a sign informs tourists on the island of Mauritius about the degradation rates of different kinds of litter.

THE OCEAN AND SUSTAINABLE DEVELOPMENT

The 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) were adopted by the United Nations in 2015, including one SDG number 14 devoted to the seas and oceans [1]. Kiel researchers led by Martin Visbeck contributed to the UN discussions that created the SDGs and supported the development of SDG 14 [2,3]. But what does it mean in practice?

Humankind and the oceans form a single interacting system. Researchers at Kiel - with backgrounds in disciplines ranging from economics to oceanography - have looked at what they term the health of the system and how to measure it. Since "health" is itself a metaphor, the vision of a "healthy" ocean must be specified in scientific terms such as resilience, productivity and diversity.

Kiel researchers have critically observed and assessed global approaches to measuring sustainable ocean development, as proposed for example by Halpern et al. (2012) [8] through the development and annual updating of the Ocean Health Index. This work is a seminal contribution to better understanding and management of the human-ocean system. However, Kiel scientists have shown that precautionary and sustainable ocean governance requires the social evaluation of ocean benefits, and of the risks and uncertainties involved in our interaction with the ocean. This points to issues of concern with an index of ocean health that has unlimited substitution possibilities, so that a healthy result in one area can compensate for poor performance in another, such as the Ocean Health Index. Policy assessments carried out in this way could certify the health of the human-ocean system for countries that neglect important aspects of ocean health, and might wrongly identify damaging development trajectories as sustainable.

These insights also suggest that we need a better way of measuring progress against SDG 14, the Goal which emphasises the health of the oceans and the life they contain. An interdisciplinary Kiel research team led by Wilfried Rickels, and including economists as well as physical scientists, has tackled this issue.

The group has looked at the implications of SDG 14 for the waters around the nations of the European Union. One complicating factor is that the 17 Sustainable Development Goals have within them 169 specific targets. According to Rickels and colleagues, this large number of objectives means that the SDGs are bound to involve many synergies and trade-offs. Their sheer number also shows that innovative policies and management approaches will be needed to achieve the SDGs by the target date of 2030.

HEALTH OF EUROPE'S WATERS

Their approach to seeing whether SDG 14 is being achieved in European waters involves looking at the status of 17 indicators of sustainable ocean use. They range from the recovery of plastic packaging, a major pollution threat to the oceans, all the way to threatened fish and other animals. The findings suggest that Germany and France have the healthiest seas, while Bulgaria and Greece are the least successful at marine sustainability.

HOW DOES INTERNATIONAL LAW REACT TO ENVIRONMENTAL CHANGE?

As the Earth gets warmer, sea levels are rising around the world. And because the ocean takes time to respond to global warming, they will continue to rise even if we act soon to prevent further climate change. This calls for new political, diplomatic and legal solutions as well as scientific ones.

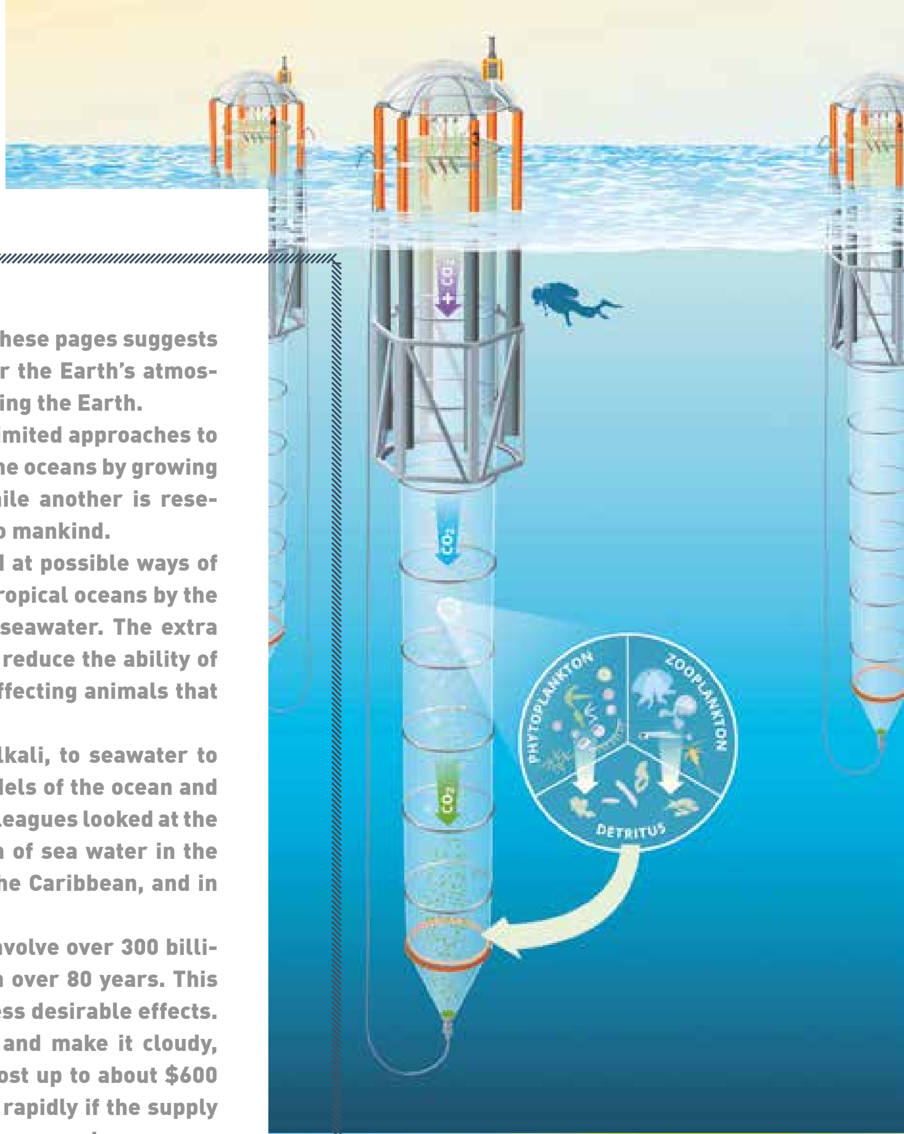
This issue is important. It involves large populations as well as big economic costs. In addition, we now appreciate that global average figures for sea-level rise do not tell us what will happen along a particular stretch of coast. Better ocean observations are essential if we are to map and predict the very variable effects of sea-level rise in different parts of the world [7].

International courts have indicated that changes in the actual coastline of a state will affect the location of the baseline as defined by the international law of the sea. An island does not have to vanish beneath the waves to lose its legal standing as the outermost marker of a state, but merely has to become uninhabitable.

For example, sea-level rise would cause extensive loss of land in Florida and in neighbouring Caribbean islands, but would have far less effect on the coastline of Cuba. This might feed demands for Cuba's maritime zones to expand at the expense of its neighbours, including the United States, in delimitation cases between them.

Legal scientists also point to the situation of India, Bangladesh and Myanmar in the Bay of Bengal. It could be India that suffers the most severe loss of dry land, which could drive Bangladesh to claim larger areas of ocean as zones under at least functional jurisdiction, an aspect which is important for exclusive rights over fisheries and non-living resources on the seabed.

As a consequence of sea-level rise, migration too becomes a wicked problem. The concept of climate-induced or environmental refugees is ill-defined and responsibility for displaced persons is unclear. Worldwide, millions of people are moving towards coastal regions just as the climate-induced risks increase in such areas. The ethical topics involved in these dilemmas are at the intersection of climate ethics, the ethics of migration, and ocean policies.



OCEAN RESTORATION?

Kiel research on climate intervention described in these pages suggests that there is little justification for attempts to alter the Earth's atmosphere, or for adopting other artificial means of cooling the Earth.

But one team of Kiel scientists is examining some limited approaches to preventing or reversing the damage being done to the oceans by growing atmospheric concentrations of carbon dioxide, while another is researching ways of making the oceans more valuable to mankind.

A group led by Andreas Oschlies at Kiel has looked at possible ways of counteracting the damage done to coral growth in tropical oceans by the increasing amount of carbon dioxide dissolved in seawater. The extra carbon dioxide makes water more acidic. This may reduce the ability of some animals to secrete their shells, and is also affecting animals that do not grow a shell.

It may be feasible to add calcium hydroxide, an alkali, to seawater to reverse its growing acidity. Taking established models of the ocean and atmosphere as their starting point, Oschlies and colleagues looked at the effects of adding calcium hydroxide to the top 50m of sea water in the region of the Great Barrier Reef off Australia, in the Caribbean, and in the South China Sea.

They found that this tactic could work, but would involve over 300 billion tonnes of material being injected into the ocean over 80 years. This intervention would have a range of desirable and less desirable effects. Calcium carbonate could be created in the water and make it cloudy, which is not good for coral growth. It would also cost up to about $600 billion a year, and the positive effects would cease rapidly if the supply of alkali to the sea were to cease. This expenditure represents an opportunity cost which could also be spent on other goals.

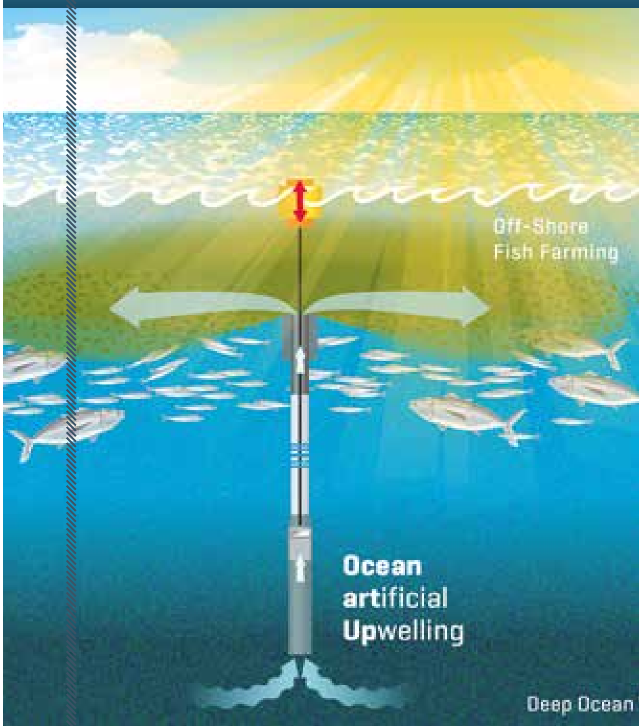
Another ocean technology being examined at Kiel is inspired by the natural upwelling of seawater. A €2.5 million project led by Ulf Riebesell is evaluating the possibility of inducing more such upwelling.

In parts of the ocean, cold, nutrient-rich water wells up to the surface and gives rise to the most productive marine ecosystems. Accounting for less than two per cent the Earth's ocean area, they contribute over 20 per cent of marine fish catches. If more such upwelling could be induced, fish production could be enhanced and pressure on existing fish stocks could be reduced. At the same time, upwelling of cold deep water would cool the atmosphere, helping to mitigate global warming.

The project, called Ocean artUp, is assessing the benefits of forced ocean water upwelling, but will also address the possible risks and side effects for marine ecosystems.

Riebesell's group will be gaining knowledge from experiments at all scales, from small simulations of artificial upwelling to field tests at the Plataforma Oceánica de Canarias (PLOCAN) ocean platform off Gran Canaria. Of special importance are "mesocosms," self-contained marine environments in which conditions can be controlled to allow the ecological impacts of upwelling to be assessed.

The group has developed a deep-water collector capable of collecting 100,000 litres of water at depths down to 800 meters in a giant plastic balloon. This water will be added to the mesocosm enclosures to simulate artificial upwelling, allowing the researchers to follow the response of the surface layer communities to this intervention.



The Project Ocean Artup is looking into the consequences of artificial upwelling to assess the opportunities and risks of such a technique.

Mesocosms are large swimming laboratories, which can be used to study organisms in an environment, where chosen parameters such as oxygen or CO_2 concentration can be manipulated in an otherwise natural system.

Their approach allows trade-offs between different indicators to be assessed, identifying countries which have an unbalanced performance across the indicators. The different indicators are assigned equal weight in the calculation and the substitution possibilities are limited, allowing development to be assessed against the criteria of strong sustainability. In addition, the assessment is not restricted to ecological indicators, but also takes into account the other dimensions of sustainable development. For example, it might be ecologically desirable to close a fishery for some years so that it can recover its population level. But that recovery would come at the cost of reduced short-term earnings from the fishery and the potential loss of economic capital, preventing other forms of sustainable development. Accordingly, the group points out that sustainable development is not necessarily the right objective for all ocean-related governance decisions. Policy makers should aim for solutions that help fisheries achieve transformation with both increased fish stocks and modernised fishing fleets, even if the goal of sustainable development is violated temporarily.

Furthermore, Kiel researcher Barbara Neumann et al. (2017) argue that the sub-targets of SDG 14 implicitly presuppose a concept of strong sustainability that makes the preservation and restoration of depleted natural capital mandatory for the sake of future generations.

Kiel research is therefore central to reforming our existing systems of ocean governance. The present approach is too weak and fragmented to support improved ocean management.

Improved ocean governance and policies, and the tools to implement them are needed, because of the potential [4] (see page 110) for damaging disruption of the ocean. If the oceans are destabilised, ecosystems and coastal societies are put under pressure, with the loss of human life, of marine habitats, and of infrastructure. Kiel research is helping to develop risk management strategies that are based on a thorough understanding of the chain of events that can trigger ocean disasters, as well as their progress and their impacts on land. This approach will lead to increased ecological and social resilience and so contribute to human prosperity.

ETHICAL OFFSHORE MINING?

One controversial example is the possibility of mining the mineral resources of the deep ocean. Many nations, including Germany, anticipate exploiting gas hydrates, polymetallic nodules, and massive sulphide resources there. This exploitation will add to the pressures on poorly-understood deep-sea environments. Kiel researchers are leading experts in this area, with expertise in policy and international law as well as ocean science. They have experience and international networks in this field, and have led national and EU projects on seabed resources. They have also established close collaborations with industry, environmental NGOs, and regulators, and have created the technology needed to evaluate deep-ocean environments. Deep-sea mining will almost certainly be contested on environmental grounds, since we know that onshore mining has many impacts on ecological systems. The burden of proof falls onto the companies and authorities that regard deep-sea mining as feasible and sustainable.

Martin Visbeck says that Kiel marine research is producing three types of

Spreading the knowledge about ocean issues in a positive and informative manner is key to raising ocean awareness.

solution to today's issues in science and human development. Its first positive effect is to generate "ocean literacy," the ability to understand the ocean and factor it into social thinking. According to Visbeck, this is itself a solution to an important problem, the low level of public engagement in ocean issues.

The Cluster has produced a wide range of publications as part of its work in this area, including the World Ocean Report on Sustainability and the novel Ocean Atlas (see box). There is also a Massive Open Online Course [4]. Formats are being developed to get Kiel research more widely appreciated in the developing world, including in Africa. Visbeck adds that Kiel's work on the ethics of ocean use adds a deeper level to its outreach work and takes it beyond the "understanding of science" approach. Environmental ethics has recently informed Kiel research on ocean acidification; cultural services at the Baltic Sea; ocean restoration and recovery; and climate change and environmental migration as it affects small island states.

Visbeck says: "This work is especially important when we engage with people who have authority over ocean-related actions, in business or government, or in the engineering community. We do science that will engage all these type of actor."

After this, says Visbeck, comes the second stage, Kiel's work on developing scientific and technological solutions. He says: "We are developing systems that get ocean eddies to draw more carbon into the deep oceans. We are also working on less environmentally-damaging aquaculture foods."

The third type of solution, and for Visbeck the most satisfying, involves using research to generate transformational behaviour in society. He says: "How do we get society to accept the need to fish less; or to become ecotourists; or to favour marine reserves and artisanal fishing rather than industrial fishing? Our work now is increasingly about changing attitudes."

Hans von Storch from the University of Hamburg and Mojib Latif from GEOMAR at Kiel discuss the consequences of climate change during a public discussion event in Kiel.

ENGINEERING SUSTAINABILITY?

Our growing awareness of climate change has led to a range of proposals for engineering the atmosphere to combat the impacts of climate change. Collectively termed geoengineering or climate intervention, these schemes range from putting mirrors in orbit to divert sunlight away from the Earth, to pumping water from the depths of the Arctic Ocean to encourage sea ice to form, or fertilising the ocean to increase its capacity to absorb carbon dioxide from the atmosphere.

There are two main approaches to climate intervention: solar radiation management, and carbon dioxide removal. Both groups of technologies have highly specific effects. Most experts agree that climate engineering cannot replace deep and rapid cuts in emissions, but some propose using them to buy time by complementing emission abatement temporarily.

However, a group of researchers, including climate scientists and specialists in law, government and the humanities, have cast doubt on these drastic approaches to modifying the environment. The group, whose members include Kiel's Konrad Ott, write that "There is no emergency argument for climate engineering." [5]

Climate intervention has been proposed as a way of avoiding major, damaging events in the Earth's climate evolution, often termed "tipping points." Possible examples include the catastrophic collapse of the West Antarctic ice sheet. The problem is that even these planet-altering events do not happen overnight. They occur over decades and there would probably never be a point at which climate intervention could be used to stop them.

The authors add that global warming is likely to cause big social and economic disruption. It would be hard to cure these through climate intervention. Climate change could damage global supply chains for food and other vital resources. These routes are thousands of kilometres long and involve complex flows of materials and information.

In addition, the authors warn that cutting the amount of solar energy entering the Earth's atmosphere, a favourite target for geoengineering proposals, might have unpredictable effects that outweigh the intended benefits. These might include changes in the jet stream, which influences the weather across heavily populated areas of Europe, Asia and North America. Or it could alter the monsoon, which is vital for agriculture throughout South Asia.

They conclude that despite its apparent potential, "The climate emergency narrative as an argument for (reducing solar energy at the Earth's surface) must be constantly scrutinized. There are many tragic examples of where normal politics has been suspended in the name of science and 'objective evidence'."


ozean der zukunft

Die Ölkatastrophe im Golf von Mexiko – was bleibt?

Hintergrundinformationen und offene Fragen zu den Folgen der Explosion der „Deepwater Horizon" für die Meere und ihre Küsten - von Wissenschaftlern aus dem Kieler Exzellenzcluster „Ozean der Zukunft"

Global ocean literacy will help develop support for solutions to ocean sustainability, one of world society's most urgent problems. In order to grow this support, interdisciplinary research at Kiel is taking on a new and more comprehensive approach. Its remit now ranges from discovery and understanding to the assessment of research findings and issues, and on to the generation and consideration of solutions to urgent problems facing genuine sustainable development.

Is this the future? Once the ocean is gone,
all that remains is desert and litter.
Foto: Robert Kurzawski

RESTORING NATURAL CAPITAL

It may be hard to reconcile climate intervention with Strong Sustainability (see previous chapter), a key concept originally developed by Herman Daly and now enhanced by Konrad Ott and colleagues in Kiel. Strong Sustainability argues for decisions to be taken that preserve and restore the natural capital of specific environments, rather than trying to reinvent them for a different future. According to Strong Sustainability, rapid and substantial cuts in greenhouse gas emissions can address the root causes of many ocean-related problems such as warming, acidification and sea-level rise, while climate engineering just addresses the symptoms. Address the root causes of ocean related problems; preserve remaining stocks and funds of natural capital; release pressure from marine and coastal systems; and restore and recover depleted natural capital - these maxims define a comprehensive strategy for the ocean based on the logic of Strong Sustainability.

Alexander Proelss, professor of international law at Trier University and formerly at Kiel, adds that there is very little legal basis for altering the Earth's climate [6]. Most international treaties on air pollution are too modest in scope to govern the deployment of major climate-altering technology. Indeed, the use of this technology might itself be regarded under existing law as a form of air pollution, although his reading of current international law also suggests that geoengineering is not specifically illegal. In any case, he adds, the generally-accepted precautionary principle discourages climate intervention by making it essential to consider the possible down side of any innovation.

This makes it likely, he says, that the solution to the dilemma lies in the hands of individual states, not global organisations. Nations will probably have to take responsibility for specific geoengineering measures, in consultation with the broader international community and with global opinion.

Martin Visbeck points to climate engineering as a case of Kiel interdisciplinarity in action. He says "We do not do engineering experiments in the field, for instance on seeding the oceans with iron," one proposed approach to enhancing carbon capture in the oceans. Instead, "We look at legal, moral and ethical aspects and ask if something is economically or societally feasible. Our approach has influenced the German programme in this area.

"If we release carbon into the atmosphere and cause global warming, that is happening by accident," he explains. "But if we do geoengineering, the effect is intentional. So we need to think about the legal and moral regime in which we do it."

Nele Matz-Lück, an international law expert in the Kiel Cluster, adds: "The ocean is the biggest store of carbon on Earth, but it is not mentioned in the Paris Agreement on climate change. So there needs to be debate around ideas such as using iron to fertilise the ocean and capture more carbon, or enhancing carbon sequestration in seabed geological formations. Discussions on the Sustainable Development Goal for the oceans may involve these issues, in terms of protecting the oceans from adverse effects as well as capturing more carbon there."

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IMPROVING OCEAN LITERACY

There is a growing amount of information on the oceans. But we are still a long way away from a comprehensive account of the key issues raised by our use of the oceans for the future of humankind, and for the seas and oceans themselves. The Future Ocean Cluster has taken up this challenge through a range of initiatives.

The most recent is the Ocean Atlas, published online and on paper in collaboration with the Heinrich Boell Foundation. This highly-illustrated 52-page document is subtitled "Facts and Figures about our relationship with the Ocean." The Atlas is intended for users from school age upwards. Its current, first edition, published in May 2017, contains chapters on the whole range of ways in which people and the oceans interact, from plastics pollution to overfishing, via sea level rise and pollution.

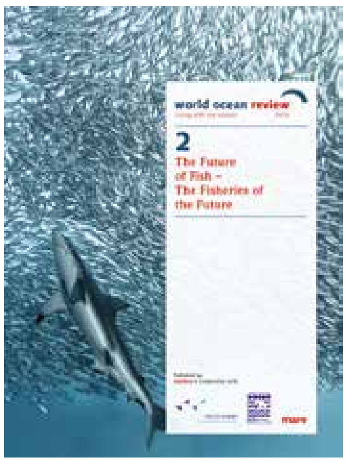
As might be expected for a report from the Kiel Cluster, the Atlas stresses human interaction with the ocean for tourism and other purposes, and investigates the legal and political problems that must be solved for the oceans to be governed fairly and sustainably. Take a look and download a copy from ocean-atlas.org.

The Cluster also has a strong interest in speaking to informed audiences in business, policy, the media and elsewhere. To enhance this effort, it has worked with the International Ocean Institute, a non-profit body based in Malta, and its marine-themed magazine mare, to launch the annual World Ocean Review.

Each issue of the review goes into a specific area of concern in detail. Topics so far have included the sustainable use of the seas; fisheries; and the opportunities and risks associated with the use of ocean resources. The latest issue, number five, runs to 150 pages.

The content includes immediately relevant research-based material accessible to a general audience. It stresses the uncertainty in our knowledge and looks at threats and risks to the oceans and to people and societies. But it also maps routes to more sustainable and satisfying forms of ocean use and ocean management. Contributors are drawn from the Kiel Cluster and from other centres of ocean expertise around the world.

Past and current issues of World Ocean Review can be downloaded at http://www.worldoceanreview.com.



Ocean Literacy: the *Ocean Atlas* is published by the Boell Foundation and the Cluster of Excellence The Future Ocean from Kiel. It aims to show the escalating crisis at sea. The *World Ocean Review* tackles imprtant issues in depth for the interested public.

The saddest aspect of life right now is that science gathers knowledge faster than society gathers wisdom.

Isaac Asimov

VIEWS

Symbiosis: Art and design meet marine science

The Muthesius University of Fine Arts and Design, based in Kiel, is one of the founding institutions of the Future Ocean Excellence Cluster. It is also the only arts university in Germany to be an active member of such a research project within the Excellence Initiative of the Federal Ministry of Science and Education.

Muthesius's involvement in the Cluster has evolved over time. It began as a modest relationship in which the Future Ocean Exhibition and other artistic activities were developed to communicate marine science to the public, alongside artists' perceptions of the ocean. Students supported the Cluster and its researchers by designing artistic installations and events, and by improving scientific graphics and designs for publication.

Later on, art turned into an integral part of the cluster's thinking and into a self-contained cluster topic in its own right. Martin Visbeck, speaker for the Cluster, says: "When we ask how we might communicate our findings in some subject area such as fisheries, art has become an important part of our approach."

This joint working with Muthesius has turned it from an external source of design knowledge into an important part of the academic work of the Cluster.. This collaboration, Visbeck adds, is far simpler to accomplish in a small city such as Kiel than it would be in a major center such as London, New York or Berlin. The collaboration has become a feedback mechanism to the Cluster's researchers and to the public as a whole. As research comes up with findings and explores their consequences, artistic insight helps the Cluster to understand and communicate them. These feedbacks provoke discussion which broadens everyone's understanding in many ways, improving research, science communication, and the arts in Kiel.

In the following discussion, Muthesius professors Tom Duscher (Interactive media), Stephan Sachs (experimental film) and Manfred Schulz (scenography) reflect on their experience of working collaboratively with artists, designers and scientists.

Where did your desire to engage with science come from?

SACHS Curiosity played an important role for me. I had always been interested in the natural sciences, but had no idea how things actually work in a research community, except the thought that it would probably be very different from the art world.

DUSCHER I had already found it motivating to work with different disciplines such as spatial strategies and film, and to look beyond my own discipline. And I was interested in finding a relevant and important theme such as marine research.

SACHS I would not have come on board if the content hadn't been so interesting.

SCHULZ For our group, the "Future Ocean" project made it onto the agenda easily. The theme of the sea is exciting, charming, erotic .. . I'm looking for the right words ... The theme of oceans is very complete and inspiring on many different levels, not just that of the natural sciences.

SACHS And of course it plays a special role here in Kiel, the city by the sea.

Interactive scientific posters attract exhibition visitors for their information content and their astonishing design alike. This one tells viewers about the link between underwater landslides and tsunamis.

When we joined the prospective cluster in 2006, I'd been in this city for just a year. I didn't really know it properly yet.

SCHULZ One could see that the scientific organization of the prospective cluster included expertise, infrastructure, traditions and a history of marine science in Kiel. In our eyes it was the right theme, in the right place, at the right time.

DUSCHER And there was great interest in us from the scientists. They invited us in with open arms, and the collaboration with an art institution was new and challenging for them, especially the first moments spent getting to know each other.

What expectations did you have for this collaboration with the Excellence Cluster?

SACHS When we started to deal with the scientists, the Cluster did not exist. There were no models for such a collaboration. Against this background we had the idea for the first exhibition in Halle 400, a large exhibition hall in Kiel.

SCHULZ The initial phase involved just a few people. This small circle decided to try and create some publicity by doing an exhibition on the Day of German Unity. That was shortly before the decision about which excellence cluster was to be recognized, and we wanted to make an impression. Our idea was to install an "Underwater World" in Halle 400, to show that there was collaboration between diverse members who intended to be recognized as an excellence cluster.

We sought out simple, meaningful aspects of the science with broadly understandable content, and formulated possible questions. For example, the scientists gave us insights into international maritime law. From there we formulated the question "Who does the sea belong to?" From that, other scientists formulated similar simple questions such as "Will the Gulf Stream continue to flow?" or "Can algae heal people?" and then tried to answer them using appropriate text and visual material.

How did you and the scientists communicate day to day?

SACHS When the scientists first explained the content to us, we didn't understand anything. And they didn't understand that we hadn't understood anything. Knowing where the other stood was very difficult at the beginning.

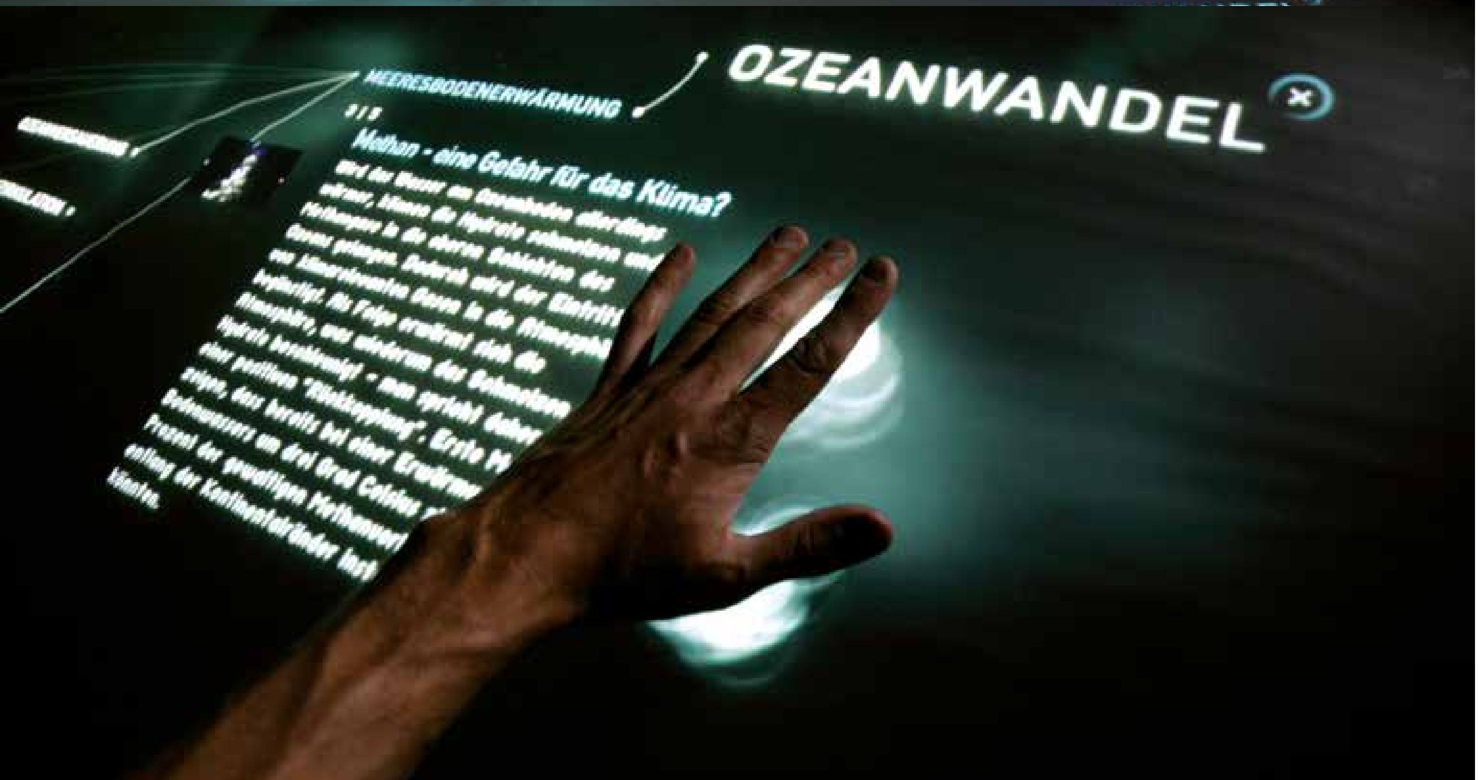
DUSCHER It's also about a common attitude. The interest and the passion that one finds in the scientists, which really goes deep, has an important parallel in us creative types.

SCHULZ With scientists there is a "right and wrong" logic which controls decision-making. We found repeatedly that the scientists presented interesting topics to us, we developed ideas from them, and then the scientists said: "That result is not yet final" or "We don't yet have enough measurements to be able to fully affirm that". We had to make it clear that the exhibition may also ask questions - of the sea, of people and of science.

DUSCHER Real collaboration and mutual benefit began when we realized that we work very differently with images. Scientists create technical images to assemble data. From these images, we've made emotive presentations that the scientists could relate to, so they saw where our expertise lay and how we approached the issues.

SCHULZ In the area of design, we have a clearly formulated series of tasks ranging from the identification of the problem to well-argued, conclusive solutions in an individually crafted piece of work. But other qualities can play a role even though they escape clear logic. At the beginning the scientists asked how we can be sure that of these three possible poster designs, the one in the middle is the best. They were not clear how one could get to a result with something that in their view couldn't be evaluated. Here mutual understanding developed over the years.

The Ocean Explorer, a six meter interactive multitouch table, attracted and informed visitors to Future Ocean exhibitions.


OZEANWANDEL
MEERESBODENERWÄRMUNG
Methan - eine Gefahr für das Klima?


CHANCEN

The Future Ocean exhibition has been displayed at Deutsches Museum in Munich, in the house of the Federal Parliament in Berlin, and at many other venues in Germany and abroad.

The whole thing resolved itself in wondrous ways in the exhibition in Halle 400, a highly immersive space. In the preliminary stages there was a lot of scepticism. Our ideas for the exhibition were expressed by means of plans and descriptions, which made them difficult to comprehend. Then when the exhibition was prepared and had opened, the majority were suddenly able to understand what we had been doing and how for the past few months.

SACHS It became clear that each of us had a unique approach to the theme. Whilst trawling through video material at GEOMAR, I discovered recordings which immediately fascinated me. They were of slow journeys across the sea floor, many taken by GEOMAR'S own manned submersible JAGO. They showed barren ground, sand, gravel, volcanic rocks, but mainly vastness and emptiness. Now and again a small fish, but mainly nothing. I positioned three big flat-screens alongside each other to form a triptych. Different sea floors came to the observer from all three screens, the locations were blended, there was no sound. It was quite a suggestive video installation. Nothing was explained - it was rather the posing of a question.

How have your experiences with scientists been different from the different perspectives of art and design?

DUSCHER It became clear that the rational approach of the scientists was more like a design attitude. For example, they needed a visualization of climate evolution over the past 10,000 years. As a designer

The scientific poster was demonstrated by designer Konrad Rappaport at the Red Dot award show, where it was the winning entry.

you start by thinking about concrete problems of presentation, so there's possibly a closer relationship between design and the natural sciences. If one approaches art and asks for a concrete solution for this or that ... it's perhaps not so easy to establish.

Is the difference between the natural sciences and art that art can be open in the form of its results?

SACHS For me a certain sensuality, and the provocation of uncertainty, are important. When art enables the recipients' view of things to be just ever so slightly changed, that's a victory.

DUSCHER One can call the process of getting to a conclusion research, exploration or experimentation. For me, it's inspiring to experiment with new technologies to find out what they do or don't make possible. The new plays a central role for me, maybe because not everything that is new is also good or better. It is about shaping the future, assessing new technologies and asking what one can achieve with them. I find it fascinating to do this within the realm of ocean research, because I can question whether it helps and supports the scientists.

What does the tension between art, design and science look like, and how have artists and scientists influenced each other through the collaboration?

SCHULZ I don't believe that our work has influenced the scientists' research work.

DUSCHER I find that it has changed their attitude in some ways. For example, they have conceived and realised the latest exhibitions by themselves. We have changed the way they see themselves, how communication or presentation is thought about, and as a result maybe the way they act.

SCHULZ The scientists' research work was not influenced, but the way they interact with the public has changed. In the past few years, the communication culture within scientific research has changed, and we've made a contribution. But it has also developed its own momentum.

DUSCHER In the application for the second phase of the excellence cluster funding, Muthesius contributed to the definition of a focus for the research, and introduced the themes of culture, society and responsibility. Our position was that sustainability can be achieved if strong self-awareness and willingness to change behavior emerge in society. And that did influence the direction of the research and has made communication and visualisation themselves the object of research. The societal aspect is now taken much more seriously than before.

Was there actual collaborative work, or did the scientists, artists and designers just happen to work on the same content?

DUSCHER Think of the collaboration on the Next Generation Scientific Poster. We approached the scientists with a suggestion for a new technological form of visualisation, formulated our own creative questions, and after that asked the scientists about appropriate research content. This led to a very close collaboration in which we learned a lot about specific visualization problems in science.

Was that typical?

DUSCHER That was the fruit of the level of trust which had built up in our collaboration. Previously, the scientists had no time for the presentation of their topics, or it wasn't important enough for them. Scientific communication now has a high value in the cluster. It is seen as profitable and insightful by both sides.

Left to right:
Muthesius experts Tom Duscher, Interactive Media; Stephan Sachs, Time Based Media; Manfred Schulz, Scenography/ Spatial Strategies.

Looking to the future, which approaches could be developed further?

DUSCHER It would be beneficial if the designers, artists and scientists could literally work more closely together. This is already happening at the Center for Complex Network Research at Northeastern University in Boston. Here scientists and data visualisers work together in a team. This would go beyond working together in the initiation phase, after which everyone goes back to their own work and then takes a look at the end to see what has come out of it.

SACHS I was on a research ship and we were locked up for four weeks, with no possibility of disembarking. The scientists were well disposed towards us, but also skeptical. The situation on a ship is an intimate one, you inevitably come close and can't easily get out of each other's way. I was often asked: "What are you actually doing there?" I had to explain that I was trying to understand and was gathering a bit of initial material. What it would ultimately result in was not clear to me yet. That did lead to a certain degree of astonishment.

If scientific knowledge about the natural world is generated in the natural sciences, what kind of knowledge can art and design generate?

SACHS A current point of contact between art and design, and the natural sciences is the awareness that one must think holistically. That's the case in modern physics and medicine, or with oceanography and climate research. For me, it is very important for art to have the whole picture in view in all its complexity. The medium of film in particular seems to me predestined to achieve this. That's one reason I love it so.

SCHULZ In medicine, one no longer looks at nerves or organs separately from each other. Rather one examines the communication between them. We creatives are good at providing ideas for new ways of seeing.

SACHS With regard to ocean research, one would be the close relationship between ocean currents. Only a fraction of them, and their impacts on our climate, have been subject to research. So far we have only understood a fraction of it. I don't think anyone really knows to what degree we can understand such highly complex systems.

DUSCHER From an artistic or creative perspective, there are actions which emerge intuitively, which follow our instincts and are hard to explain rationally. That is perhaps something which has been lost in the verifiable world of the natural sciences.

Sometimes scientists refer to scientific theories as elegant or beautiful - what do you think, can one have aesthetic or sensual experiences in science?

DUSCHER I think that in every area there is a type of good solution, a creative or intelligent solution. And that one then refers to these as beautiful, which is of course completely understandable. And we have nature as the entity to actually define beauty. Everything is measured against it.

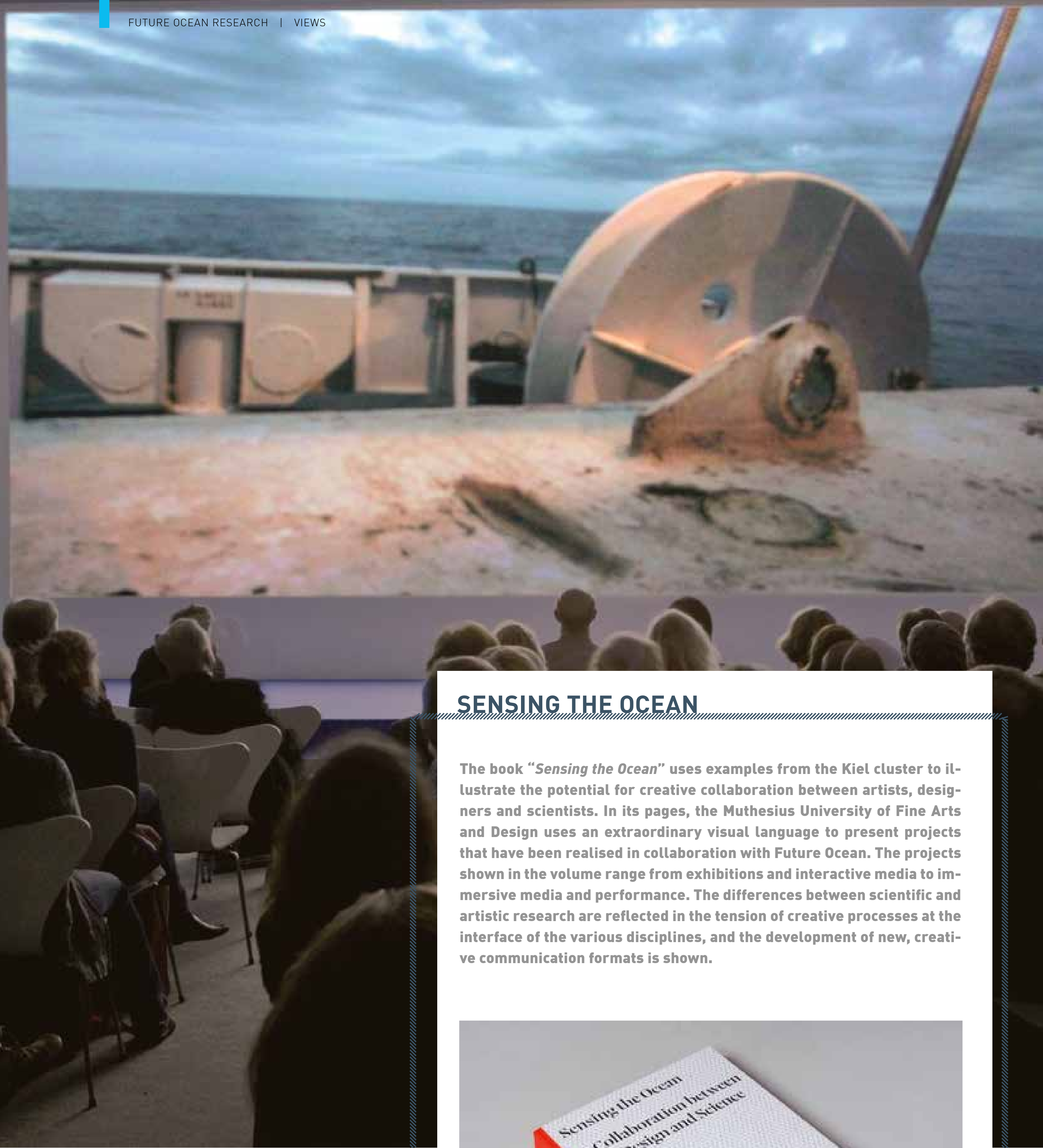
SACHS In the natural sciences, a beautiful formula is the formula which can express a complex issue in the briefest of terms. I don't believe that aesthetics plays a role for scientists in this regard. And art is by no means just about beauty.

SCHULZ Perhaps there is a possible goal in both art and in science, which is a contemplation of the world freed from all superfluousness.

DUSCHER Simplicity.

SCHULZ Simple, clear, precise.

The interview took place on April 14, 2016 in Hamburg, and was carried out by Jolan Kieschke. It was first published in the book "Sensing the Ocean – A Collaboration between Art, Design and Science". It was abbreviated for this publication by Martin Ince.



SENSING THE OCEAN

The book "*Sensing the Ocean*" uses examples from the Kiel cluster to illustrate the potential for creative collaboration between artists, designers and scientists. In its pages, the Muthesius University of Fine Arts and Design uses an extraordinary visual language to present projects that have been realised in collaboration with Future Ocean. The projects shown in the volume range from exhibitions and interactive media to immersive media and performance. The differences between scientific and artistic research are reflected in the tension of creative processes at the interface of the various disciplines, and the development of new, creative communication formats is shown.

A "performative lecture"on the oceans, developed as an experimental piece comprising film, literature, theatre, music and actual scientific lectures.

Social and political science: Helping to make the ocean relevant to everyone

Silja Klepp is a social anthropologist, now working as a human geographer, and Aletta Mondré a political scientist with a strong interest in the law of the sea. Both recent arrivals at Kiel, they say that the interdisciplinary approach they find there is already working for them as researchers engaged in generating new knowledge which can lead to valuable social innovation.

In the deep ocean, says Mondré, the legal problem is "to see what governance is possible beyond the limits of the state." Interdisciplinarity is key to her work. She points out that "scientists are steadily discovering an intersecting ecosystem" in the oceans. As a result, a legal regime that is just about minerals or about fish will not do. There need to be compatible, intersecting legal regimes for many different types of activity. This is why many of the most coherent calls for new forms of ocean governance now come from scientists.

Mondré says that the existing Law of the Sea, written in the 1970s, is still untested in many ways. It was written when concern for the environment was at a lower level than today. Green NGOs, as well as legal academics and practitioners, all agree that nobody truly knows what it means, or what would be involved in implementing it in full.

The example that Mondré is now pursuing concerns deep-sea mining of massive sulphide deposits, metal nodules and crusts (see page 62). While the mining industry is excited about the prospects, which have been under discussion since the 1960s, it is still not certain that metals prices will support the massive costs of mining the deep ocean floor. As Mondré sees it, this technology raises big questions and uncertainties, especially concerning its environmental impact. But at the same time, "it is hard to tell people in Papua New Guinea to leave this resource undeveloped if it also means leaving their own people hungry." She points out that so far, the mining companies have done ocean mining deals mainly with poorer nations which have little clout at the negotiating table. Her research studies whether adequate regulation can be produced under these conditions of inequity and uncertainty, and whether international regulation could supplement low national capacity for regulation.

Klepp's background as a researcher is in Italy, with work on refugees and boat people in the Mediterranean Sea. But her current research centres upon Kiribati in the Pacific, an island nation of 100,000 people whose very existence is threatened by sea level rise. She explains that unlike most people threatened by rising sea levels, the people of Kiribati cannot move to another part of the country. The whole Republic is set to disappear or become uninhabitable in 30-50 years. This is a new turn in history and would have been unimaginable even a few decades ago. The solution adopted by the islanders, says Klepp, is to "migrate with dignity." They are buying land in Fiji, which has accepted the idea of welcoming them on an emergency basis.

Klepp is using the skills of a critical social scientist to look at this unique example of climate change adaptation. This involves developing new ways of looking at climate change adaptation in the Pacific. Many such initiatives, she says, take a technocratic approach reminiscent of the development aid projects of the 1970s. They make too little use of local knowledge and can neglect traditional social structures and systems of government.

She says: "I am interested in looking at how the idea of sustainability is interpreted around the world, for example whether it leads to construction-based hard solutions or to softer approaches, and in the implications for regional and global solidarity between peoples." Intercultural studies is already working for her as an approach to this issue. It can help western researchers to take a broad view that may help them respect traditional knowledge.

"Sustainability itself is an idea that is interpreted in different ways in different places," says Klepp. "Issues like coastal protection will arise in many forms in the near future, and the whole subject means different things to different people" Effective solutions, she thinks, are likely to centre on solidarity between peoples and on innovative technology that respects local practices. Pacific Island identity and solidarity may offer a way through this conundrum,

Prof. Silja Klepp researches the consequences of climate change in Fiji and other small island states.

as may those of people in other threatened areas such as Bangladesh.

For the next phase of this work, Klepp plans a new interdisciplinary approach for the Future Ocean cluster. It will look at relations between human societies and the sea, and at the ways in which our ideas of nature and culture are produced. This will involve recruiting expertise from across Kiel and beyond.

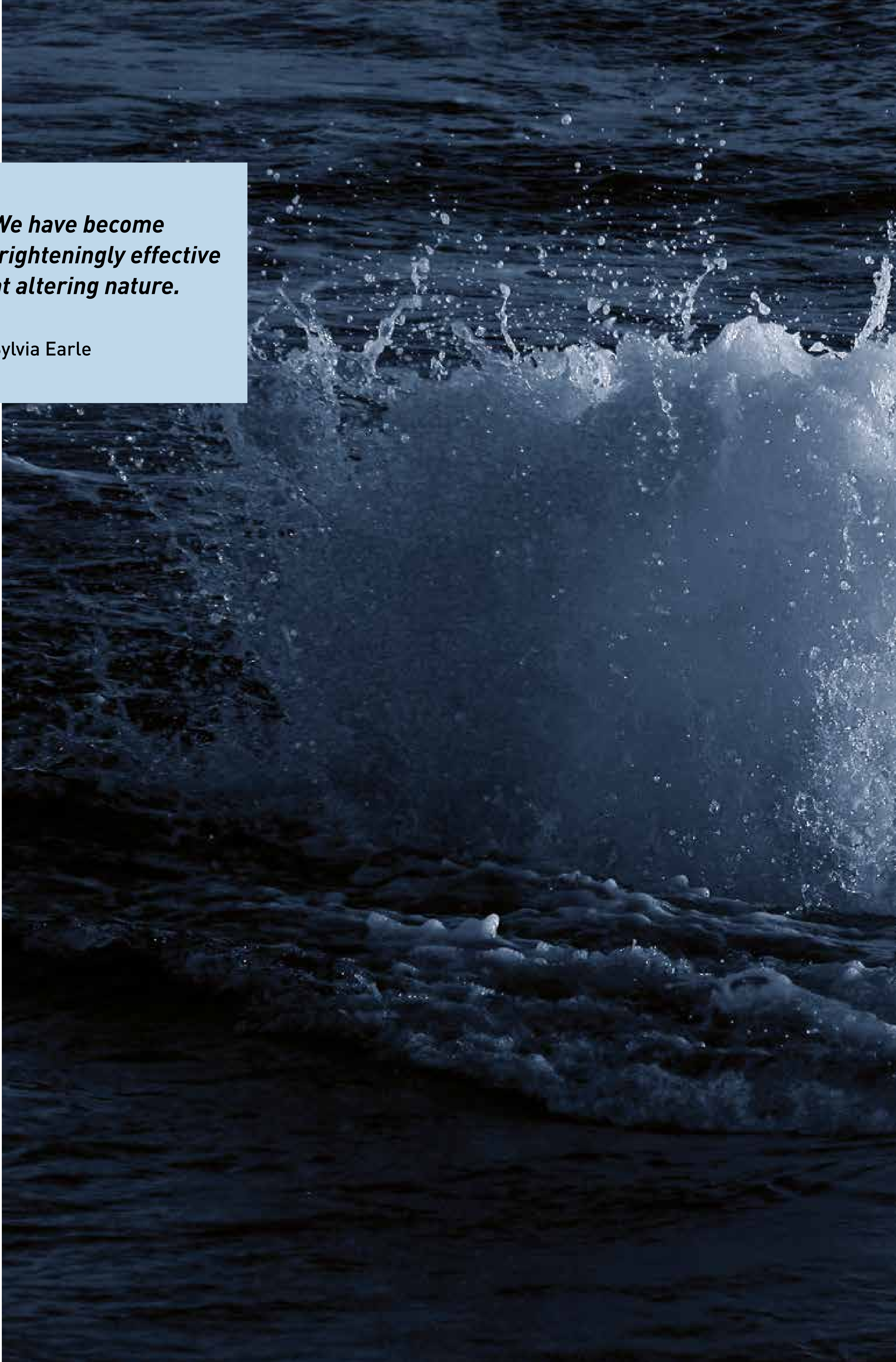
Aletta Mondré agrees that the level of interdisciplinary research at Kiel far exceeds her previous experience. "Usually it is regarded as a success if a biologist talks to a physicist, or if someone from the politics department talks to someone from the law school. Here we mix all these disciplines."

Aletta Mondré is professor of political science at the Kiel University.

Mondré sees marine research in Kiel contributing both to our ideas about the oceans and to the ways in which we interact with them. She thinks that future ocean thinking may be able to avoid replicating past errors. "We have learned from the destruction of tropical forests for timber that it is possible to make mistakes that cannot be repaired. There is now widespread public interest in protecting the oceans, and it is not confined to specialist NGOs."

One symptom of this interest is the existence of the United Nations' ocean-oriented sustainable development goal (SDG) 14. The subject of the SDGs themselves, who frames them and how success is measured, are all fascinating to Mondré. "What gives these international processes their legitimacy and authority?" she asks. "We have no world authority to decide when fishing to feed people takes priority over protecting some rare habitat. Mankind is not going to stop using the oceans. The issue is to see what options are taken away from future generations by choices we make today."

Like Klepp, Mondré is keen on the interdisciplinary focus of the Kiel cluster and has already worked with the group researching deep seafloor resources. She says: "This approach means that I learn about natural science. But natural scientists learn that facts don't speak for themselves. Scientific results need to be translated to reveal what they really mean for people. What does a marine protected area mean for a local community? After all, most political decisions are the result of struggle. A community may prefer different goals from the ones identified by scientists."



We have become frighteningly effective at altering nature.

Sylvia Earle

SUPPORTING SCIENCE

Science Support Facts

260 Members in the Alumni Network

280 Members in Young Scientists Networks*

*at the end of 2017

53% Female

40% International

53 Children's University Lectures*

*2008-2017

>19.000 Tickets Sold

16 Synthesis Reports*

*WOR, Ocean Atlas, Oil Spill Report

>2600 Participants in Citizen Science Projects

78 Newsletters

11 Annual Reports

12 Career Coaching Events for Women

256
Events Organized*
*2007-2017

6
Summer Schools

37
Workshops / Conferences

11
School Events

83
Stakeholder Events

19
International Science Marketing Events

53
Public Exhibition Events

47
Internal Events

Graduate School and Career Support

ISOS and IMAP – tailored support for academic careers and beyond:

Pursuing a career in science is a challenging endeavour. It requires a multitude of skills: subject competence; vision and creativity in developing new research questions; perseverance and determination; writing skills to produce high-impact publications and research proposals; presentation skills to convince colleagues at workshops and conferences; an understanding of how to interact with stakeholders, and possibly the public as a whole – and last but not least, the ability to talk to potential employers.

The Kiel Future Ocean Cluster recognises the importance of developing its scientific talent, and in particular the need for researchers in all fields to start building a professional network. Future Ocean's early career initiatives, the Integrated School of Ocean Sciences (ISOS) for doctoral candidates and the Integrated Marine Postdoc Network (IMAP) for young postdocs, strive to do exactly that: empower early career scientists to develop their skills by providing scientific mentorship and learning opportunities, in a network of peers where young academics can learn from each other and discuss the challenges of career tracks in research and beyond.

ISOS - INSPIRING RESEARCH AND CAREERS

Kiel's unique approach to the integrated ocean sciences means that our masters students and our doctoral and postdoctoral researchers become exceptionally valuable members of the research community and of the ocean community as a whole. Their career development is supported by a huge array of courses and events designed to inform and inspire them on academic topics and the wider implications of their work.

THE ISOS MISSION

The doctoral programme ISOS, Integrated School of Ocean Sciences, focuses on interdisciplinary education outside of curricular courses. It offers supplementary training, a framework of supervision, mentoring and mobility for doctoral candidates. At ISOS, doctoral candidates sharpen their scientific profile and are challenged to think beyond their discipline and to equip themselves for life after a doctorate.

Aside from the intense topic-related collaborations, as well as the intense topic-related collaborations it generates, I have always benefitted from both the Ph.D. and the postdoc networks within The Future Ocean. Most recently, I have enjoyed participating in the wide range of courses offered within the IMAP postdoc network, but also the opportunity to get in touch with postdocs from different disciplines working in the same field.

Mark Schürch, Geographer, ISOS Alumnus and IMAP Member

Mark Schürch researches the effects of climate change and rising sea levels on salt marshes.

Avan Antia, Head of the ISOS doctoral programme, describes it as "an inclusive model of doctoral education that supports three pillars of our community – doctoral candidates from all faculties at Kiel University, professors and supervisors, and the institutions that host the research projects."

The ISOS program is designed to support doctoral candidates and their supervisors alike. It unites candidates from all the natural science disciplines, law, economics, ethics, art and many other subjects. Here, early-stage researchers are challenged to see their research in a wider context that includes complex problem-framing in a multidisciplinary environment. The programme takes a holistic view of research-based education, involving partners from academia, industry, politics and NGOs, and bringing in ad hoc expertise where required. An active alumni network provides input to the programme, especially in supporting career perspectives beyond the doctorate.

Martin Visbeck, speaker of the Future Ocean, says: "Doctoral research is a pillar of scientific innovation. It generates an immense volume of data and scientific papers, and fuels further research. At the same time, it is the first step towards independent research for hundreds of young people who make the transition from student to research scientist. This process generates new knowledge, but it also creates a pool of people who are empowered to seek their professional direction within academia, or in a wide variety of jobs in industry, organisations and society at large. ISOS is a must-have for doctoral candidates and their advisors."

Avan Antia adds: "Kiel offers a world-class research environment that bristles with the excitement of bridging hard-core scientific findings to societal needs, and deploying them in real-life challenges. Our doctoral programme enables early-career researchers to use their personal talents to produce better scientific outputs, and to consider how best to transition into their next stage as a professional. This means going beyond academic excellence to include all-round personal and intellectual growth."

To achieve this, a network of partners from universities and from industry, policy, NGOs and elsewhere give perspectives and context to academic research, in regular "from PhD to.." and "Meet the Expert" seminar series. ISOS creates a banquet of opportunities for doctoral candidates to start their own research projects, gain international exposure, moderate discussions and shape their own programme through their own initiative.

The existence of ISOS allows the Cluster to be better-informed about the doctoral phase of a scientific career, including funding, supervision and institutional support. This helps the Cluster and its institutions as well as the student. In turn, ISOS alumni are spread around the globe. They stay in touch and return to inspire their colleagues.

IMAP - NETWORKING FOR A PROFESSIONAL FUTURE

After success as a doctoral student, the postdoctoral stage of a research career holds fresh challenges.

Future Ocean speaker Martin Visbeck stresses that "The postdoctoral researchers of the Future Ocean are well-trained, highly motivated, and dedicated to the research enterprise. They are a vital part of our work in integrated marine sciences." But he is also aware that most of Germany's postdoctoral researchers hold temporary, project-based positions, and that Germany lacks a well-structured career path for researchers.

THE IMAP MISSION

The mission of the integrated marine postdoc network (IMAP) is to provide researchers working at the postdoctoral level in the marine sciences in Kiel with an inspiring and empowering environment for interdisciplinary research. The aim is to increase the reputation and attractiveness of Kiel as a hub in marine research, nationally and internationally, by

- **maintaining an active network of postdoctoral researchers in marine sciences in Kiel, including alumni,**
- **communicating and addressing the needs of postdoctoral researchers and supporting the career development of young researchers,**
- **helping to establish a performance-based career advancement pathway at Kiel University and nationwide.**

The support of postdoctoral researchers was identified as a strategic goal for the Kiel Cluster of Excellence in 2012. "We set up IMAP, the Integrated Marine Postdoc Network, to make this aim a reality. Now operational for six years, it is a vibrant network of postdoctoral researchers within The Future Ocean." says Gesche Braker, coordinator of the IMAP Network. Many members of the IMAP community have come to Kiel from other marine science institutions around the world, creating an excellent opportunity to facilitate international networking. More than 130 IMAP members work at the Cluster's partner institutions - at Kiel University, the GEOMAR Helmholtz Centre for Ocean Research Kiel, the Kiel Institute for the World Economy and the Leibniz Institute for Mathematics and Science Education.

The Future Ocean has offered postdocs a range of project-based research opportunities lasting between two and five years. As principal investigators for these projects, postdoctoral researchers have a unique opportunity to gain independence and develop their individual research profiles.

IMAP's members work in the full range of subjects encountered in the Future Ocean, from the natural, social and life sciences to computing, economics, law and philosophy. In addition to being a valuable basis for developing all the competences a researcher needs, these positions and the support provided by the network allow postdocs to expand their portfolios into new fields and take on additional tasks in line with the Cluster's overall mission. These might include engagement in politics and dialogue with stakeholders, as well as the management of larger-scale projects and cooperation with industry. These broader challenges call for additional professional skills, and the Cluster provides opportunities to develop them through training, coaching and mentoring.

FOLLOWING UP, KEEPING IN TOUCH

Early career researchers are of special interest to the Cluster's alumni strategy. Their high mobility makes them excellent multipliers for the achievements of marine science in Kiel. At the same time, they gain from the connections provided by Kiel's global networks as they find their way through the jungle of career opportunities available to them around the world.

The Future Ocean's high level of investment in its people has long-lasting effects. A growing number of ISOS and IMAP alumni are continuing their careers at research institutions in Germany and abroad, or hold leadership positions in the non-academic sector, further enhancing the networking which the Cluster makes possible. Many former ISOS and IMAP members stay in touch with marine science in Kiel and support the Cluster as role models for future careers, as external reviewers or as members of conference steering committees.

Gesche Braker summarises: "We appreciate that only some of these young researchers will have a career in Kiel. Many will go on to leading positions in research centres and universities around the world. Others will continue their careers in policy, the ocean industry or related areas. Whatever direction they take, we will regard these talented individuals as Kiel family for life, and as members of the global Future Ocean alumni network."

Top: Dr. Christian Bücker, DEA Group, talks to early career scientists during an ISOS retreat.

Middle: The Alexander von Humboldt Foundation promots research alumni activities at Kiel University.

Bottom: Alumni are excellent multipliers for the achievements of marine science in Kiel.

Kiel's Massive Open Online Course on the Oceans:

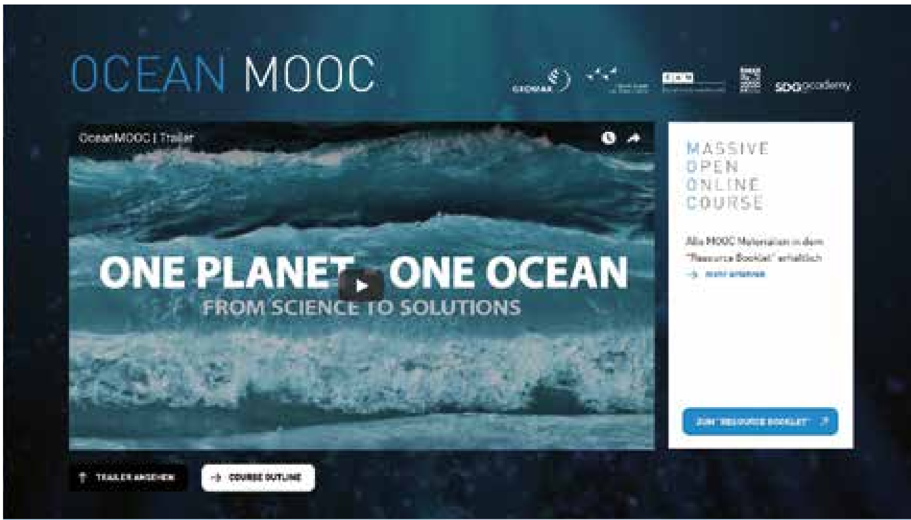
"One Planet – One Ocean: From Science to Solutions"

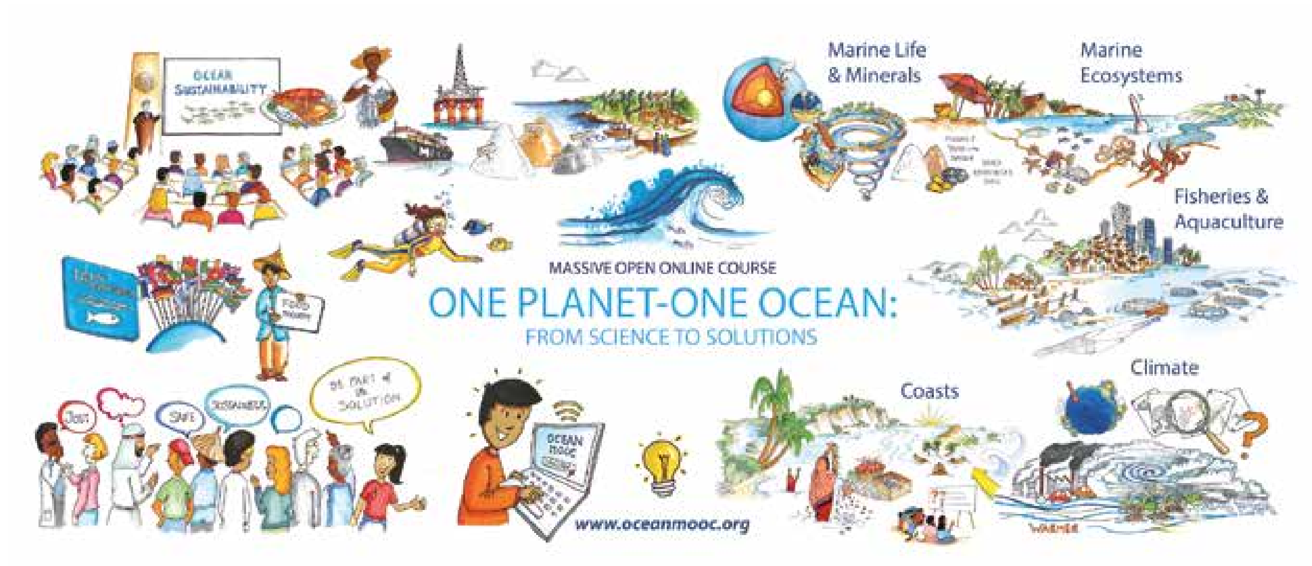
The need for better, more informed, science-based ocean management has been a guiding principle of the Excellence Cluster from its inception. In 2015, the Cluster teamed up with the SDG Academy in New York and the International Ocean Institute (IOI), a long-time partner in ocean literacy based in Malta, to upgrade its education outreach efforts through the production of a Massive Open Online Course (MOOC) "One Planet – One Ocean: From Science to Solutions".

As their name indicates, MOOCs are aimed at a large audience, need just an internet connection to participate, and have "learning" rather than public outreach as their goal. These open-source, mostly free and non-accredited, courses bring scientific knowledge to global citizens, students, practitioners, and anyone interested in upgrading their knowledge. So they present a powerful path for the Future Ocean Cluster to bring its knowledge to a broad community, and interact with external thinking.

The Ocean MOOC included modules on topics such as coasts, marine ecosystems, fisheries and aquaculture, and climate. Each theme was approached in a holistic manner, pairing scientific knowledge with an understanding of human interactions with the ocean and the discussion of options for better stewardship and sustainable management of our blue planet. Cluster scientists and IOI members from all the natural sciences, law, economics and philosophy were involved in the MOOC's production.

Each module included several video lectures, material for self-study, assignments involving online research, and quizzes that were mandatory to those aiming for a course certificate. Gaining new knowledge was one goal, but the true excitement lay in the online forums, where participants discussed the issues among themselves and with the lecturers. Weekly live Q&A sessions with international invited





experts gave personal, direct access to senior scientists. Over 60,000 video views, 4000 discussion threads and more than 6000 forum entries reflected a huge level of active participation. The Ocean MOOC has been broadcast twice, in 2016 and 2017, and reached a total of 6500 registered participants from 62 countries. Despite requiring several hours per week of study, a respectable seven per cent of participants got the Ocean MOOC certificate of achievement.

The idea of the MOOC was suggested to Cluster Speaker Martin Visbeck by the SDG Academy. The Academy wished to make ocean knowledge part of its portfolio of global education for the implementation of the UN Sustainable Development Goals, including SDG 14, "Life Below Water". Partnership with the IOI in production and as a co-funder of the MOOC followed on from the successful knowledge dissemination achieved by the two organisations in their co-production of the World Ocean Review Series. "Interdependencies in the ocean system are complex, and the ocean forms the largest interconnected system on the globe. Our MOOC offers free access to ocean knowledge to a global learner community" says Martin Visbeck, lead author and a Speaker of the Cluster. "Science forms the basis upon which each of us can campaign for the sustainable use and protection of our blue planet."

Avan Antia, the scientific editor of the MOOC, recalls that its original target audience was students at the undergraduate and graduate level. But in fact, many turned out to have completed master's or doctoral degrees, or to be working in ocean-related jobs, for example in ocean management, fisheries, NGOs or ministries. She says: "We were excited to see so many ocean professionals actively engage in the MOOC. They enriched the forum with their case studies and brought context into the discussion." Another key group of participants were teachers, communicators and multipliers, some of whom have gone on to use MOOC materials in their teaching.

The Ocean MOOC remains online (www.oceanmooc.org) as an open-source product even when it is not being broadcast on the learning platform. The resources include a rich collection of lecture videos, reading material, links, assignments and quizzes. Antia says: "We wish to carry the MOOC momentum forward and make dissemination easier, especially in countries without access to expertise in the integrated ocean issues we present. This material is also a valuable resource for independent learners who want a self-paced introduction to ocean issues."

The Cluster experience with this participative format shows that it is a powerful tool for educational outreach. It will be invaluable in disseminating the solutions-oriented research that will emerge from the Cluster's next phase. MOOCs, together with activities such as embedded learning and learner networks, are a very suitable platform for international dialogue on ocean issues and sustainable ocean solutions. They are an exciting new communication path to interact with the interested public that has only just begun to reveal its potential.

The variety of assignments and the amazing amount of additional materials and links are very valuable for learning.

MOOC participant

Citizen Science – a new model for future research

There has always been "citizen science," in which people who are not professional scientists join in the scientific process. It has been especially important in observational sciences such as astronomy, geology, botany and meteorology.

Now citizen science is growing as a novel way to conduct research. The IT revolution has made it simpler for people to join in scientific projects, and there is more awareness of the need for citizen science as connective tissue between researchers and the public. Laypeople, students and school pupils participate in research projects, often by collecting or verifying data. They have the potential to provide a massive workforce for scientists wanting to conduct labour-intensive projects.

There are four levels of cooperation between professional research and laypeople: Cooperation, Collaboration, Co-production and Co-design. While Cooperation allows research projects to access someone's resources, for example computing power on unused desktop PCs. Collaboration means that people support research actively by collecting data for a project designed by scientists. The data is sent to a data hub, and is analysed and published by a professional science team. An example would be a project in which people collect mosquitoes in their neighbourhood and submit pictures of them to a project web page, in order to map the occurrence of different mosquito species.

Citizen Science Co-production projects actively involve the public in the analysis and interpretation of the research data, while in Co-designed projects, laypeople and researchers work together at all levels, including the initial design of the research project as well as data acquisition and analysis.

The most appropriate level of citizen science cooperation depends on the scope of the project and the motivation of everyone involved. In Kiel we are experimenting successfully with a number of citizen science projects, large and small, in order to gain knowledge of what strategies are useful, which project designs may be successful, and what the additional benefit of these interactive projects may be.

SEVERAL PROJECTS STARTED

Four citizen science projects funded by the Future Ocean are currently active (see boxes). They all involve laypeople very fundamentally. Plankton ID uses volunteers to identify species in automatically-taken photographs. Another project, conducted in collaboration with schools in Germany and Chile, looks

COASTWARDS

People like nothing better than a visit to the seaside. Why not combine your fun with some scientific research?

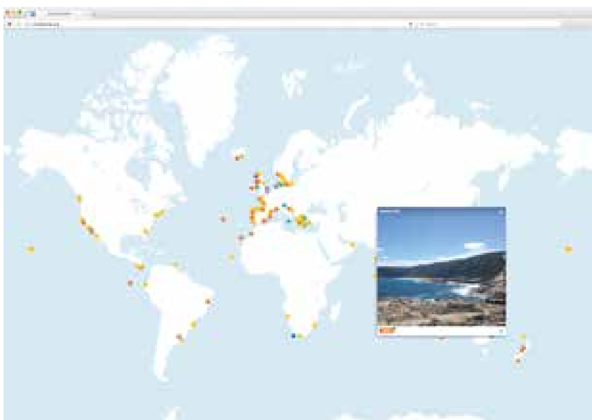
Coastwards is an online platform which makes this positive experience easier. It helps citizen scientists anywhere in the world to gather data for research into sea-level rise.

Participants go to www.coastwards.org and upload images of coasts to a world map. They do this anonymously, and for privacy reasons, the images have to contain no faces. Other citizen scientists then categorise the images, for example into rocky, sandy or icy coast. This data is incorporated in a spatial coastal database which underlies the Dynamic Interactive Vulnerability Assessment (DIVA) modelling framework, run by Kiel's Coastal Risks and Sea-Level Rise Research Group. This framework is used to assess the risk to coastal regions from global sea-level rise.

Research Group leader Athanasios Vafeidis explains that although satellite images of anywhere in the world are simple to get, they do not convey the detail seen in images from ground level.

He says: "Coasts are a highly attractive topic, and images of coasts are readily available around the world. Because it has an extremely low barrier to entry and one of the broadest audiences possible, 'Coastwards' is successful Citizen Science. Social media has played a crucial role in attracting participants, as it has with many Citizen Science projects. The next step is to run social media campaigns to engage new audiences."

Websites: http://www.coastwards.org/
http://climate-adapt.eea.europa.eu/metadata/tools/dynamic-interactive-vulnerability-assessment-model-diva



SCHOOL CHILDREN INVESTIGATE PLASTICS POLLUTION

The "Kieler Forschungswerkstatt" (Kiel Science Factory) runs two citizen science projects dealing with plastics. They are "Plastikpiraten – Das Meer beginnt hier" (Plastic Pirates – the ocean starts here) and "Dem Plastikmüll auf der Spur ("tracing plastic litter").

In these projects pupils collect data at the sea shore in "Tracing Plastic Litter" and along river banks in "Plastikpiraten". They gather plastic bottles, bags and wrapping, larger pieces of plastic, fishing nets and other waste, as well as sediment samples from the shore. These are used to look for smaller plastic pieces under the microscope.

Katrin Knickmeier in Kiel explains: "The projects are aimed strongly at public schools. They bring together pupils and teachers to conduct real science, in order to excite children and engage them in actual research projects. They experience how complicated and time-consuming research is, but also how rewarding it can be to collect and interpret the results.

"In both projects, pupils collect data at the shore and upload it to a project website. The project description, and the cooperation of teachers, guarantee that scientific standards are met and that the data is of high quality. It also ensures that data collected by different people in different locations is comparable. The data is then analysed by project scientists."

In order to simplify and motivate their participation, the project provides explanatory videos, brochures and other material to explain its goals and methods to teachers and children alike. It includes teaching instructions, project suggestions and templates. The material explains the ecological system of the seas, rivers and oceans, ocean currents, and how the ocean is utilised by humans. It also covers the characteristics of plastics and how they get into the oceans, including the long period over which plastic remains in the sea. The children learn that a plastic bag takes over 20 years to decay, while the nylon cords used for fishing nets may last more than 600 years. An empirical side study looks at the influence of these projects on the behaviour of the pupils who take part.

So far, 1642 children have participated in the Project "Plastikpiraten" in 2016/17, and 374 groups analysed and uploaded data to the website. After reporting the data, children will find them plotted onto an online map, making it visible to the public and rewarding for the participants.

Both projects were coordinated by the "Kieler Forschungswerkstatt" in collaboration with Professor Martin Thiel and coworkers from the Universidad Catolica del Norte, Coquimbo, Chile.

Links:
https://www.wissenschaftsjahr.de/2016-17/mitmachen/junge-wissenschaftsinteressierte/plastikpiraten.html
https://www.save-ocean.org/

Riner Kiko from Plankton ID installs the deep sea camera used to take plankton images, which are identified by this citizen science project.

PLANKTON ID

Mastering the deluge of marine image data

The ocean is full of particles, and they come in all sizes. Due to their harmful effects on marine wildlife, recent attention has focused on microplastics. But scientists try to understand the role of every particle in the ocean, from nanometer-sized bacteria to blue whales.

Modern optical instruments allow digital images of marine organisms of many sizes to be gathered in situ. The problem is that this process produces extremely large datasets of millions of images. And the images are useless unless the organisms in them can be identified.

PlanktonID used a hybrid approach, combining machine learning and Citizen Science, to identify plankton organisms from a dataset of over three million images obtained with an Underwater Vision Profiler 5, a specialist device for imaging underwater particles. Rainer Kiko from Kiel says: "The machine learning approach allowed us to narrow down the number of images to be identified to some 200,000 candidates from 11 zooplankton classes, which were subsequently validated on https://planktonid.geomar.de. More than 350 citizen scientists then helped to sort these images, and contributed over two million image validations between January and August 2017."

This project shows that citizen science is a valuable tool for image recognition if internal controls are incorporated to monitor the participants' success. Feedback, especially regarding the users' level of success, is much appreciated and provides the motivation needed to engage citizen scientists. Local activities, such as articles in local newspapers and participation in outreach events, are the most successful approach to engaging new users. The next stage of PlanktonID is to develop flexible assignment strategies to recognize novel or unusual animals in the ocean. We will then be able to analyse even larger image datasets to investigate yet more species.

Kiko adds: "Beyond even that phase, a major goal for ocean optics is to develop a truly integrated image analysis pipeline. This would combine autonomous imaging using oceanographic gliders, image analysis and recognition via machine learning, and category validation and novelty detection by citizen scientists. It will enable us to monitor and understand the role of marine organisms in unprecedented detail, but will also enable everyone to engage in the scientific effort and to experience the beauty and fascination of marine organisms."

Webpage: https://planktonid.geomar.de

at the widespread problem of plastic litter around the coasts. A third asks lay scientists who do Scuba diving to submit photographs of fish, while a fourth requests pictures of the coast to map the occurrence of certain types of landscape feature. Each of these produces unique scientific data and results which would not be possible without the collaboration of people who are not trained, or at least not yet, in scientific research and scientists.

LESSONS LEARNED

In order to make such projects successful, significant challenges to citizen science projects have to be taken into account. These include choosing potential partners, maintaining their motivation, communicating the results, and making all participants feel like part of the scientific community in the chosen research area.

Experience at Kiel, including the cases described here, shows that scientists and funding agencies often underestimate massively the amount of time needed to supervise, teach and enable Citizen Science groups to conduct a project and collect useful data. Feeding back data and results to participants also involves a massive amount of work which is not needed in normal research projects.

Katrin Knickmeier of Future Ocean says: "If the citizen project partner simply submits photographs to a website, software tools exist which make this easy to achieve. The citizen's participation in such a project is easy to implement, but their real involvement in the science is small. By contrast, the amount of work and thought required to produce explanatory documentation and material to permit deep citizen involvement in a big, complicated project is large.

"It is necessary to put the learning barrier low to encourage participation and to keep people motivated in order to receive high-quality data. And if difficult analysis is needed, for example of microplastic, people need to send samples to the lab for cross-checking. If the project works with teachers as multipliers of impact, it is important to support them properly, with pre-arranged booklets, material and work books."

This means that although useful citizen science is rightly supported by society as a whole, its planning and delivery are complex. If it is not conducted with the necessary care, there can be mistakes and frustration on both sides. More basic participation is much easier to achieve, but it involves citizens only as low-level data producers. But for either kind of citizen science, thorough documentation, and permanently updated communication on the project, are crucial for its success. Nevertheless, research projects which involve scientists in supporting the interested public can be a very rewarding activity for both - researchers and citizens.

SCIENCE MEETS SCUBA

Our knowledge of geologically recent events in evolution, such as the emergence of Darwin's finches in the Galapagos and of cichlid fishes in East Africa, has helped us understand how species emerge in a changing world. The citizen science approach is now allowing scientists to work with a unique community, the scuba-diving fraternity, to see the same forces at work in the ocean. The "Pick your Hamlet" project looks at colour changes in hamlets, a group of coral reef fishes from the Caribbean and surrounding ocean areas.

As with many reef fishes, colour patterns play a fundamental role in the ecology and evolution of the hamlets. These patterns are highly variable and not well characterised, and a large-scale survey is beyond the capabilities of a single research group.

Oscar Puebla in Kiel explains the citizen science approach to this problem. "In this project we have engaged recreational scuba divers, contacted through scuba shops and training centres, to photograph hamlets across the wider Caribbean and send us their photographs with information on location, time and depth. We have learned that establishing an international contact network with citizens takes more effort than we expected. But on the positive side, it can be sustained relatively easily once it is established." This initiative is currently establishing the structures needed to approach divers and collect data. It will continue beyond the immediate funding period for the project.

Science communication: Outreach off the beaten track

The Future Ocean Cluster of Excellence and its partners in Kiel are a globally-important centre for interdisciplinary ocean research in the full range of academic disciplines. But the Cluster has always recognised that producing new knowledge is only part of the story. The other equally important part involves communicating that knowledge, getting in dialogue with a non-scientific audience and spreading new findings to promote marine topics.

This approach addresses the classic stakeholders such as NGOs, politicians, industry and decision makers, but even more so the general public, who ultimately fund this science.

The Future Ocean recognises its responsibility to communicate both general knowledge on marine topics, and also new findings from research. It brings its insights to the public in formats that are dialogue-orientated, easy to digest, and understandable to both highly educated and less informed citizens. Children are a particular focus. "If we can't teach our research to our children, we cannot expect the general public to understand what our mission is about" says Friederike Balzereit, outreach manager from the Cluster. Science communication is therefore central to the Future Ocean's thinking and activities.

Balzereit continues: "To address this priority, our science communication activities build on a global record of innovative outreach. The focus is on growing public awareness for scientifically sound solutions to real-world problems." And while the Cluster works with excellent communications specialists, this activity is not delegated exclusively to these experts. It informs the thinking of everyone in Future Ocean, including researchers, technicians and students, who are actively involved in bringing science to the public. Dialogue is the key to the whole communication strategy, which is intended to fill people with enthusiasm about the ocean and to strengthen the interface between science, policy and public to increase engagement. This means that the aim of making science understandable to those beyond the ocean community is critical.

To achieve this, the Cluster has successfully implemented a number of initiatives. Some are traditional outreach options for publicly-funded research, including a project website, a blog and school materials. But the cluster goes far beyond those activities. It has developed original concepts for science exhibitions, a full social media strategy, and a lab for school children and their teachers. It works with partner organisations to improve outreach to their stakeholder groups and in one of its latest endeavours, plans to implement a so-called Ocean Media Lab. Here the latest visualisation techniques will be used to make science education appealing for young as well as adult participants.

ONLINE PRESENCE

The Future Ocean's main presence in cyberspace is still its website. This is the first point of contact for news from Kiel's research institutes and partner organisations. It also links visitors to other activities, such as the ocean-blogs platform and the cluster's social media resources. And the website does not just provide immediate news about research projects. It provides deeper information on topics such as plastics [1] and is a virtual guide to the travelling exhibition "Future Ocean Dialogue"[2] (see box).

Social media have been growing into an important piece of Kiel's online presence. By setting up the oceanblogs platform [3] to host numerous ocean-related blogs in one place, it has become possible to create stronger links between events, expeditions and research projects, while presenting visual content in line with the demands of the younger generation for science communication. This participatory activity is intended to reach new public and cross-disciplinary audiences, and includes popular Twitter and Youtube channels.

APPROACHING PEOPLE

Another important part of the cluster's public communication activity is the Future Ocean Exhibition (see box). A particular strength of the exhibition is that it is brought to exactly the places where people already go for entertainment. These might include the Kiel Week, a large annual sailing fair, the celebration of German Unification, where the exhibition represents the State of Schleswig Holstein, involvement in the European Researchers Night, or

The Future Ocean scientific exhibition is an important part of the Cluster's outreach activities.

FUTURE OCEAN DIALOGUE – SCIENCE ON THE ROAD

Even in the 21st century, effective communication is not all about the internet. The Future Ocean addresses the general public through public lectures and debates as well as online and in print. But outside Kiel, its science exhibitions are a compelling example of a situation where people from areas far from the coast, and who usually have no deep relationship to the ocean, dive into marine science. To make the science even more attractive, the scientific modules, and sometimes the whole exhibition, are themselves a piece of art. The Muthesius University of Fine Arts and Design in Kiel (page 92) accepted the challenge of exploring whether a stunning design can support the communication of knowledge (see pictures) and if so how.

As a consequence the Future Ocean Dialogue, an innovative marine science exhibition that has travelled within Germany and internationally, was a huge success. It contains several modules which each reflect a specific research topic of the Future Ocean Cluster. Scientists are involved in developing explanatory texts as well as in the mechanics of interactive modules.

The exhibition has been shown in numerous places in Germany, including the Paul Loebe Haus, part of the German Parliament in Berlin, and at the world-famous Deutsches Museum in Munich. It has been to Brazil, the Cape Verde islands, Italy, France, the UK and Poland. It has been displayed at partner institutes, the European Parliament, and the German Federal Foreign Office.

The display strives to inform people about topics that are relevant to them personally. These include material on the latest marine science and technology, covering such subjects as "How we know about the ocean, the seafloor and the climate?", but also addressing the question "Why is ocean science important for me?" Here it showcases topics like overfishing, marine litter and sea-level rise, all of which require interdisciplinary answers.

NEVER WALK ALONE – A MEDIA PARTNERSHIP

The dialogue we wish to encourage is easier to accomplish if there is a well-informed global community of journalists with an awareness of the issues. To build up close international relationships with young journalists in fields such as science and economics, the Cluster's Public Outreach Team has begun a cooperation with International Journalists' Programs (IJP, www.ijp.org). The IJP is a non-profit, is financially and politically independent, and exists to develop young journalists.

Our partnership began in June 2012 with a research grant to support a reporter covering the topic of sustainable fisheries. This young journalist accompanied the Kiel topic group on "Living Resources – Fisheries Management," where 18 scientists, including professors, postdocs and PhD students, work together. She said: "Probably no other research association in Germany, if not in all of Europe, has as much expertise on the subject of fisheries as the Cluster in Kiel." Since this initial contact, several young journalists striving for a career in science writing have visited the cluster for internships on marine science topics. New partnerships are planned to support ambitious journalism projects, now with a more transatlantic perspective than in the past.

In another initiative to provide background information on marine science to journalists, the cluster has recently organised a hands-on workshop on current research topics in the Baltic sea. This two-week workshop conducted in spring 2017 and called RADO [4], attracted 40 participants from a range of media including online, radio, television and print. Students of journalism also attended. The program included detailed presentations from leading experts from science and politics, as well as excursions on land and work on a research vessel. The participants undertook practical exercises to help them make well informed judgements and write sound, in-depth articles on marine topics.

In addition, our outreach strategy will benefit from upcoming PhD projects on the Kiel Science Outreach Campus (KiSOC). This important initiative is intended to make outreach as effective as possible. Funded for four years by the Leibniz Association, KiSOC conveys the significance and the attainments of science in a comprehensive and inspirational way, and is located at the Leibniz Institute for Science and Mathematics Education (IPN) in Kiel. One of its research projects asks which mathematical core competences are needed to understand the content of science exhibitions. This topic is highly relevant to the outreach and research teams of Future Ocean, for example to inform their exhibits on sustainable fisheries management.

School children explore the ocean during the Future Ocean Dialogue exhibition in Fortaleza, Brazil.

simply a display in a shopping mall or at a science conference. At all these events, researchers and students answer questions, in order to improve the presentation of knowledge. They have found that people are eager to learn what marine research is all about. This is an exceptional exchange with the public, and it trains scientists to explain their research in simple terms. This concept works extremely well and is part of the reason why the exhibition is the cluster's most-requested outreach tool.

MODERN TECHNOLOGY - THE OCEAN MEDIA LAB

We are leaders in exploiting the potential of new technologies in science and presentation. 3D visualization, the animation of scientific data, and immersive virtual reality are all becoming practical. In Kiel, scientific groups consisting of engineers, geologists, and computer scientists are working on virtual seafloor models, constructed from actual measurement data. They aim to overcome the challenges of deep sea photography and test its application in research.
The new Kiel Ocean Media Lab (OML) will use this data to display virtual reality content in order to make scientific knowledge more accessible to the public, but also to stakeholders and decision makers. This approach will grow collaboration and exchange in ocean science, stressing scientific accuracy as a prerequisite for sustained credibility. The OML will be a science showroom for pupils, students and citizens, where artists and researchers can work on projects in scientific knowledge-building, virtual reality in Earth Sciences education, and data as an aid to interdisciplinary science.
Another example is the development of the Next Generation Interactive Scientific Poster, an award-winning technical innovation, which was developed in collaboration between a group led by Tom Duscher from the Muthesius University and researchers at Kiel University and GEOMAR. Each poster covers particular research topics, using interactive computer techniques to illustrate natural phenomena. Examples include the modelling of mass flows, or the display of large datasets, for example borehole data or data on natural disasters. Gesture-operable multimedia are used to transfer complex scientific content. Their use underlines the approach of the Muthesius University to finding artistic solutions to visual, communication and scenography questions for improved knowledge presentation.
The first digital poster explores dangers in the ocean from submarine slides, and their causes, effects and relevance for coastal communities. It won the German Design Award in 2016 as well as the Red Dot Award for industrial design. The second, on Ocean Observation, was especially designed for exhibition purposes. Both were displayed in many locations in Germany and all over Europe.

THE VISION

In a world where scientific evidence is threatened with being regarded as an inconvenient and avoidable truth, sound science communication is needed to keep the public informed, speak everyone's language and build strong ties between research and society. For this task it uses many channels, including social networks, blogs, podcasts, exhibitions and possibly other means such as the Future Ocean MOOC (see article on page 110)
These activities are already successful in Kiel and the state of Schleswig-Holstein. But in the long run, a worldwide ocean network involving Kiel's scientists, alumni, international partners and stakeholders, including the public and school students, needs to be established in order to make people aware how closely their fate is interlocked with understanding the ocean. The Future Ocean's science communication projects are working towards this goal.

Links

[1] http://www.futureocean.org/ozeanwissen/topics/plastic_en.php

[2] http://www.futureocean.org/dialogue/en/index.php

[3] http://www.oceanblogs.org

[4] http://www.ran-an-die-ostsee.de

From the Kid's University to ocean:lab in Kiel

Marine research is a particularly suitable route for conveying the fascination of the natural sciences to school students. The Future Ocean School programmes are designed to bring real science to the school curriculum, to promote young academics in science, and to gain the interest of talented pupils. To achieve this, the Future Ocean's outreach team has developed several measures to raise awareness at Kiel University and other institutions of the need to invest in new forms of classroom education and extracurricular activities.

Over the past decade, the Future Ocean's school programs have grown from a few initiatives to a major endeavour. One of the biggest is the Kid's University, which celebrated its ten-year anniversary at Kiel University in 2017. Each year it attracts more than 2500 pupils from grades 8 to 12 for lectures on marine topics. Over the years, a wealth of teaching material has been produced for the Kid's University, and this has led to the appearance of the first school book on ocean science, published by Cornelsen Verlag in 2011. In addition, teachers can borrow expedition boxes with materials for hands-on teaching activities, to be incorporated into the school curriculum or for project work at school. These boxes have proved popular and successful over many years.

Over time these activities have grown into close collaboration with many schools in northern Germany. This created a demand for a practical school lab for laboratory experiments including biology with animals, ocean physics, and chemistry, enabling marine science to be taught to pupils at all levels. With the support of Future Ocean and the state of Schleswig-Holstein, the Kieler Forschungswerkstatt, the school lab of Kiel University, was established in 2012 with partners including the Leibniz Institute for Science and Mathematics Education at the University of Kiel. The school lab still covers marine science, but also offers courses in Life Sciences, Engineering, Energy, Geoscience and even the Humanities, making it a remarkable success story for the Future Ocean.

School children conduct supervised experiments in the Ocean Lab of Kiel Science Factory. They experience how organisms react to their environment.

Lars the little polar bear is an 360 degree media dome animation to teach young children the consequences of global change.

Children listen to Kid´s University talks in a lecture theatre of Kiel University.


will nach Hause

Stakeholder dialogue: The road to transdisciplinary research

Germany has a shorter coastline than many European countries, but is one of the world's biggest players in marine research. Its research vessels operate within its own territorial waters, in the Atlantic and Pacific Oceans, and even into the Arctic and Antarctic seas.

How can we justify this expensive effort? It is needed because the oceans are an integral part of the solution to mankind's grand challenges – food, water, habitats, energy, and even peace on planet Earth.

The Future Ocean carries out cutting-edge research which helps us devise solutions for a better future, for the ocean and for the Earth as a whole. But finding such solutions is difficult. It involves scientific knowledge as well as an awareness of the ways in which new findings are used in society, possibly through changes in governance, technical change, or commercial innovation.

To tie all of this together, and to develop recommendations, management plans, governance structures and new techniques, a process needs to be established which allows stakeholders to share their ideas, discuss challenges, and come up with solutions or research plans leading to them. We call this overarching dialogue between many societal groups a "transdisciplinary" activity. Leading experts on trasdisciplinarity say that "Collaboration provides a type of 'reality check' for research processes and outcomes. What we see emerging then is the idea that collaboration with stakeholders and the broader community is an important characteristic of transdisciplinary research practices." [1]

The theory of transdisciplinarity has been discussed widely. We now appreciate that this kind of dialogue is difficult to establish. It requires networking, scoping meetings, discussion, feedback, and then further scoping to identify problems, plan actions and find solutions. The Future Ocean has been experimenting with a number of formats to get this process started. These have been very successful in themselves, but have not yet become part of an integrated framework for generating viable solutions. Shaping such networks is an important part of the challenge we face in transdisciplinarity.

Wiebke Müller-Lupp, knowledge transfer coordinator at Future Ocean, explains that transdisciplinary research is far more difficult than traditional technology transfer from science to industry. "Before you can do transdisciplinary research," she says, "you need to start a dialogue with external stakeholders about their visions and suggestions for solutions. Otherwise you risk trying to start a dialogue that is of no value to the partner and yourself."

Federal President Joachim Gauck (left) visits GEOMAR in 2014. Kiel is well known in Germany and beyond for its expertise in Marine Science.

The Kiel Marketplace brings together decision makers, industry and researchers to discuss hot topics of mutual interest.

ACTIVITIES FOR SOLUTIONS

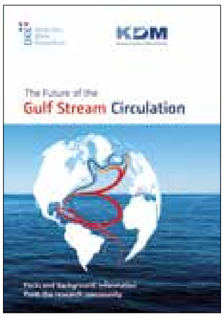
One of the Cluster's oldest and most successful dialogue projects is the Kiel Marketplace. The Marketplace is a forum where researchers and stakeholders from NGOs, industry and politics meet to discuss the latest scientific research on current topics. This series of meetings is organised by Future Ocean and the Martime Cluster Norddeutschland, an association of more than 230 companies and research institutes from the maritime sector in Northern Germany. 17 Kiel Marketplaces have been held since 2008, attracting representatives from industry and NGOs, but also the state ministries in Kiel. "The strength of the Kiel Marketplace is that it is designed around business needs and interests, although it now brings in policy makers and other stakeholders as well." says Müller-Lupp. Many discussions that started there have led to new ideas, research projects and sometimes products or recommendations in the real world.

The Maritime Technology Platform, MaTeP, has been established more recently as a follow-up activity which builds on the success of Kiel Marketplace. It exists to support joint projects between Kiel scientists, and stakeholders from industry and the public sector. MaTeP provides start-up support for pilot projects, which gain from the Cluster's application-orientated expertise. Past activities have ranged from engineering projects on the detection of toxic chemicals released by dumped ammunition to the development of new technology for shrimp aquaculture, or a political science study of the reasons for citizen reactions to local energy development. Some projects have involved collaboration between larger companies (for example RWE-DEA), small companies, and even state authorities such as the federal ministry of the interior. Knowledge exchange with political decision makers is another priority. The Cluster's World Ocean Review publication (see Box on page 124) has been presented to elected representatives in the European Parliament as well as to the German parliament in Berlin. The Review is an invaluable catalyst for discussion with stakeholders, especially those with an interest in politics and governance.

Vast and inaccessible, the oceans are difficult to comprehend and are rarely at the centre of our attention. But access to precise and sound scientific information is essential for anyone concerned with the marine environment. The Future Ocean addresses this demand through its own publications and by major contributions to policy advice. They offer easily digestible background information on marine issues to stakeholders, journalists, decision makers, teachers or simply interested parties.

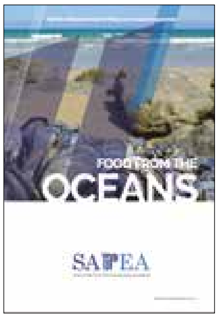
THE WORLD OCEAN REVIEW highlights specific aspects of marine science in detail, including resources, pollution, coastal change, sustainability and others. It is intended to boost awareness of the oceans, and presents a unique compilation on their condition. The World Ocean Review is published by the non-profit foundation maribus, together with its partners Mare Verlag, the International Ocean Institute, the Future Ocean Cluster of Excellence, and the German Marine Research Consortium for the last edition on coasts. By the end of 2017 more than 300,000 copies had been distributed free of charge.
http://www.worldoceanreview.com

THE OCEAN ATLAS is part of a series by the Heinrich Böll Foundation in Germany. The Atlas, published together with the Cluster of Excellence "The Future Ocean", focusses on well-developed graphical presentations of statistics and numbers on the state of the ocean. It was published in early 2017 and within the first year, over 20,000 copies had been distributed.
https://meeresatlas.org



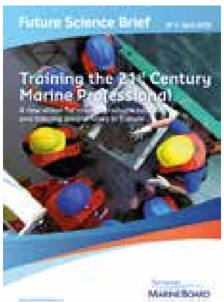
DKK-BROCHURE:
THE FUTURE OF THE GULF STREAM CIRCULATION

There has been a lot of speculation about the Gulf Stream, but what kind of scientific evidence exists? Nine experts, among them Cluster Members Mojib Latif, Dirk Nürnberg and Martin Visbeck, summarize the evidence in this brochure, published by the Deutsches Klima-Konsortium (DKK) and the German Marine Research Consortium (KDM). The publication is available in German and English.
Download:
www.deutsches-klima-konsortium.de/en/climate-topics/climate-facts/gulf-stream-circulation.html



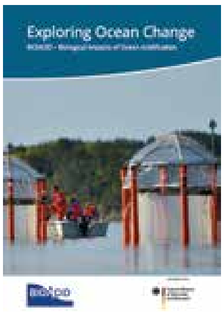
"FOOD FROM THE OCEANS" PUBLISHED BY THE EUROPEAN COMMISSION

"Food from the Oceans - How can more food and biomass be obtained from the oceans in a way that does not deprive future generations of their benefits?" is a comprehensive scientific opinion written by the High Level Group of the Commission's Scientific Advice Mechanism (SAM) at the request of Karmenu Vella, Commissioner for Environment, Maritime Affairs and Fisheries. The reports intends to inform maritime, fisheries and policy development groups and will contribute to the further development of the Common Fisheries Policy's science advice system. Rainer Froese from GEOMAR and Martin Quaas from Kiel University are among the 72 experts who contributed to the report.
Further Information:
www.sapea.info/wp-content/uploads/FFOFINALREPORT.pdf



"TRAINING THE 21ST CENTURY MARINE PROFESSIONAL" FUTURE SCIENCE BRIEF OF THE EUROPEAN MARINE BOARD

A new publication that examines the European landscape for the training of marine graduates has emerged from a Working Group of the European Marine Board, a think tank in marine science policy. Whereas the emerging "blue economy" requires highly skilled graduates from marine and maritime programmes, training across sectors (academic, applied sectors and industry) presents a real challenge. The brief was produced in consultation with 12 experts from across Europe, among them Avan Antia, Head of ISOS, the Cluster´s Integrated School of Ocean Sciences. It presents a vision for future multi-disciplinary training that will equip graduates to address complex marine issues that cut across scientific, environmental and social systems.
www.marineboard.eu/training-21st-century-marine-professional



BIOACID BROCHURE ON THE OUTCOMES OF EIGHT YEARS OF RESEARCH ON OCEAN ACIDIFICATION

In November 2017 BIOACID, one of the largest national research programmes on ocean acidification, reached its conclusion after eight years of scientific activity. Experiments and analyses carried out by more than 250 scientists, among them many members of the Future Ocean, clearly indicate that ocean acidification and warming, along with other environmental stressors, impair life in the ocean and compromise important ecosystem services it provides to humankind. The Federal Ministry of Education and Research (BMBF) supported the project that was coordinated by Ulf Riebesell of GEOMAR. The report summarises major outcomes for policymakers and the public.
www.oceanacidification.de/wp-content/uploads/2017/10/BIOACID_brochure_e_web.pdf

Panelists from industry, politics, NGOs, and research during a public topical discussion event organized by the Future Ocean. Such events on pressing topics improve the communication between marine research and its stakeholders.

The Cluster is active, too, in European and global ocean policy. It helped to identify experts for the implementation of the EU's Marine Strategy Framework Directive (MSRL), which encourages EU member states to improve the condition of their water territory by 2020. The Cluster became the contact for relevant experts and for the organization of MRSL stakeholder workshops. In addition, it has been at the centre of Fisheries Discussions arising from the reform of EU fisheries policy. Together with the Humboldt-Viadrina Governance-Platform [2], Kiel researchers are running debates on marine food security using the novel "Trialoge" format during 2017/18. Finally, the Cluster has worked with the Dräger Foundation and its partner institute, the Earth Institute of Columbia University, New York, to run the Dräger Conference series on the sustainable use and protection of the oceans [3]. This conference series tackled the key question of how the oceans can be researched and how their resources can be utilised for economic growth without damaging exploitation. These discussions included many stakeholder groups in a comprehensive way and were intended to identify practical solutions for better ocean governance.

TYING IT ALL TOGETHER

So where are we heading with these measures, and how can we transfer them into transdisciplinary research?

To implement transdisciplinary work streams, Kiel Marine Science plans to establish an Ocean Solution Centre in the near future. This central facility will engage the wide array of academic backgrounds represented in Kiel, and will support the development of methods and tools to facilitate transdisciplinary research activity. Müller-Lupp says that involvement in stakeholder dialogue and co-design increases the confidence of non-academic stakeholders in the results of research. As she sees it, small meetings and face-to-face contact are more important in building trust than major conferences. She stresses too that academics need to learn the right language for a good discussion wth external stakeholders. "Researchers like to suggest solutions on the basis of their findings, but they sometimes do not appreciate the complex world that business or policy operates in. So they need to think carefully in advance about, say, how they plan to speak to an audience from the fisheries industry."

A fresh example is the Cluster's role in the establishment of a new oceanographic research centre in Cape Verde. There, the Cluster is looking not only at the nation's research needs, but also at the requirements of Cape Verdean society and industry. There have been discussions, says Müller-Lupp, with ministries involved in the economy, energy and the environment, and the Cluster has facilitated an innovative programme for collecting and reusing ocean rubbish around the islands.

The stakeholder involvement of Kiel's Marine Science will get steadily deeper over time. We aim to build on our success in stakeholder dialogue to create genuine research co-design in a transdisciplinary way.

References:

[1] Wickson, F., Carew, A. L. and Russell, A. W. (2006). Transdisciplinary research: characteristics, quandaries and quality. Futures, 38 (9), 1046-1059.

[2] http://www.governance-platform.org/en/governanceprojects/fiti/

[3] http://www.futureocean.org/en/cluster/veroeffentlichungen/print/draeger_brochure.php

[4] http:/worldoceanreview.com

[5] http://meeresatlas.org/en

Internationalisation of research: Is it worth the investment?

Research is a global activity, and the internationalisation of research is an emerging priority for universities and scientific institutions in Germany. Internationalisation is essential if Germany is to recruit the brightest minds and the best ideas on the global science market, and to raise the profile of its universities and research centres.

Excellent universities everywhere use international cooperation and networks to gain an advantage in global competition. Intensive exchange, and the creation of research consortia with renowned partner universities, are strategic elements of internationalisation.

The Plan of Action from the BMBF, Germany's Federal Ministry for Education and Research, emphasises the fact that international mobility and exchange promote excellence in research and innovation. The BMBF sees a national advantage in cooperation, especially from the broad impact which often accompanies the bilateral promotion of cutting-edge research.

Much of the world's new knowledge is generated outside Germany, so it is important for Germany to attract top researchers. But Germany also has a prominent position in science, research and development, in Europe and across the world, giving it an advantage in the hunt for talent.

Future Ocean is addressing these challenges by setting up an internationalisation strategy, which is mainly based on four distinct activities: institutional partnerships; support for research mobility; an active marketing initiative for Kiel as an excellent research location at conferences and workshops and proactively maintaining contact with former employees and visitors through an alumni network.

INSTITUTIONAL PARTNERSHIPS

Kiel's ocean research involves three forms of international collaboration through institutional partnerships. The most important partners are major North American universities, Columbia University in the US and Dalhousie University in Canada. Their partnerships with Kiel work at all levels, from collaboration between PhD students to senior scientists proposing and running substantial research projects cooperatively.

Peter Schlosser, professor of Earth and environmental engineering at the Columbia University Earth Institute, says: "We have collaborated with Future Ocean in Kiel on our conference series on Sustainable Oceans, and to explore future directions in research and education in sustainable development. We are exploring long-term collaboration in the Earth sciences, resource economics and other fields. We expect that this growing collaboration will be beneficial to our institutions and to the broader Earth science and sustainable development communities."

A slightly different type of joint working is seen in Kiel's cooperation with Ocean University of China and Zhejiang University in Hangzhou, China: In 2011, the Center for Sino-German Cooperation in Marine Sciences (SGMS) was founded jointly by the Ocean University of China (OUC) in Qingdao, Kiel University (CAU) and other partners. The SGMS strives to expand cooperation between both countries in the areas of higher education, research and development. Main activities of the SGMS include summer schools and symposia.

Kiel also collaborates closely with the marine science excellence cluster LabexMer in Brest, France, which includes the research institute Ifremer and the Université de Bretagne Occidentale and the University of Bergen in Norway, including the Bjerknes Center for Climate Research.

Kiel's work with these leading institutions involves special partnerships and programmes as well as collaborative working on specific projects. Like Kiel, the centres at Brest and Bergen are home to social sciences and arts researchers working on the oceans.

A third type of cooperation is exemplified by Kiel's work with its colleagues at the Instituto Nacionale de Desenvolvimento das Pescas (INDP) in Cape Verde. Kiel marine scientists are involved in joint learning and capacity-building in marine science and related areas with their Cape Verde colleagues. Dr Oscar Melicio, former director of INDP, says "The INDP and Kiel Marine

Top: Research in Germany and the Future Ocean join forces to represent German research on international conferences.

Middle: Zheijiang University in Hangzhou, China, and Kiel University sign an agreement on cooperation in marine science.

Bottom: Kiel Marine research presents its publications and funding opportunities at selected key conferences in Europe and the USA.

The Future Ocean invited foreign students for a summer school on coastal development in Schleswig Holstein.
Left Prof. Karl Stattegger from Institute of Geosciences at Kiel University.

Sciences have established a future-orientated research and training program that has been active for several years, for example on Climate-Biogeochemistry Interactions in the Tropical Ocean, as well as the BMBF-funded Surface Ocean Processes in the Anthropocene Project (SOPRAN). We look forward to broadening this cooperation."

Kiel marine scientists are also helping to build research capacity in South-East Asia. The Future Ocean Cluster is home to one of a dozen UNESCO chairs in Germany, in the field of integrated marine science. It plans to nominate researchers to the chair for two years at a time who are involved in capacity building measures and would find it valuable as a door-opener in developing nations. The chair is currently held by sedimentologist Karl Stattegger.

The Kiel Ocean Cluster is keen to discuss potential partnerships at any level of cooperation with research institutions in any location. Like Kiel's own research, such joint working can be in the social and human sciences, for example law or economics, as well as the natural and life sciences.

TRAVEL AND MOBILITY

The Future Ocean supports science mobility by offering travel grants to Cluster members for individual research collaboration and to attend conferences. This measure also enables members to attend conferences beyond their core expertise, offering them a glimpse into other research disciplines, helping them decide whether closer involvement might enhance their own research. The Cluster also organises and finances joint conferences and workshops with international partners to create opportunities for international collaboration for our scientists. This grows career networks and employment opportunities for our researchers , but also for our partners. And it helps generate future cooperation, which is strongly dependent upon personal contact and familiarity.

SCIENCE MARKETING

Kiel is not the most familiar point on the map of the world. But the opportunities Kiel affords are many, especially in the marine sciences. The Future Ocean actively promotes its marine research, open positions, funding opportunities, summer schools and workshops, as well as open calls to co-host research proposals at international conferences, exhibitions and workshops. For this purpose it teams up with federal initiatives like Research in Germany, German funding agencies like the DAAD (the German academic exchange network), DFG (Deutsche Forschungsgemeinschaft), AvH (the

Future Ocean Speaker Prof. Martin Visbeck (left) meets
early career scientists during a symposium in Kiel.

Alexander von Humboldt Foundation) and others by sharing conference booths and hosting events together. This strategy effectively offers full support and guidance to scientists interested in joining the network and conducting research in Kiel. Questions on careers in Germany, host institutions and funding can be addressed and individual solutions for researchers at various career levels can be discussed with the potential host – Kiel Marine Sciences – and German funding organizations. This collaboration on a national level, within an international context, has been widely recognized within the science community and has since been copied by other nations as well.

ALUMNI ADVANTAGE

Since 2013 the cluster has been developing a research alumni network, and has organized workshops and conferences with alumni participation. The goal of this network is to engage former co-workers and friends who know the research environment in Kiel well and are happy to spread the word about the advantages and opportunities. Within that context Future Ocean plans to establish a network of research alumni ambassadors to act as multipliers of our effort and as advisers on potential areas of collaboration.

The mobile nature of today's academic life means that many top ocean researchers spend a part of their career in Kiel. In fact the cluster's network of postdoctoral researchers (IMAP) employed in Kiel has about 40% non-German members. The university values them as future international allies. There are now plans for an Ocean Young Leaders Forum, co-organized between Kiel, Columbia University, New York and the Dalhousie University, Nova Scotia, Canada, which would articulate the energy of early-career scientists.

Dr Wendy Watson-Wright, CEO of the Ocean Frontier Institute at Dalhousie University, is keen on this aspect of joint working with Kiel. She adds: "Dalhousie has collaborated with Future Ocean through joint workshops on research and education in integrated marine sciences, through a joint expedition headed by Ralph Schneider of Future Ocean with Markus Kienast and Stef Mellon from Dalhousie in 2015, and through the joint Helmholtz/Dalhousie graduate research schools in ocean science. Nurturing and supporting the present and future alumni community who will carry our message to a broad audience within academia and beyond is an integral part of this strategy of collaboration." So it seems as if the answer is "yes!". Internationalisation is worth the investment!

Data management: Making Ocean Data FAIR for all users

The data center on *RV SONNE*. All shipboard data is processed here and prepared to be transferred to on-shore repositories after each cruise.

GETTING A HANDLE ON MARINE RESEARCH DATA

Big science produces a lot of data, and the Future Ocean Cluster is no exception. Its people make use of research vessels, marine vehicles, sensors, laboratory instruments and massive computational infrastructure. Between them, these assets generate many terabytes of data on every aspect of the oceans, from their weather to their chemical composition and temperature, and the life they contain.

But the unique character of the marine sciences in Kiel means that even this is not the full story. The Cluster is now producing data on social, human and cultural aspects of the ocean such as arts, poetry and narratives, including material on the people who live near the sea and the uses they make of it.

We must keep this data as a record of the past that informs present-day research, and as proof that we have conducted sound and reproducible science.

This demand for sophisticated data management grows out of changing requirements for science, and especially for openness in the scientific process. Funding organisations and other sponsors of research now expect data created in the course of publicly-funded projects to be accessible through data archives in a reproducible, comprehensive and public way. This is a big change for the current generation of researchers.

At Kiel, this challenge is being addressed by the implementation of a structured Data Management Plan. Its approach follows the FAIR concept, which is to make data Findable, Accessible, Interoperable and Reusable as soon as possible. The aim is to guarantee that anyone wishing to interpret and create knowledge and information from Kiel data can do so. The plan contains incentives which will motivate young researchers to be serious creators and providers of properly-organised data.

It is critical that all data repositories not only store data files, but also describe them systematically. This initiative involves capturing data in a systematic way as it is created or measured, and placing it into a new and innovative data system which encompasses the acquisition, curation and use of these vast flows of research data in data pipelines. Where have they been gathered? Who recorded them? How was this data collected? When? What instrument was used to gather these numbers, and how was it calibrated? This information, data about data, is called metadata. It is essential if data is to be reused, or if different datasets are to be compared.

In the Internet era, the possibilities for disseminating data are endless. But sound, transparent science needs a single point of "truth and trust," so that marine research data is used in a documented manner in line with established policies, in the knowledge that it will remain available after the lifetime of any individual research project. This development goes beyond today's practice of allocating money for data management to a specific project. We are now creating a single structure which will make our data useful indefinitely for the whole research community and its stakeholders.

Dirk Fleischer from Kiel Marine Sciences recognises that "topics ranging from the natural sciences to environmental

Ship tracks, sampling locations and data are publicly accessible through a data portal and a Google Earth interface.

ethics, the social sciences, law, economics and the political sciences require different data strategies." Several side projects have been launched to address these issues on a joint basis, involving the Kiel university library and computer centre alongside research groups across the University and at the GEOMAR Helmholtz Centre for Ocean Research Kiel.

PEOPLE POWER

This ambition calls for the establishment of a substantial data infrastructure. A core data management team is carrying out this task for the marine sciences in Kiel, and exists on a permanent basis.

To set standards, the team has implemented guidelines which inform the data policies of all Cluster projects. It has also established a platform for data management projects in the marine sciences, and is the point of contact for data management services to individual research projects. In addition, the team helps Kiel Marine Science to work with other data resources. "We support Kiel scientists in archiving their publications and data at the Pangaea world data centre for the Earth sciences, as well as in our own institutional publication repositories, OceanRep and Kielprints." says Carsten Schirnick from the Kiel Data Management Team.

Recent developments include a dedicated media server for images and video data, to store the large volumes of content generated by remotely operated and autonomous vehicles. Biigle, a tool for image and video annotation, has been added to this server and allows researchers to digitally annotate and store pictures and videos from underwater camera systems.

Another benefit of structured data sets is the ability to connect applications to the data repository. As a result, it is now possible to display Kiel's ship expedition data through interfaces such as Google Earth. This is valuable for scientists, but also opens up new possibilities for the public exhibition of complex data. For example, a slider display can be used to show how seawater salinity and temperature have varied over time in some regions of the ocean.

Fleischer stresses the need to educate students as well as staff in the importance of data, through the curriculum and in other ways. "We believe it is possible to create a data environment in the near future which can collect all data generated at a research site in a structured way. To teach the next generation of scientists the value of research data planning, we need to add some twists to our teaching. We could produce research-ready data sets from annually-repeated practical courses, teaching students the value of reused data. That will involve considering students not only as consumers of teaching, but also as being actively involved in research. Their course research could lead to small publications which are only possible if research data has been properly stored and documented. That will demonstrate the benefits of structured work with research data."

At heart, the data management project is about people, not bits and bytes. As database pioneer Jim Gray put it: "May all your problems be technical, we can deal with them. It's the social problems which are the real hard ones." This message is well-understood in Kiel.

Anyone who believes in indefinite growth on a physically finite planet is either mad, or an economist.

Sir David Attenborough

APPENDIX

Future Ocean in Numbers

When they were first established in 2006, the idea of using Excellence Clusters to help universities focus on particular scientific areas and develop new interdisciplinary disciplines was new to the German science landscape. Very few administrative controls were applied to the clusters, and the recipients of Excellence Cluster funds were given a lot of freedom in the way they spent the money. Little was known about how this initiative might develop.

Now, more than 10 years later, this report offers a brief look at the development of one of these clusters, The Future Ocean. Here we present statistics to illustrate its growth, and underpin the report with some numbers.

The cluster's overall funding per year has varied between €4.4 million and € 7.4 million, with an average of €5.5 million excluding overheads. Except in the first year, this money has mainly been spent on personnel (75%) and equipment (15%; see figure 1). In the first phase (2006-2011), most of the funding was allocated to the cluster's 13 newly-established research groups. In the later stage (2012-2018), the funds have mainly been allocated to individual research projects (see figure 2). A total of 18 internal and external proposal calls were issued (figure 3), closely tailored to the research topics of the Future Ocean. The evaluation process was very competitive, and only about 30% of all submitted proposals were approved.

On average, the cluster has supported about 100-120 positions at any one time. While women were underrepresented in several areas at the start, the cluster strived to create a research environment that would be attractive for female researchers. Consequently the proportion of women in research positions was raised throughout its lifetime, and especially towards the end of the project (figure 4).

YEAR	BUDGET/€
2007	7400000 €
2008	5000000 €
2009	5850000 €
2010	5630000 €
2011	4410000 €
2012	4969500 €
2013	4430000 €
2014	6600000 €
2015	5100000 €
2016	5750000 €
2017	5342000 €

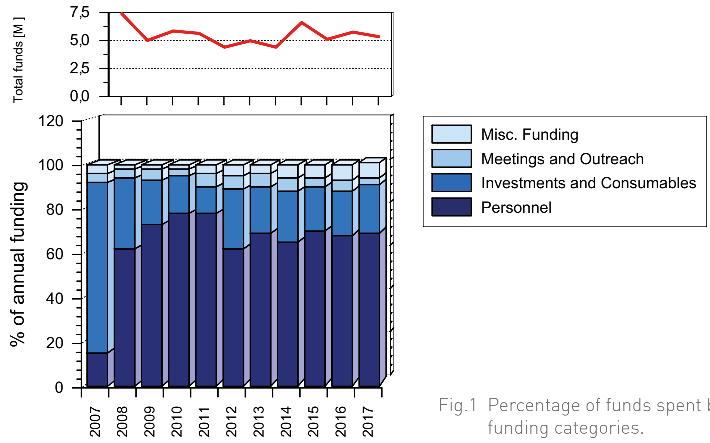


Fig.1 Percentage of funds spent by funding categories.

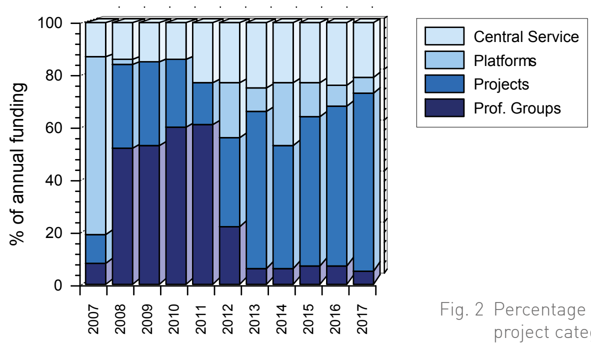


Fig. 2 Percentage of funds spent by project categories.

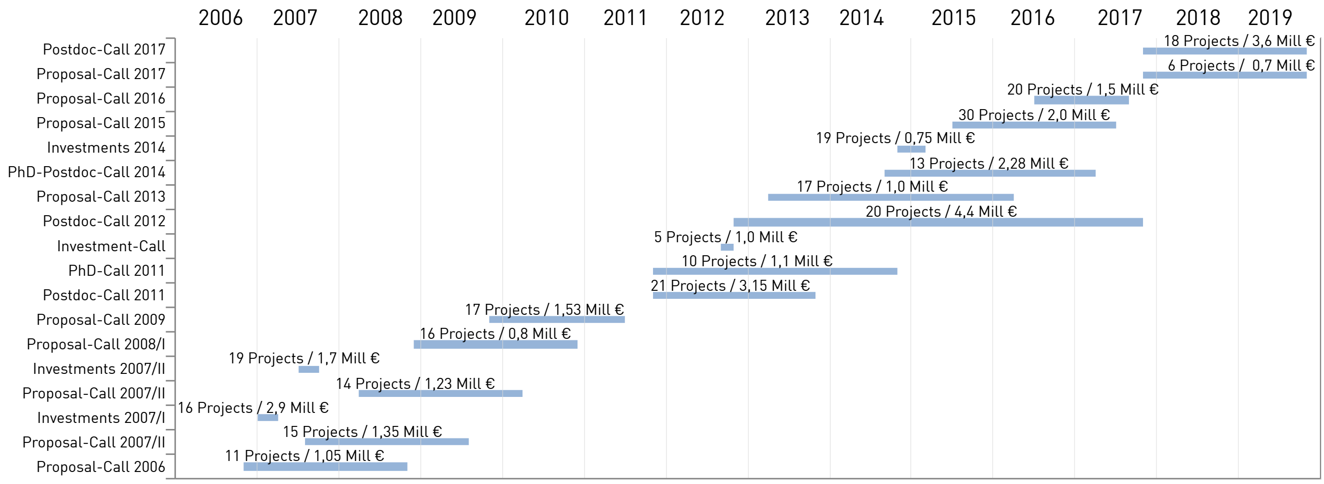


Fig. 3 Timing and volume of advertised cluster project rounds.

One of the cluster's most important goals was to establish support for early- and mid-career scientists (see page 106). For this reason, the ISOS PhD Network was established in 2006, followed by the postdoc network IMAP in 2012. These networks have become central hubs for our career support activities, and involve growing numbers of active participants (figure 5). Unusually for German universities, ISOS and IMAP also maintain a lively alumni network, which organises regular meetings and get-togethers for Future Ocean alumni at conferences and elsewhere.

Science today is measured in one currency – publications. We could publish extensive statistics on the numbers and relevance of our publications in several fields of research. But instead, figure 6 simply shows the publication record over the lifetime of the Future Ocean. The cluster's publications started at a modest level, with the establishment of its first interdisciplinary research groups. After 4-5 years, with the conclusion of the first phase, the cluster produced about 500 publications per year. 2013 saw "only" 400 publications. This could be attributed to the beginning of the new cluster phase in 2012 and the adjustment to a new, project-focused, funding strategy for the Future Ocean. However, the overall record of 5400 publications within 11 years, nearly 500 per year, is a definite success story for a group of this size.

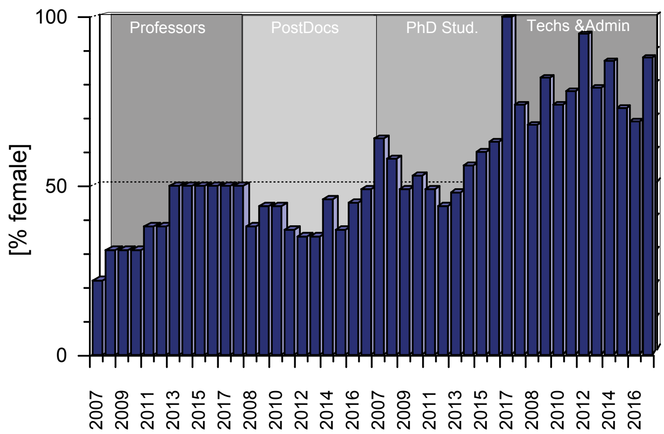


Fig. 4 Percentage of women in different employment status groups over the course of the Future Ocean project. It is obvious, that the Cluster's effort to establish equal opportunity conditions to it's employees is successful.

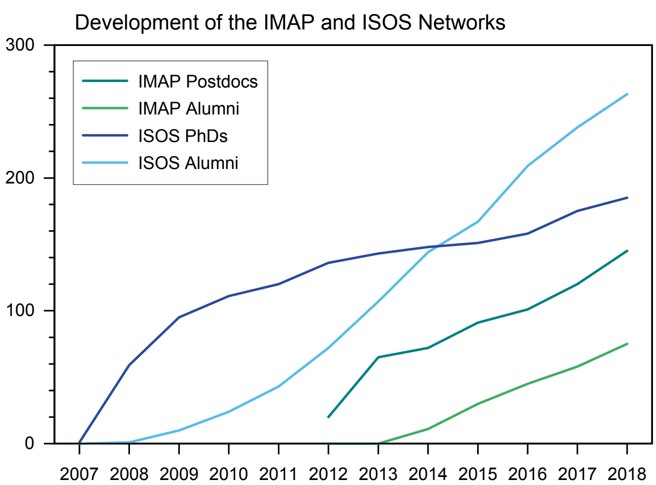


Fig. 5 The number of members and alumni registered in the Future Ocean's PhD Network ISOS, established in 2006, and the postdoc network IMAP, established in 2012, is still rising.

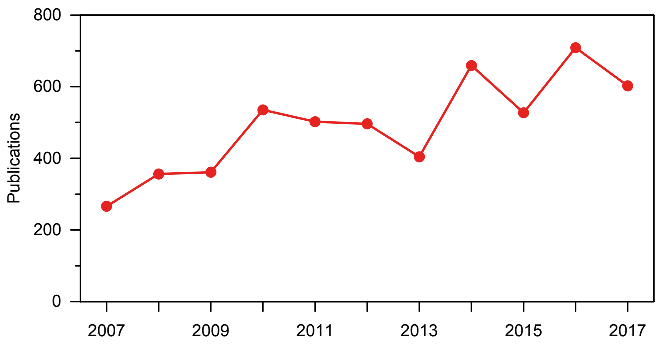


Fig. 6 Number of publications from the cluster per year. In total more than 5400 publications were published by the Future Ocean.

Future Ocean Family

Ebrahim Mama Abda
Eric Achterberg
Rainer Adelung
Josefin Ahlkrona
Derya Akkaynak
Nadine Albrecht
Ute Alketib
Andrea Anasetti
Nils Andersen
Avan N. Antia
Sonja Arend
Damian L. Arévalo-Martínez
Oliver Auge
Jin Ba
Christian Baatz
Lennart Bach
Ninja Backasch
Miguel Baltazar-Soares
Friederike Balzereit
Hermann Bange
Nasser Bani Hassan
Joanna Barcelos e Ramos
Andrea Barco
Johanna Barnbeck
Juliane Barth
Katja Barth
Michael Bartz
Wiebke Basse
Thomas Bauer
Thorsten Bauersachs
Martina Baum
Till Bayer
Aaron Beck
Meike Becker
Jan Behrmann*
Roberto Benavides
Wolfgang Bensch
Christian Berg
Nina Bergmann
Christian Berndt*
Victoria Bertics
Christine Bertram
Martin Beyer
Maya Beyer
Rachel Bezard
Jörg Bialas
Arne Biastoch
Jan Bielecki
Wolfgang Bilger
Alexandra Bititelli
Sonja Blanco-Ameijeiras
Ursula Blanke-Kiessling
Markus Bleich*
Jana Block
Martina Blümel
Frauke Blunck
Anna-Christina Bockelmann
Jens Boczek
Frederike Böhm
Gunda Böhm
Timothé Bolliet
Sören Bolte
Claus Böning*
Katharina Bork
Steffen Börm
Thomas Bosch*
Michel Bourban
Malte Braack*
Gesche Braker
Marlitt Brandes
Philipp Brandl
Jens Brandt
Peter Brandt
Sarah Breimann
Dennis Brennecke
Elizabeta Briski
Ralf Bröck
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Christian-Albrechts-Platz 4, 24118 Kiel
www.futureocean.org

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Emanuel Söding, Friederike Balzereit

LAYOUT

Maria Malmberg, Tine Pape

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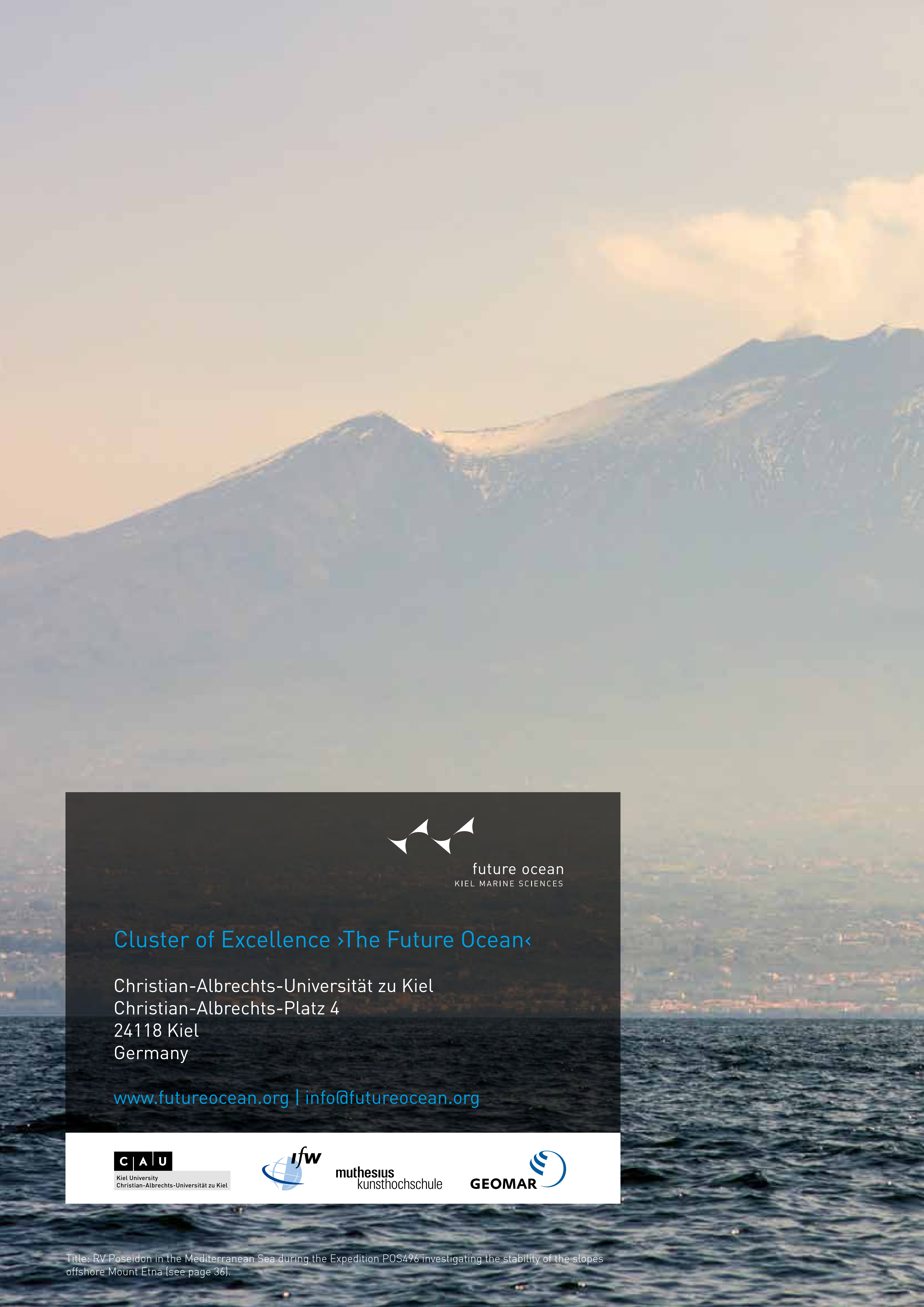

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Cluster of Excellence ›The Future Ocean‹

Christian-Albrechts-Universität zu Kiel
Christian-Albrechts-Platz 4
24118 Kiel
Germany

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Title: RV Poseidon in the Mediterranean Sea during the Expedition POS496 investigating the stability of the slopes offshore Mount Etna (see page 36).