Scientia

COMBATTING CLIMATE CHANGE & ECOLOGICAL COLLAPSE

HIGHLIGHTS:

- Glacial Retreat and Marine Life in Greenland
- Can Climate Change Cause Earthquakes?
- Tackling the Urban Biodiversity Crisis
- Promoting Inclusion in Environmental Policy Development

EXCLUSIVE:

- The Royal Meteorological Society

Issue: #124

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WELCOME...

In this critical issue of Scientia, we address the two greatest threats that humanity has ever faced: climate change and ecological collapse. As two sides of the same coin, these human-induced global emergencies hold the potential to destroy our societies, unless urgent action is taken in the next few years.

Earlier this month (May 2019), the UN released a summary of their upcoming report, which provides the most detailed assessment of life on Earth ever conducted. The findings were terrifying: one million of the Earth's species face extinction due to human activity, while countless others are experiencing rapid population declines. Climate change, pollution, exploitation and invasive species were all identified as significant drivers of this accelerated biodiversity loss. However, human changes to the planet's land and oceans were announced as having the most devastating impact. In fact, a whopping three-quarters of Earth's land has been severely altered by humans, with much of this area being used for agriculture.

To open this edition, our first article explores how people have been significantly altering the natural landscape over the course of human history. Here, we meet Dr Nathalie Dubois at the Swiss Federal Institute of Technology, whose research tells us more about how we are harming the planet, and how long it might take the environment to recover.

As the third greatest driver of ecological collapse, climate change is the focus of our first section in this edition. In addition to ravaging the delicate ecosystems we depend on, climate change directly threatens our human civilisation, through increasingly severe and frequent heatwaves, droughts, flooding, mega-storms and epidemics. In this section of the edition, we pay homage to the scientists whose diligent research irrefutably demonstrates the disastrous impacts of our emissions on the climate. Their research is critical for continuing to highlight the enormity of the situation to governments, who must now finally take drastic action, to limit further destruction.

The latter half of this edition is dedicated to conserving and restoring Earth's precious biodiversity, using a multitude of different approaches. From documenting currently-unnamed species, so that they can be protected, to eradicating invasive species, the researchers featured in this section are working tirelessly to find ways to reverse the great damage we've caused to our home planet.

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LAKE SEDIMENTS UNLOCK THE PAST

People don't often think about mud, but this valuable sediment can record history, especially when deposited in lakes. The study of such lake sediment is known as palaeolimnology – analysing the physical, chemical and biological information preserved in sediments to reconstruct the history of lakes and their surroundings. **Dr Nathalie Dubois** and her team at the Swiss Federal Institute of Technology (ETHZ) and the Swiss Federal Institute of Aquatic Science and Technology (Eawag), are pioneering approaches that use fossil molecules (biomarkers) found in lake sediment to understand historical events and search for traces of early human impacts.

CREDIT: Nemiah Ladd

CREDIT: Nathalie Dubois

Humans Modify Their Environments Through Time

Humans are the only animal species that modify their surroundings on a large scale, leaving markers in the sedimentary record that can be analysed by scientists today. Changes to the landscape are closely related to human history, and Dr Nathalie Dubois and her multidisciplinary team of geologists, chemists, sedimentologists and ecologists seek novel methods to extract these clues.

As humans cut down trees and cultivate the land, nutrients, such as phosphorus or nitrogen, and biochemical markers, such as plant lipids, are released into watersheds (rivers and lakes), modifying the aquatic environment. Understanding how humans change their environments and how these effects have varied over time is of particular relevance in the present day, especially if we are to understand the long-term impacts of human-induced climate change on our surroundings.

Dr Dubois and her PhD student Mischa Haas explored one local example in a recent study. More than 2,000 years ago, when the Romans built the city of Aventicum, the largest city in Switzerland at the time, they began to extensively deforest the region to establish farmland. By analysing a 10-metre sediment core from Lake Murten downstream of the ancient city, the research team was able to show that human activity drastically impacted the lake until the Romans abandoned this city at the end of the 3rd Century AD.

This information was revealed by the amount of soil material suddenly deposited in the sediment, among other things. The team showed that the Romans caused extensive changes to the sedimentary record over a period of more than 300 years. During this time, the bottom of the lake became anoxic – meaning that it was almost entirely devoid of oxygen – leading to the death of many bottom-dwelling creatures. Subsequently, the environment took another 300 years to recover – a result that resonates today. How long will it take our planet to recover, if ever given the chance, from the dramatic changes induced by humans over the past few hundred years?

CREDIT: Nathalie Dubois

Reconstructing the History of Farming

One key research area for Dr Dubois and her team involves reconstructing the history of farming. In particular, they are interested in finding out how farming destabilised soils over time as farming techniques evolved. This sedentary mode of life evolved relatively late in human history, and impacts have tended to vary depending on the region and type of farming. Soil erosion due to humans is of particular concern, especially today, as evidenced by recent action plans put in place by many national governments.

To comprehensively assess the effects of varied farming models at different times spanning human history, Dr Dubois and her team analyse seeds and pollen, molecular biomarkers, and radiocarbon in sediment cores. They are currently investigating a range of different sites spanning Switzerland, Russia, Greenland and remote Pacific Islands.

In Europe, initial human activities within an area tend to be marked by the appearance of cereal crops alongside reductions in pollen from local trees. The use of fire to clear the landscape is often indicated by increased charcoal abundance in sediment cores. Animal grazing, on the other hand, is associated with certain kinds of fungi that grow on animal dung.

In one recent project, Dr Dubois and Haas explored the unconventional transition from ploughing to grazing in Russian Karelia. This return to pastures and low-intensity land use occurred when Karelia was politically transferred from Finland to the Soviet Union in the 1940s. The researchers investigated how this key regional political change is reflected in soil erosion over time. They used radiocarbon dating approaches to date different organic fractions within the sedimentary sequences of three lakes and tracked changes in erosion over time.

By radiocarbon dating different sediment fractions, the research team was also able to show that the soil was stable in this region prior to industrialisation. Soil erosion increased dramatically when intensive agricultural practices started as Karelia was part of Finland. Once ceded to the Soviet Union, biomarker distributions and soil erosion indicators show a short period of forest regrowth and soil stabilisation. Since the 1960s, as pastures came to dominate the region, soil erosion decreased to pre-Industrial values, but nutrient inputs started to rise.

This research shows that both soil erosion and stabilisation processes, linked to changes in agricultural practices, can be efficiently tracked using geochemical and sedimentological techniques. The innovative approaches used by Dr Dubois and her team opens the door to quantitatively evaluating human impacts on land use and ecosystems over time.

Migrations and Settlements: The Tropical Pacific

On a more global scale, Dr Dubois and her team also use their skills to address early human migration questions, including those surrounding the settlement of remote Pacific islands. These questions are important in terms of reconstructing human migrations around the world over time, but also because the arrival of people into pristine environments led to dramatic changes. The team uses traces left in lake and swamp sediments to reconstruct such changes. Perhaps more importantly, this knowledge can be applied to predict the likely future effects of human-induced environmental changes.

By pioneering new approaches based on sediment cores from a range of Pacific islands, the team has been able to utilise preserved lipid biomarkers to provide insights to a number of debated questions, including when food production first appeared in the Pacific archipelago of Vanuatu. In this project, the team extracted lipids from plants and used them to develop

CREDIT: Danny Nef

species-specific plant biomarkers to reconstruct vegetation and land-use changes. This approach has proved especially useful in cases where more traditional pollen analyses cannot be performed. In particular, the team was able to use their approach to assess the occurrence of culturally important crop plants, such as Taro (*Colocasia esculenta*), a tropical crop grown mainly for its edible corms.

Dr Dubois's master's student Christiane Krentscher and postdoctoral researcher Dr S. Nemiah Ladd analysed the lipid content of various plants from Vanuatu using chemical techniques including gas chromatography-mass spectrometry (GC-MS). This technique allowed them to identify a lipid that was unique to the Taro samples they had collected. This is important, because although this particular lipid has been found in other plants, none in this region of the Pacific are known to produce it in such quantities as Taro.

The identification of Taro in sediment archives from Vanuatu opens the door to determining the history of settlement and subsistence activities on this island with a much higher degree of accuracy than before. It will also help Dr Dubois and her PhD student Giorgia Camperio to clarify the complex interactions between humans and remote tropical environments across Oceania.

In another recent example of their innovative approach, Dr Dubois and her PhD student Ronald Lloren are addressing the greatly debated question of when the Maori people arrived in New Zealand. They are doing so by investigating faecal biomarkers (such as coprostanol), which are related to cholesterol and are found in human waste. This tactic, combined with the analysis of leaf wax data, allows the researchers to evaluate changes in vegetation cover and human presence.

Current Relevance of Palaeolimnology

The usefulness and potential applications of the team's research go way beyond reconstructing historical changes and human impacts. This field of palaeolimnology is key because it is becoming increasingly important to care about the impacts that humans have on their environment. This research can tell us more about how we are harming our planet, and for how long – so that we can start to minimise the damage we cause.

In future work, Dr Dubois and her PhD student Remo Roethlin plan to analyse the heavy metals present in lake sediments to trace and interpret the impacts of mining and industrial developments, including water contamination. This is important because the impacts of past heavy metal contamination on aquatic ecosystems remain poorly understood, especially whether this legacy is still influencing modern ecosystems.

These innovations make the field of palaeolimnology particularly relevant to modern times, as they allow us to predict the impact of pollution into the future and make accurate assessments of future modifications to the environment.

Meet the researcher

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Dr Nathalie Dubois completed her PhD in Oceanography at Dalhousie University (Canada) in 2010. She then worked as a postdoctoral research associate at the University of Manchester (UK) before moving to Woods Hole Oceanographic Institution (United States). Dr Dubois then started her current position of Sedimentology Group Leader at the Swiss Federal Institute of Aquatic Science and Technology in 2013, before becoming an SNF Professor of Palaeolimnology at ETHZ in 2016. She is a member of the Swiss Geological Society, the Swiss Society for Quaternary Research, the American Geophysical Union, the International Paleolimnology Association and the International Association of Sedimentologists.

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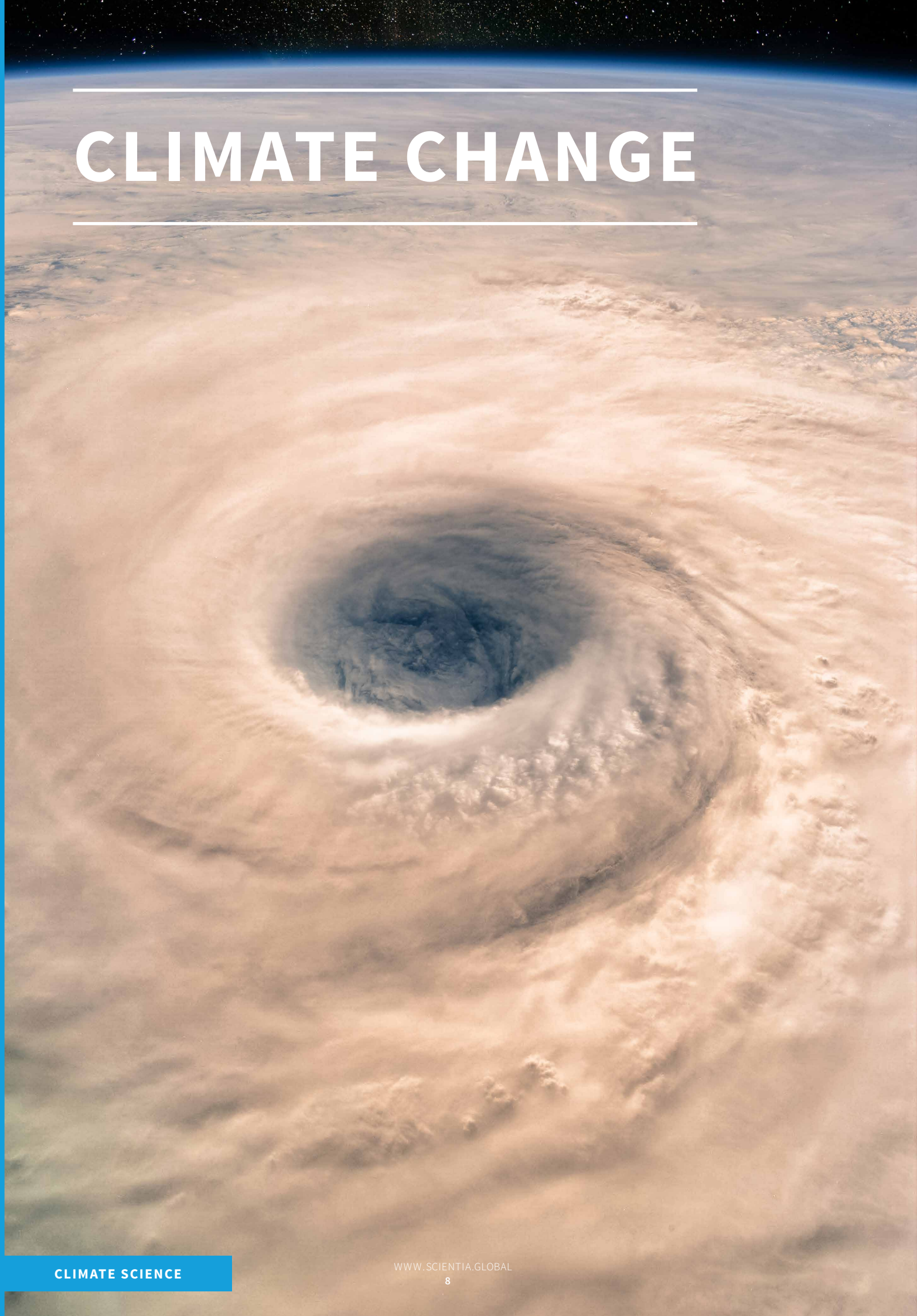
CLIMATE CHANGE



TACKLING THE CLIMATE CRISIS BEFORE IT'S TOO LATE

Extreme heat, drought, wildfires, crop failure, flooding, storms and sea-level rise – the devastating effects of human-induced climate change are now becoming increasingly apparent. Worryingly, the severity and frequency of these events are even worse than many scientists had predicted when climate change first made headlines over 30 years ago.

Last year, 2018, was a particularly bad year for Earth's climate. Rather than seeing a reduction in our carbon dioxide emissions (the primary driver of climate change), they actually shot up, reaching a record high of 37.1 billion tonnes. Although renewable energy technologies also saw rapid growth, it wasn't enough to offset the increased combustion of fossil fuel. With record levels of carbon dioxide and other greenhouse gases in the atmosphere, 2018 was also the fourth hottest year since modern record keeping began about 150 years ago. This is far from being an 'anomaly', as an alarming 20 of the hottest years on record have all occurred within the last 22 years.

2018's abnormally high temperatures triggered heat waves and wildfires across the globe, claiming the lives of thousands of people in the US and Europe alone. Devastating wildfires were even experienced as far north as the Arctic circle. In March 2018, record-breaking rainfall in Kenya and Somalia displaced more than 200,000 people and also triggered a serious outbreak of cholera. Meanwhile, Argentina was hit with its worst drought in decades, leading to widespread crop failure and driving up the price of corn and soya worldwide. Similarly, drought in Afghanistan caused food shortages that forced 300,000 people from their homes. In India, the worst floods seen in a century hit Kerala, killing almost 500 people and displacing 1.5 million.

And unprecedented extreme weather has continued into this year. In particular, Tropical Cyclone Idai caused devastating floods and tragic loss of life in Mozambique, Zimbabwe and Malawi, and has been named the worst weather-related disaster to hit the southern hemisphere.
Above is just a small selection of the catastrophic events that have devastated communities across the globe. The impact of climate change on the world's ecosystems is similarly catastrophic, with alarming declines in wildlife populations and countless species being pushed to the brink of extinction.

And all of these climate disruptions can be related to Earth's current level of global warming, which has reached just 1°C above pre-industrial levels. With our current trajectory putting us on course for *at least* 3°C of warming by the end of this century, such disastrous climatic events are set to become immensely more frequent and severe in the coming decades, seriously impacting billions of people with extreme food shortages, drinking water shortages, intense heat and mega-storms. Sea-level rise, caused by the thermal expansion of seawater and melting of ice sheets and glaciers, is set to wipe whole cities off the face of the Earth. Such a scenario could cause the collapse of human civilisation as we know it.

For the sake of damage limitation, the Intergovernmental Panel on Climate Change (IPCC) released an emergency report last year (Special Report on Global Warming of 1.5°C), calling for global warming to be limited to 1.5°C. If this ambitious goal is achieved, the most disastrous impacts of climate change can be mitigated, and dangerous climate 'tipping points' – abrupt and irreversible changes – can be avoided. However, to achieve this goal, our global carbon dioxide emissions need to fall by about 50% from their current levels by 2030, and reach 'net zero' by around 2050, according to the IPCC report.

Considering our emissions still appear to be on the rise, due to global economic growth coupled with inaction, this is an ambitious goal. What we do now, and in just the next few years, will profoundly affect the next few thousand years for life on the planet and the future of our human societies. However, governments, corporations and individuals are finally starting to wake up to the realities that we are facing, thanks to several decades of scientific research into human-induced climate change.

In this section of the edition, we pay homage to the scientists who have worked tirelessly to gather data that irrefutably demonstrates the disastrous impacts our carbon emissions have had on our home planet. Their research has been and continues to be critical

for highlighting the enormity of the situation to governments across the globe, who must now finally begin to take drastic and urgent action, to limit further warming. However, even if we manage to limit warming to 1.5°C, the frequency and severity of climate events will continue to rise, meaning that climate research is also necessary for helping people to remain resilient in a changing world.

To open our section on climate change research, we speak to Professor Liz Bentley, Chief Executive of The Royal Meteorological Society, who discusses their upcoming conference – the first RMetS Climate Change Forum. This event aims to facilitate effective dialogue between government, business and science, and encourage decision makers to take urgent action against climate change.

Next, we focus our attention on Earth's ice sheets, which are shrinking at an alarming rate due to rising global temperatures. Global sea-level rise is an obvious consequence of melting ice, but the increased flow of freshwater from glaciers into the ocean can also disrupt ocean currents, impacting weather systems and marine ecology. Furthermore, decreased ice cover on the planet's surface means a reduced albedo effect: ice reflects more radiation back into space, while liquid water absorbs more, creating a feedback loop that accelerates global warming.

At the forefront of this research is glaciologist Dr Martin Sharp at the University of Alberta in Canada, who is attempting to pin down the exact mechanisms by why which this glacial shrinking is occurring in the Canadian Arctic Archipelago. This group of islands extending north of Canada contains almost a third of the world's glacier ice. Through painstaking research, Dr Sharp and his colleagues are significantly increasing our knowledge of this archipelago, and the melting behaviours of its glaciers. Their results are making our forecasts of changes to come ever-more reliable and accurate, allowing governments to make the most effective decisions.

Also studying shrinking glaciers in the Arctic circle is Dr Shin Sugiyama of Hokkaido University in Japan. In the next article of this section, we meet Dr Sugiyama and his colleagues, who focus on glaciers near the village of Qaanaaq in northwest Greenland. As well as quantifying the rate of ice loss, the team also looks at how the flow of glacier meltwater into the nearby fjords causes deep, nutrient-rich, water to rise to the ocean surface, disrupting marine ecosystems. Such ecological disruptions can impact resource availability for communities in northwest Greenland, who are reliant on hunting and fishing to survive. Therefore, Dr Sugiyama and his team also work with local people to help them build a sustainable future in the face of climate change.

As mentioned earlier, shrinking glaciers cause a myriad of negative effects, including sea-level rise, ocean current disruptions, weather pattern changes, ecological chaos and accelerated global warning. However, glacial shrinking may also have effects on the behaviour of Earth's continental plates. This is the focus of our next article, which showcases the work of Dr Christian Brandes of Leibniz Universität in Hannover. In particular, his team explores how glacial retreat, such as that caused by human-induced climate change, can trigger earthquakes and other seismic events.

As mentioned earlier, shrinking glaciers and the resulting flow of freshwater into the oceans cause serious disruptions to marine ecosystems. However, the rising temperatures that cause glaciers to melt also directly impact marine life. Such ecological impacts can hinder the ocean's ability to remove carbon dioxide from the atmosphere, since marine organisms called phytoplankton are responsible for absorbing vast quantities of atmospheric carbon, partially offsetting our emissions. As atmospheric carbon dioxide is the primary driver behind human-induced global warming, this reduced ability to capture carbon accelerates further increases in global temperatures.

This is the focus of our final article in this section, where we meet Dr Mark Ohman at the Scripps Institution of Oceanography at the University of California. Using advanced technologies, Dr Ohman and his colleagues investigate exactly how marine ecosystems are responding to our warming climate. The team's research is helping us to understand how such ecological responses to ocean warming will affect the global carbon cycle in the future.

THE FIRST ROYAL METEOROLOGICAL SOCIETY CLIMATE CHANGE FORUM

As the UK's professional and learned society for weather and climate science, the Royal Meteorological Society (RMetS) has become a leader in advancing our understanding of anthropogenic climate change. On the 4th of June this year, the Society will host its first Climate Change Forum, which will run under the theme 'Risks and Resilience: Emerging challenges in a post Paris world'. By bringing together UK climate scientists, business leaders and government officials, this seminal event will offer a platform to discuss current needs, research challenges and policy requirements. In this exclusive interview, we speak to Professor Liz Bentley, Chief Executive of RMetS, who discusses how the Forum aims to facilitate effective dialogue between government, business and science, and encourage decision makers to take action towards mitigating climate change.

To begin, please tell us a little bit about the history of RMetS. How has the Society's mission changed over the past few years in this new era of climate change?

The Royal Meteorological Society was founded in 1850 and its mission throughout that time has remained broadly similar – to advance the understanding of meteorology. And although it has remained unchanged, it also recognises significant changes in the meteorological community with an expansion in both the science and application of this interdisciplinary field. Our mission is still as relevant today as it was 170 years ago.

When we talk about climate change, we often refer to a 'pre-industrial' baseline. Some would suggest that when the Society was founded, it fell into that 'pre-industrial' period. So, over the course of the Society's lifetime the climate has changed – for example, global temperatures have increased by approximately 1°C above pre-industrial levels and sea-levels have risen by more than 20 centimetres. These numbers may seem small to some people but they are global averages and the impacts of these changes on ecosystems and the increase in extreme weather can be much more dramatic.

Since the Society is the learned and professional body for weather and climate in the UK, our focus has been on the climate as much as it has been on the weather. We have groups that oversee our activities on climate science communication, such as briefing papers and statements and meetings and conferences.

On the topic of conferences, this year will see the Society host the first RMetS Climate Change Forum. Tell us a bit about this event.

The idea to bring the climate science community together actually evolved from the community itself. We have a 'Climate Science Special Interest Group' here at the Society that was formed a few years ago. This group brought the idea for this event forward.

Climate change is an extremely complex topic, covering many scientific disciplines and affecting all sectors locally and globally. There is a clear need to provide an opportunity for the community to meet, to discuss research challenges not isolated from each other, but across the disciplines, and to also involve decision makers. The Society is very happy to facilitate this event. About 130 participants are expected to attend.

‘Climate change is an extremely complex topic, covering many scientific disciplines and affecting all sectors locally and globally. There is a clear need to provide an opportunity for the community to meet, to discuss research challenges not isolated from each other, but across the disciplines, and to also involve decision makers.’

The RMetS Climate Change Forum will offer a new space for UK climate scientists to collaborate and discuss evidence-based ideas for tackling climate change. However, if their ideas are to be put into practice, government officials, business leaders and other decision makers will need to be involved too. How do you aim to facilitate *effective* dialogue between scientists, industry and government?

Effective dialogue is indeed key to bring ideas across, and our team here at the Society tries its best to facilitate this. We expect a very diverse audience including scientists, journalists, policy and decision makers and people from industry to attend our event. All are invited to share their contributions related to climate change during the poster session. To facilitate an effective dialogue at the conference, we encourage contributions to be written and presented in plain language. This means avoiding jargon that is specific to the respective scientific disciplines, giving some extra background information, highlighting wider implications of the research findings and keeping it simple.

The interactive round table discussion in the afternoon are also designed to engage all participants. We are currently looking for two co-chairs for each of the tables, who both offer different perspectives. For example, the round table on sea level rise could be chaired by an academic and somebody from an engineering company.

Climate change affects the environment, biodiversity and human society in countless ways. How do the event’s organisers plan to effectively address the challenges posed by climate change?

The first part of the event, in the morning, will include keynote talks followed by a panel discussion. These will be led by representatives of government, business and research highlighting key emerging requirements for scientific evidence to guide the responses to climate change. This part of the day will introduce the audience to the variety of challenges the community is facing. The following interactive poster session will encourage informal discussions of the challenges and possible solutions.

The sessions in the afternoon – the round table discussions – are then dedicated to different hot topics in the climate change community. The topics for the first round of the round table discussions include ‘Risks of Weather and Climate Extremes’, ‘Risks of Sea Level Rise’, ‘Water Cycle Risks’ and ‘Global Climate Response’. All of these topics require the whole spectrum of scientific disciplines and the involvement of decision makers.

‘To facilitate an effective dialogue at the conference, we encourage contributions to be written and presented in plain language.’

Much of the responsibility for tackling the challenges posed by climate change will inevitably fall on today’s young scientists and students. How does the Climate Change Forum plan to support and empower young climate scientists?

In the afternoon, we will have one round table dedicated to ‘Supporting Young Scientists’. The next generation of scientists is facing numerous challenges – funding, job insecurity, work-life balance, to name only a few. The chairs of this round table will include an early career researcher as well as a scientist at senior level to provide a basis for a wide-ranging discussion. We would also like to explore solutions and how the Society can help in implementing them.

Science communication and public outreach will be a large focus of this year’s Forum. Please explain why effective communication and outreach are particularly important in the field of climate research.

Climate change will not stop at country borders. Everybody on this planet will be affected by it in some way or another. Many scientists are still confronted with the question from the general public whether climate change is real, despite so many years of climate change communication. Thus, it is essential to communicate this topic in a way that is tangible to everybody, while at the same time remaining scientifically accurate. In order to mitigate climate change and to adapt to it, we will need the general support from everybody.

Finally, what *tangible* changes within government and industry do you hope the Climate Change Forum might lead to?

Over the past few years, we have recognised that the discussion at government and industry level has shifted quite a bit. Since the last Intergovernmental Panel on Climate Change (IPCC) assessment report (AR5) was released, the question is not anymore about the scientific evidence and whether it is really happening, but more about how government, industry and society can mitigate and adapt. The Climate Change Forum will only help to cement that shift and allow scientists to focus more on the impacts and solutions rather than the need to provide evidence that climate change is happening.

www.rmets.org
www.rmets.org/event/1st-rmets-climate-change-forum

RMetS
Royal Meteorological Society

MELTING ICE: UNDERSTANDING THE SHRINKING ARCTIC ICE CAPS

The Arctic ice caps are shrinking at an increasing rate – part of a global pattern that may have grave consequences for the planet and all its inhabitants. Glaciologist **Professor Martin Sharp** and his team at the University of Alberta in Canada are attempting to understand exactly how and why this is occurring, before it is too late.

The Canadian Arctic Archipelago

A frozen landscape, ice-covered mountains, blistering snowstorms and intrepid explorers riding sleds pulled by huskies – these images often come to mind when we think of the Arctic, that ice-covered region surrounding the North Pole. Yet the Arctic is far more than this. It is a unique area unmatched by any other location on Earth – land that is largely ice-free in summer and snow-bound in winter, surrounded by an ocean that freezes over in winter.

A major part of this land is known as the Canadian Arctic Archipelago – a group of islands extending north of Canada up towards the North Pole. Covering over 1.4 million square kilometres and sparsely inhabited by humans, this area is a vast stretch of frozen snow and ice for much of the year. This makes it a vital part of the Arctic environment – outside of the Polar ice-sheets, the Canadian Arctic Archipelago contains almost a third of the world's glacier ice.

Yet this ice is in danger, as steadily-increasing regional and global air temperatures lead to increased thawing and melting in the summer season. This melting depletes the mass of ice stored on land, and the resulting seasonal flood of water that it releases makes its way to the ocean and contributes to a rise in the global mean sea level. Feedbacks associated with melting and shrinking glaciers can lead to more rapid melting and further changes in the global climate, as well as changes in river runoff regimes and the release of an archive of historical pollutants stored in the glacier ice.

These are the dangers that Professor Martin Sharp and his colleagues at the University of Alberta are trying to understand and hoping to deflect. A researcher in the field of climate change and glaciers, Professor Sharp is well aware that knowledge of how the ice in the Arctic Archipelago is changing is now vital for modelling what will happen in the future if the climate continues to warm.

Counting Ice Cubes

The loss of ice in Arctic regions is a significant worry for researchers. Through their research, Professor Sharp and his collaborators discovered that the Canadian Arctic Archipelago has lost over 60 gigatons (60 billion tonnes) of ice per year in recent years – an amount

that is almost impossible for most of us to comprehend. For comparison, imagine that every person in the world moved to Canada, all 7.7 billion of them. This literal mass of humanity would weigh roughly half a gigaton – in other words, less than 1% of the ice mass that is being lost each year.

This is quite worrying, naturally. But it is also a source of confusion for many who hear about it – how can Professor Sharp and his colleagues actually know the amount of ice being lost? A gigaton is a lot of ice, roughly a cube one kilometre high, wide and long – obviously too much to just break off and weigh. The

solution to this problem, and many others in Arctic research, requires a combination of old-fashioned methods and space-age technology.

Measuring the mass of ice in the Arctic, for example, relies on the plethora of satellites in orbit around the Earth and the vast number of measuring devices that are attached to them. NASA's ICESat satellite, for example, was launched purely to provide information about changes in the ice in the Polar regions, using laser ranging devices to determine the height of the ice-sheets and thus their volume and mass – and how they change over time. The GRACE mission used two satellites flying in formation to map the subtle variations in Earth's gravity field, using the pull exerted by the ice sheets and glaciers on the satellites to calculate the amount of ice and how it changed over time. Each of these methods independently show a dramatic decrease in the mass of Canada's Arctic glaciers, as do more traditional measurements made by scientists on the ground.

Core Melt-Down

Yet for all the modern technology that is available these days, Professor Sharp and his colleagues nonetheless turn to older methods when necessary. One of the classical techniques they use is known as ice core sampling – using a hollow drill to bore into glaciers and then pulling out a long core of ice stretching for many tens of metres.

This ice core provides a record of the past in much the same way as the rings of a tree – every winter a new layer of snow is formed, which is then compacted over time into a visible layer in the ice. Warm summers cause the ice to melt, and the water then seeps downwards and freezes below the surface. This refrozen water has far fewer trapped bubbles than a normal layer of compacted snow. By looking along the length of the ice core (and comparing ice cores from nearby drilling locations), Professor Sharp and his colleagues can see when (and how often) warm summers have occurred in the past.

The major advantage of ice core samples is that they reach back far into the past. The multitude of cores collected by researchers, including Professor Sharp and his colleagues, provide a reliable record of ice-cap melting over the past 11,000 years.

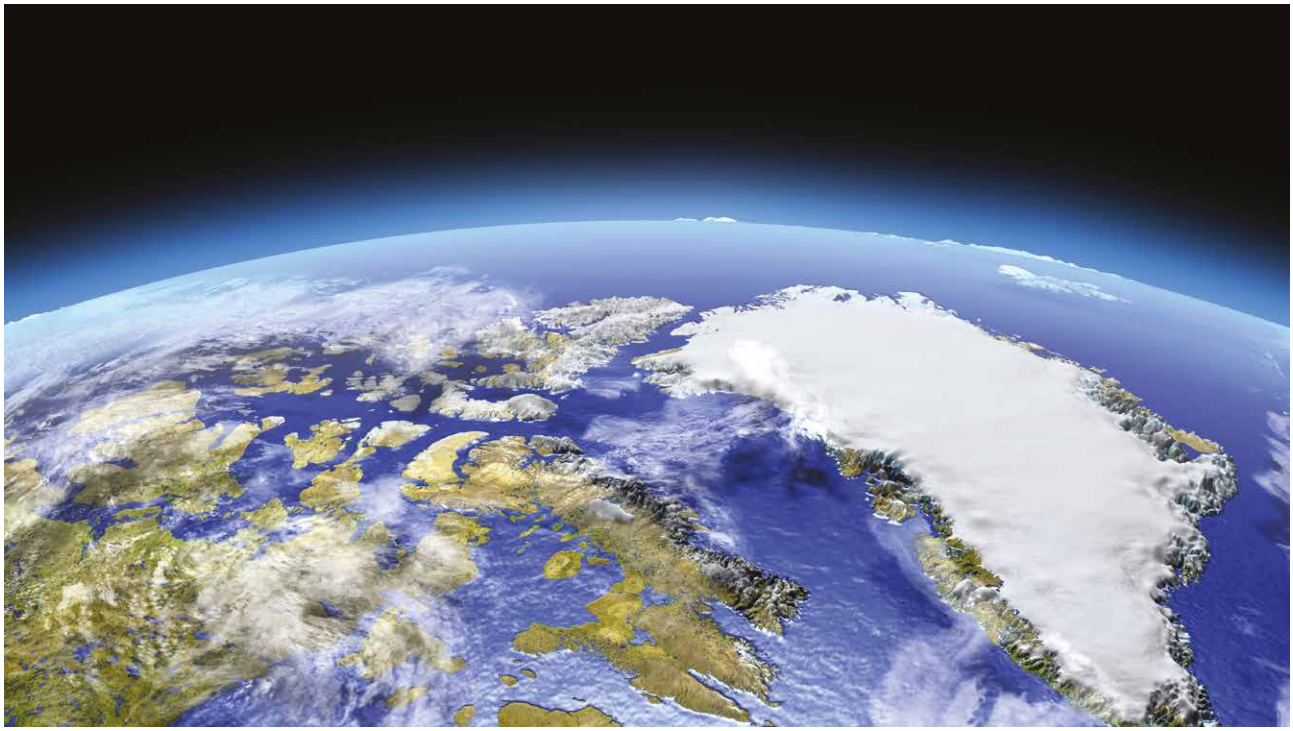
These data show that melting of the Arctic ice-caps has increased significantly since the mid-1990s. Indeed, the rate of melting occurring now is the highest that has been seen in the last 4,000 years.

This is, obviously enough, not a good thing. Thus, Professor Sharp and his colleagues decided to move onto more detailed methods to study this melting in further detail.

Clear Skies and Warm Breezes

Numerous studies by Professor Sharp and his colleagues have shown that the amount of ice present in the Canadian Arctic Archipelago has decreased significantly in recent years. This drop is enough that the melting of glacier ice in this region is now the largest contributor to rising sea levels after the Polar ice-sheets in Antarctica and Greenland. Yet the melting process is more complex than we would think.

The climate of the Canadian Arctic Archipelago is fairly constant during the winter (with consistent levels of snow falling every year) but quite variable in the summer, when daytime temperatures bring temperatures above



the melting point of ice. Previous research has shown that the periods with maximum glacier melting are usually associated with higher air pressure over the Canadian Arctic Archipelago. These high-pressure systems, known as anticyclones, usually have clear, cloudless skies in the centre surrounded by a large-scale clockwise circulation of air. In the Canadian Arctic Archipelago, these anticyclones tend to move warm air from the south into the colder north, leading to higher air temperatures over the ice caps. The clear skies also allow more solar radiation to reach the ground, warming things further. This in turn leads to increased melting.

To examine this phenomenon, Professor Sharp and his colleagues examined historical records of the occurrence of summer high-pressure systems in the region using a dataset covering over six decades from 1948 to 2012. The team correlated these records with records of other factors such as ice melting. The researchers were able to show that the presence of these anticyclones was directly related to the changes in Arctic ice-cap thickness and the intensity of surface melting during the summer months.

A Matter of Degree

How much of an effect did this process have? The answer to this came from orbit. Professor Sharp and his colleagues used data from two satellites owned by NASA, known as Terra and Aqua, which provide full visualisation of the Earth's surface every 1–2 days. This provides a near-constant dataset that can be used to track surface temperatures over a long period of time. In the case of their latest study, the researchers focused on the Queen Elizabeth Islands in the Canadian Arctic Archipelago over a period stretching from 2000 to 2015.

They were able to show that the surface temperature of glaciers on the island increased by approximately 0.06°C every year. This seems like a small amount, but one that adds up – over the period they studied, temperatures increased by almost an entire degree. Much of this increase was concentrated in the seven years from 2005 to 2012, which had particularly warm summers and was the warmest period since reliable meteorological data were first collected in the region. Similar to the previous studies, the team was able to show that these warm summers are correlated with the presence of high-pressure regions in the area.

But it's only one degree, you might say, surely this is not that important? Professor Sharp and his colleagues recently carried out a study of the largest lake in the Arctic. Increasing temperatures by only one degree led to a ten-fold increase in the amount of meltwater runoff from the surrounding glaciers. The increasing flows of water and fine sediment into the lake led to thawing of the lake's icy surface in summer, and a complete change in the ecology of the lake. A change in temperature of only a single degree, they note, led to conditions that have not been seen for centuries.

Melting Hopes

The current set of data is not looking good for the future of the Arctic glaciers, or indeed the planet. Record levels of melting are regularly seen, and glaciers and ice-sheets are thinning and shrinking. Professor Sharp and his colleagues are responsible for increasing our knowledge of the area, making our forecasts of changes to come ever-more reliable and accurate. Yet all the information in the world does nothing if it is not acted upon.

That part, by contrast, is up to us.

Meet the researcher

Professor Martin Sharp
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Professor Sharp began his long research career with a PhD focusing on the glaciers of Iceland. He followed this initial interest with a decade-long stint in the famed halls of the University of Cambridge, taking roles of successively greater responsibility. In 1993 he jumped across the Atlantic to the University of Alberta, Canada, where he rose to his current role as Professor in the Department of Earth and Atmospheric Sciences. His long and successful career has led to over 200 publications, each providing yet more knowledge in his chosen field of the Arctic and its environment.

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UNIVERSITY OF ALBERTA

GLACIAL RETREAT AND MARINE LIFE IN GREENLAND

Dr Shin Sugiyama and his colleagues at Hokkaido University in Japan study the shrinking glaciers near the village of Qaanaaq in northwest Greenland, where local people are reliant on hunting and fishing. His team's analysis shows that glaciers in the area have shrunk (or 'retreated') in recent years due to increasing melting and calving (shedding of ice chunks). Their further work centres on the outflow of glacier meltwater into the fjords, which causes deep, nutrient rich, ocean water to upwell to the ocean surface, supporting marine life.

The Impact of Glacial Retreat

Under the influence of a warming climate, the Greenland ice sheet has been shrinking at an increasing rate since the 1990s. As well as contributing to sea-level rise, this has the potential to seriously impact on the local marine environment. Dr Shin Sugiyama and his colleagues at Hokkaido University have conducted studies quantifying the rate of ice loss at several sites in Greenland, as well as studying the impact on the local ocean environment.

Dr Sugiyama's research focuses on the region near Qaanaaq, a village in the northwest of Greenland. The village's 600 inhabitants lead a traditional way of life, and they are seeing the effects of climate change at first hand. For example, the season in which their dog sleds can be used on the sea ice has already become much shorter. As Dr Sugiyama explains: 'We realised that changes in the natural environment can have serious impacts on the lives of people living in Qaanaaq. For instance, glacier and ocean changes affect populations of fish and marine mammals, which are important resources for the people.'

Observing Glacial Retreat in Greenland

Much of Dr Sugiyama's research has focused on the Bowdoin Glacier, which is located at the head of a fjord 30 kilometres northeast of Qaanaaq. In a 2015 study, Dr Sugiyama and his colleagues found that the Bowdoin Glacier had retreated rapidly over the preceding years. By analysing satellite images of the glacier obtained in the period between 1987 and 2013, the team compared the position of the front of the glacier nearest the ocean to its 1987 position. The researchers found that the glacier remained roughly the same size between 1987 and 2008, with the exception of a 230-metre retreat between 1999 and 2001.

However, at some point between July of 2008 and June of 2009, the glacier began to melt rapidly. It shrank by an average of 220 metres per year between July of 2008 and September of 2013, although the rate of retreat decreased in 2011 and increased again in 2012, and it was not uniform across the width of the glacier.

Glaciers are formed from the accumulation of many years of snow, which becomes compacted and transforms into solid ice. This solid ice is capable of slowly deforming and sliding, and the glacier flows down the valley like a river due to gravity. The researchers found that the rate of this ice flow at the glacier outlet, where the glacier flows into the fjord, increased by more than 100% several years before the periods of rapid shrinking. In total, the western margin of the glacier shrank by a massive 2 kilometres between 2008 and 2013, but the retreat was less than 500 metres at the eastern margin. This glacial retreat is consistent with the atmospheric warming observed in the region. In a further experiment, the team

measured the shape of the seafloor in the fjord near the glacier front, and found that it also played a critical role in the rapid retreat and acceleration. Subsequently, Dr Sugiyama and his colleagues looked at 19 separate glaciers in the same region and found that they had retreated by 30 metres per year on average between 2000 and 2014. This study centred on Prudhoe Land in northwest Greenland, using satellite imagery collected between 1987 and 2014. All 19 glaciers shrank, with the rate of retreat ranging from 12 to 200 metres per year between 1987 and 2014. Five of the glaciers retreated by more than a kilometre over the study period.

The ice loss began in earnest after the year 2000, with the rate of retreat increasing from 3 metres per year in the late 1980s to 40 metres per year by the early 2010s. The researchers also calculated the speed of glacial flow from the glaciers into the sea. Locations with more rapid acceleration of glacial flow experienced more rapid ice loss over the study period. Again, the researchers were able to link the onset of the glacial retreat to the fjord bed geometry as well as to atmospheric warming.

Glacial Retreat and Marine Life

Glacier loss has the potential to seriously affect marine life through its impact on the nearby ocean water, by disrupting ocean circulations and critical nutrient supplies. In a study aimed at understanding the glacial flow from the Bowdoin Glacier into the fjord, Dr Sugiyama collaborated with Dr Guillaume Jouvet from ETH Zurich, Switzerland. They used a drone equipped with an onboard camera to observe the flow of the ice near the so-called calving front of the glacier. The calving front is the point at which the glacier meets the sea and sheds ice 'calves'. By understanding the flow of the ice in this region, the researchers hoped to work out how changes to this process are affecting the marine environment and aquatic life.

The researchers carried out two drone flights per day over a 13-day period, always following the same route over the glacier's calving front. The velocity of the ice at various locations was deduced from the images taken by the camera. The glacial flow averaged at around 1.5 metres per day, but at one stage there was a remarkable speed up to 2.6 metres per day over a 2-day period. This was more pronounced at the southeast side of the calving front.

Short-term acceleration in glacial ice flow can be caused by a number of factors, including additional meltwater at the base of the glacier leading to a reduction in friction, or a calving event causing a rapid change in the force acting on the glacier. This event is similar to one previously observed on Store Glacier in western Greenland after heavy rainfalls and high melt rates. The speed-up event at the Bowdoin Glacier happened after a warm period and prior to major meltwater discharge, and was probably caused by an increase in meltwater underneath the glacier or the collapse of a supraglacial lake.

Discharge of glacial freshwater into the ocean below the surface of a glacier is likely to affect nutrient transport and therefore marine life. In order to understand the effects of such subglacial freshwater discharge on nutrient transport, Dr Sugiyama and his team carried out further observations at Bowdoin Fjord next to Bowdoin Glacier. The results showed that a plume of water upwelling at the water surface

near the glacier contained significantly higher concentrations of nutrients and dissolved inorganic carbon than the surrounding water. This was due to nutrient-rich deep fjord water upwelling along with the glacial discharge. This caused phytoplankton blooms, which the team observed near the boundary between the upwelled deep water and the fresh surface water.

Phytoplankton are important to the local ecosystem, supplying energy to animals higher up the food chain. This study confirmed that subglacial freshwater discharge plays an important role in the availability of nutrients, and on subsequent phytoplankton blooms, in the Bowdoin Fjord. This raises the question of how these processes will be affected as climate change affects the rate of freshwater discharge from glaciers.

In a further study, Dr Sugiyama worked with marine biologists to collect and analyse samples of zooplankton (small animals that drift in the ocean) at the sea surface in the Bowdoin Fjord. The researchers carried out observations on a boat during a 3-day period in the summer. They took temperature and salinity measurements at 44 locations in the fjord, from the edge of glacier to the open sea near the edge of the fjord, focusing on the discharge plume of freshwater originating from the glacier. They then took zooplankton samples using a net at 15 locations covering a similar area and analysed them in the lab.

Different species dominated in different areas of the fjord. In the outer fjord, jellyfish dominated the samples, large zooplankton called chaetognaths and copepods were most common at the centre of the plume in front of the glacier, and barnacle larvae (cypris) dominated in the middle of the fjord. The large zooplankton are likely to have been transported from the outer fjord through layers of bottom water, and then upwelled by the plume near the calving glacier. These large zooplankton contain more nutrition than the other two groups, so the inner fjord would therefore be a good feeding ground for fish and seabirds.

Dr Sugiyama's work shows that the upwelling of bottom water by the glacial plume is hugely important to the local marine ecosystem, and therefore to local people who depend on hunting and fishing for their livelihoods. It is important to understand these processes because they may become seriously affected by the increasing amounts of meltwater discharge due to climate change. Dr Sugiyama's work is therefore crucial to understanding the impact of climate change on marine life and human activity in Greenland.

Collaborating with the Local Community

'Now, we are on the way to connect our natural science to a sustainable future of human society in Greenland,' says Dr Sugiyama. To help people to prepare for the future, Dr Sugiyama and his colleagues hold meetings with local communities to share the implications of their research findings and to exchange ideas.

The team's community work first started when they began working with a local hunter in Qaanaaq called Toku Oshima. Toku's father is a Japanese man who moved to Greenland over 40 years ago. 'We started our collaboration when Toku helped our ocean measurements by allowing us to use her boat,' explains Dr Sugiyama. 'She became interested in our research because changes in ocean conditions and marine ecosystems are extremely relevant to her fishing and hunting activities.' Dr Sugiyama further explains that Toku is famous in Greenland for being one of the country's best hunters, and for her contributions towards preserving Greenlandic traditions.

Toku began taking depth measurements herself to collect valuable data for the team whenever she was out on the water. It was around that time that she suggested that the team should meet and interact with local people to exchange ideas and experiences. 'We think this collaboration with a second-generation Japanese person in Greenland is unique,' says Dr Sugiyama, 'and her help has been very important for making our research more relevant to the society.'

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Meet the researcher

Dr Shin Sugiyama gained his undergraduate and master's degrees in Material Physics at Osaka University in Japan. He worked as a research engineer at Shinetsu Chemical Co. Ltd., before studying for his PhD in Earth Environmental Science at Hokkaido University. After his PhD studies, Dr Sugiyama relocated to Switzerland to conduct research into mountain glaciers at the Swiss Federal Institute of Technology. He then returned to Hokkaido University, where he is currently a Professor in the Institute of Low Temperature Science. His team's research focuses on glaciers and ice sheets as well as their interactions with the ocean. In particular, he focuses on glaciers in Greenland, Antarctica and Patagonia, where he has carried out extensive field work. Dr Sugiyama has served as the Vice president of the International Glaciological Society, and as a scientific editor for both Frontiers in Earth Science and Annals of Glaciology.

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ILTS

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ArCS Arctic Challenge for Sustainability

CAN CLIMATE CHANGE CAUSE EARTHQUAKES?

Earthquakes arise deep within the Earth, usually as heat from the mantle and the pull at subduction zones move tectonic plates around on the planet's surface, causing them to interact. **Dr Christian Brandes** and his colleagues at Leibniz Universität in Hannover, Germany investigate the lesser known phenomenon of how heavy ice-sheets can also have a significant effect on the behaviour of continental plates. In particular, they explore how the melting and movement of glaciers, such as that caused by human-induced climate change, can trigger earthquakes.

Visualising Earthquakes

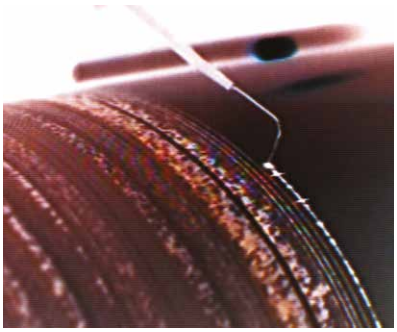
Earthquakes are well-known geological phenomena, usually caused when two pieces of the Earth's crust, called tectonic plates, bang or rub against each other. Most people are familiar with these contact zones as fault lines, the most famous of which is the North American San Andreas fault, which runs for more than 1,200 km across California. This fault marks the active contact between the Pacific Plate and the North American Plate and has been the source of significant death and destruction throughout history.

Imagine the surface of our planet as a bowl of hot custard – as the pudding starts to cool over time, a thin crust forms on the surface, analogous to the Earth's crust. This 'custard crust' then shrinks as it cools and cracks, and the pieces form plates, separate from one another and moving on top of a molten body. This liquid body, taking up almost the entire bowl, is the Earth's mantle. Heat from the mantle as convection currents and the pull from sinking of the plates at subduction zones moves the plates around on the planet's surface.

This is the foundation of the research carried out by geologist Dr Christian Brandes and his colleagues at the Leibniz Universität Hannover in Germany. They are working to understand the exact causes and effects of earthquakes. Much of the team's research is based on the testable hypothesis that earthquakes and the changes they cause to sediments on the ground can be triggered by melting glaciers and other related phenomena. However, this field remains controversial. As human-induced global warming continues to cause glaciers and other massive ice-sheets to melt, does this mean that we can expect more earthquakes in years to come?

Can Melting Ice Trigger Earthquakes?

In addition to being caused by deep Earth phenomena, Dr Brandes and his colleagues are uniquely concerned with the load that ice-sheets apply to continental plates, and how the melting of the ice can trigger earthquakes. Although it is well-known that the climate is warming due to human influences, causing ice to melt in cold regions, the effects of these changes (called 'isostatics') on earthquake generation is much less well understood.



In one recent study, Dr Brandes and his colleagues assessed changes at a major fault zone running across Denmark during the Pleistocene Epoch – the time period that lasted from about 2.5 million years ago to 12 thousand years ago. They wanted to understand the melting and shrinking of glaciers in northern Denmark, in an area called Jutland. The multidisciplinary team, which included Holger Steffen (Lantmäteriet, Sweden), Jutta Winsemann (Leibniz Universität, Hannover), Patrick Wu

(University of Hong Kong) and Peter Sandersen (Geological Survey of Denmark and Greenland), developed a series of models that allowed them to understand how changes in glaciation caused faulting and hence caused earthquakes across this region around 13,000 years ago. It turns out that much of the present-day shape of this region is the result of the retreat of glaciers as they melted – a souvenir of the last ice age.

This research is deeply relevant today if we are to understand the long-term effects of climate change, especially warming temperatures and their influence on the melting of polar ice caps and glaciers. Understanding the potential triggering of earthquakes in populated areas within Arctic and Antarctic zones of the planet is also an issue of public safety – we need to know how fast these structures can move, and how much and how rapid ice-sheet melting needs to occur before faults are activated.

Understanding How Sediment Deforms

Another key area of research that Dr Brandes and his colleagues focus on is the study of how sediments on the ground are changed by earthquakes, in a process called 'soft sediment deformation'. Because many people live in earthquake-prone regions, a huge proportion of the global population is at risk of injury or death due to buildings collapsing. Understanding the effects that earthquakes have on sediments under buildings is therefore of great importance.

Dr Brandes and his colleagues applied their skills to generate new data on soft-sediment deformation structures that result from earthquakes. Specifically, they investigated sediment structures that formed in young sediments within the upper Senne region of Germany. This region is in the vicinity of an important fault called the Osning Thrust – one of the major tectonic faults to occur in Central Europe.

The team was able to identify a number of key structures in sediments that were caused by local earthquakes along the Osning Thrust, with mysterious sounding names such as 'flame' and 'ball-and-pillow' structures. These are structures that form due to seismic shaking. Fluid sediments can move in these environments in similar ways to the lava flows we normally associate with volcanic eruptions, forming sediment tubes (clastic dykes), sills, and even sand volcanoes.

This research is important at the local level, since it is the first time that features related to the movement of fluids have been directly related to a major fault in northern Germany. There are also key global implications to this research, as discussed above – if characteristic sediment movements are triggered by earthquakes, it is possible to then predict their effects on buildings and areas with high population densities. Such clues left in the ground also allow scientists to identify the after-effects of earthquakes that happened in the past, especially those we can find in historical records.

Ice-Sheets and Earth's Crust Deeper in Time

The surface of Central Europe comprises a series of crustal pieces that were assembled like a jigsaw puzzle a long time ago, during the Palaeozoic Era, around 400 million years ago. Additional faults evolved during the Mesozoic Era. A further key research question being addressed by Dr Brandes and his colleagues, together with David Tanner (Leibniz Institute of Applied Geophysics) and Rebekka Steffen (Lantmäteriet,

Sweden) relates to how these pre-existing tectonic structures were reactivated during the Pleistocene glaciations in this region. As mentioned above, the team uses complex modelling approaches to assess these changes and has gradually built up a phased picture of tectonic evolution within the region.

The 115-kilometre-long Osning Thrust underwent a series of faulting movements over a 140-million-year period ending about 60 million years ago. The team has shown that movements along this fault also occurred very recently. Modelling these structures has enabled Dr Brandes and his colleagues to demonstrate that the Osning Thrust was reactivated at the end of the last glaciation, around 12,000 years ago. This fault reactivation was accompanied by earthquakes, which the team identified from the soft-sediment deformation structures that developed in this area. Their findings also imply that an earthquake, which took place in this region during the autumn of 1612, might have been triggered due to stress changes in the Earth's crust caused by a melting ice-sheet.

Seismology Is Relevant to Our Daily Lives

Earthquakes are hugely important globally, effecting millions of people every day. The research of Dr Brandes and his colleagues is key to develop clear pictures of how these phenomena change the nature of the sediments under our feet. Perhaps more critically, their work reveals how earthquakes are quite likely to be influenced by climate change, as the effects increase over the coming decades. Surprisingly, however, the issue of whether glacial melting can lead to earthquakes is still a subject of debate in many quarters, and research in this area remains controversial.

Intuitively, this connection makes sense. Picture a tennis ball with an elastic outer layer that recovers its shape after being squeezed. Heavy glaciers squeeze the land over time, and as they recede, the land retakes its form – this process is called 'glacial rebound' and is likely to be one of the major causes of earthquakes around the world. However, although many regions – such as Greenland, for example – are characterised by a good deal of seismic activity and postglacial rebound, it remains problematic to connect the two. However, some recent studies, such as those carried out in Iceland, suggest that glacial melting might also be related to increasing volcanism.

We know that humans are having a massive detrimental effect on the climate, causing increasing temperatures that melt polar ice-sheets and glaciers. Is it possible that the changes we are making to our atmosphere are also triggering deeper Earth events, such as volcanic eruptions and earthquakes?
Dr Brandes and his colleagues are working hard to gather more evidence.

Meet the researcher

Dr Christian Brandes
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Dr Christian Brandes received his diploma in 2002 and his doctoral degree in 2006 from Leibniz Universität Hannover in Germany. Upon graduating, he took his current role as researcher and lecturer at the Institute of Geology, Leibniz Universität Hannover. Here, his research focuses on tectonics, with a special emphasis on field-based structural geology, seismic interpretation, and numerical modelling. Dr Brandes utilises a multi-scale approach from outcrop to basin-scale, which involves geophysical methods to investigate upper crustal tectonic processes in sedimentary basins. Dr Brandes has participated in four expeditions to the Arctic in recent years, including to the New Siberian Islands, the Yukon North Slope, the Isfjorden area of Spitsbergen, and to northern Ellesmere Island.

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Leibniz Universität Hannover

NEW PERSPECTIVES ON MARINE ECOLOGY: TECHNOLOGY INFORMS OCEANIC CARBON MODELS

The world's oceans are responsible for absorbing large amounts of carbon dioxide from the atmosphere, helping to mitigate its warming effect on the planet. However, the way in which marine ecosystems respond to temperature changes can impact the ocean's ability to capture carbon, disrupting this global carbon cycle. **Dr Mark D. Ohman** and his team at the Scripps Institution of Oceanography, University of California, San Diego use advanced technologies to investigate how marine ecosystems respond to our warming climate. Their research is helping us to understand ecological responses to ocean warming, and to predict what the future holds.

The *California Current Ecosystem*

The *California Current Ecosystem* (CCE) is a vibrant and dynamic marine ecosystem formed by upwelling of ocean water along the coast of California, which is influenced by water currents and weather across the Northeast Pacific Ocean. Such coastal upwelling ecosystems are known for high production of phytoplankton and rich biodiversity.

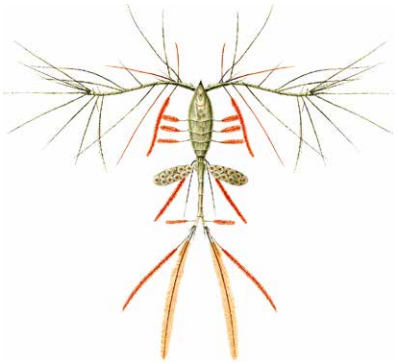
Since 1949, scientists have been observing the CCE in an ocean monitoring program known as CalCOFI, over an area off the southern California coast that ranges from San Diego to just north of Point Conception. More recently, satellites and drifting floats have been recording detailed measurements of oceanic properties that scientists can use as an additional means to measure changes in the coastal ocean.

In 2004, a grant from the US National Science Foundation drove the formation of the CCE Long-Term Ecological Research (CCE-LTER) site, which has permitted even deeper study of this fascinating marine ecosystem with the addition of many automatic sampling technologies. CCE-LTER Lead Investigator, Dr Mark D. Ohman and his team from the Scripps Institution of Oceanography at the University of California San Diego, use data from the CCE site to understand how marine ecosystems respond to large-scale changes in ocean temperature, acidity, dissolved oxygen, and anthropogenic disturbances.

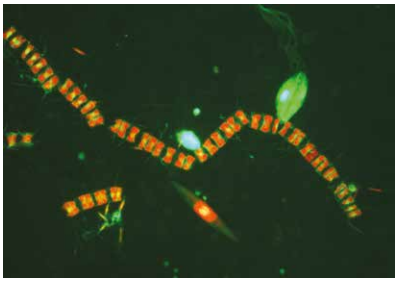
Measuring the Ocean

In addition to a wide array of satellite sensors, the team uses many advanced technologies to measure ecological and environmental factors that impact the CCE plankton food web. They use a squad of remote-controlled, sonar-equipped underwater gliders that can patrol for up to 100 days, measuring both the vertical position and density of plankton in a region of the ocean, along with temperature, salinity, and various chemical properties.

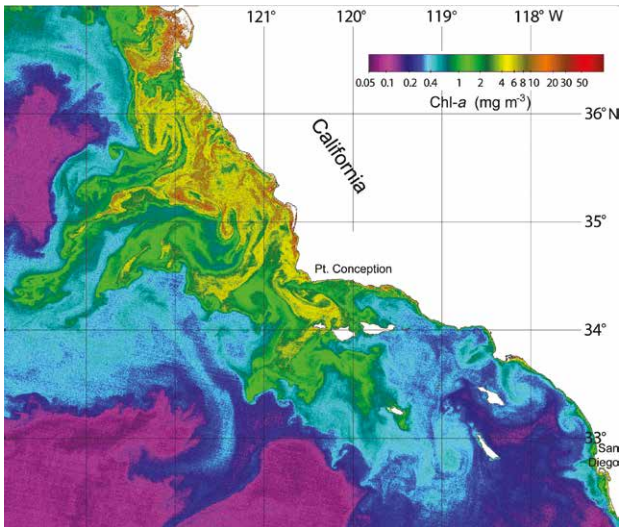
Pelagic red crab, whose presence indicates warm water intrusions in CCE. Photo by M.R. Stukel.



Planktonic copepod, Oithona. Illustration by W. Giebrecht, 1892.



Diatoms and dinoflagellates imaged with epifluorescence microscopy. Photo by M.R. Landry lab.



Coastal upwelling filaments, as illustrated by Chlorophyll-a concentration from OLCI on Sentinel 3A. Processed by M. Kahru, SIO.

While gliders cover a large spatial area, fixed-location moorings take measurements of a specific spot frequently and over an extended period of time. When used together, the moorings offer an in-depth look how an event unfolds in a specific area, while the gliders provide broader context to what is happening in the water surrounding the mooring. On shore radars map the movements of surface currents up to 150 kilometres off the California coast. Over the past few years, the CCE-LTER research team has begun to deploy a multitude of new autonomous drifting instruments with specialised sensors, which collect data on key parts of the planktonic food web and the physical and chemical factors that influence them.

In addition to the broad range of automatic sensors, Dr Ohman and the CCE-LTER team also regularly take to sea to perform fine-scale shipboard measurements. On a recent research cruise, 37 scientists and graduate students worked together around the clock for 30 days to understand the changing food web. With such a wide array of tools at their disposal, the team is able to gain comprehensive understanding of the region, even on days when it is too cloudy for satellite measurements, using instruments that extend far below the ocean's surface.

This comprehensive sampling program has allowed them to collect incredibly detailed and diverse measurements of ecological changes in the CCE, including the growth of bacteria and phytoplankton, grazing rates by drifting marine animals, and the rates of transport of carbon and other elements from the sea surface deep into the ocean's interior. They measure the structure of the food-web community using DNA-based methods, underwater cameras, microscopes and by investigating the chemical signatures of certain organisms. The team can then relate changes in plankton communities to environmental measures such as ocean temperature, acidity, and the availability of dissolved nutrients and trace elements such as iron. By leveraging CCE-LTER data, Dr Ohman's team has been able to describe ecological responses to abnormal ocean weather events in amazing detail.

Getting Warmer

From 2014 through 2016 there was a sequence of abnormal warming events affecting the Northeast Pacific Ocean. First, in the winter of 2013–2014, a large mass of warm water, nicknamed 'The Blob', formed in the North Pacific south of Alaska. This warm anomaly was the first in a series that occurred over the next year from the Arctic to Baja California, altering patterns of coastal upwelling in multiple places along the western coast of North America. Spring of 2015 appeared to be normal, but this was quickly followed by a major El Niño event that lasted until the following spring. The El Niño event also caused significant warming of ocean water in the Pacific.

The warm anomalies themselves are concerning, but even more concerning are the long-term ecological consequences of such events happening repeatedly over a short period of time. Numerous negative effects of the warm anomalies have been reported, including harmful algal blooms, contamination of shellfish populations, and impacts on seabirds and sea lions.

With its long, detailed record and advanced measurement technology, CCE-LTER provides an ideal site for studying the effects of marine temperature and other anomalies, and measuring their impact on the local ecology. Dr Ohman's team has described many of the ecological changes seen in the CCE following these abnormal warming events. They are using these data to inform advanced models of ecological responses to ocean warming with climate change.

Understanding the Ocean's Carbon Pump

Ocean fronts occur when a moving cold mass of water encounters a warm mass of water, or vice versa. Such fronts are often sites of heightened activity for marine life, where nutrients are exchanged and populations of plankton move and mix. They frequently stimulate the proliferation of plankton, in particular phytoplankton.

Phytoplankton are green, chlorophyll-producing single-celled plankton that consume carbon dioxide in the water, much like plants on land. They are a critical component of the biological carbon pump, as they convert carbon dioxide into organic matter, which can be consumed by zooplankton and other marine animals, before sinking to the ocean floor as faecal matter and carcasses. As carbon dioxide is the primary driver behind global climate change and ocean acidification, this ocean carbon pump is critical for removing carbon dioxide from the atmosphere, thereby mitigating its warming effects on the planet.

Following the warm anomalies and El Niño, the number of ocean fronts dropped dramatically across the CCE. Accordingly, there were massive drops in phytoplankton populations. Given the disturbance in the numbers of phytoplankton, the CCE-LTER team sought to understand the effects of the warm anomalies

Recovery of sediment traps.

Sorting copepods for experiments at sea.

and El Niño event on ocean carbon cycling: the production, grazing, sinking, and degradation of different forms of carbon.

The team examined how ocean warming and the influx of tropical waters impacted the persistence of different forms of carbon in surface waters. To their great surprise, they found that carbon sinking rates did not decrease following the warm events. While fewer phytoplankton were produced overall, the organic matter that sunk to the deep ocean remained steady. Marine zooplankton populations were still producing faecal matter and contributing to the biological carbon pump. This is a critical finding for the accurate modelling of carbon dynamics in ocean ecosystems.

Tracking Tiny Creatures

Copepods are tiny marine crustaceans that form the majority of zooplankton worldwide and are critical to the food web of numerous ecosystems. They are the most abundant animals above the sea floor. Without adequate numbers of zooplankton, many species of fish, marine mammals, and seabirds are without a food source. Copepod reproduction is often used as a way to measure the growth rates of animal life in a marine system, as they form the basis of many larger animals' diets.

Copepods themselves typically eat phytoplankton. The CCE-LTER team found that during abnormally warm events, the reproductive rate of these little creatures maintained its normal relationship with food availability – fewer phytoplankton generally meant fewer copepods. However, temperature did not appear to have any direct effects on their reproduction. This suggests that models can predict copepod abundance based on phytoplankton levels.

The CCE-LTER team then used the 70 years of data from the region to evaluate how zooplankton populations as a whole were impacted by the warm anomalies and the seven major El Niño events that occurred during over that time period. They found that while the total number of zooplankton was only slightly affected by the abnormal warm events, the numbers of different types of zooplankton in the region shifted dramatically. As populations of one species dropped in number, another would boom in its place. However, the populations ultimately showed remarkable resilience to the abnormal weather events, recovering to their normal composition within a year of each major warming anomaly. What remains unknown is whether this resilience will persist following future El Niño events, as the ocean warms further still.

These zooplankton abundance data help to explain why warming events that reduce the number of phytoplankton do not reduce the amount of carbon being sequestered to the ocean floor through faecal matter.

Informing Climate Models

Understanding how fluctuations in ocean temperatures impact carbon sequestration is of great significance as global climate change increases the frequency of abnormal warming events. This requires an in-depth appreciation for the complex ecology of the oceanic communities that form the biological carbon pump.

Dr Ohman and his team at the CCE-LTER site use an array of advanced measurement technologies to illuminate the interplay between environmental changes and the CCE food web. Their discovery that zooplankton levels of carbon sequestration during a warming event remain steady despite drops in phytoplankton is an important finding in oceanic ecology with major implications for models of carbon movement.

Warming events are predicted to grow increasingly common with global climate change and it is critical to understand how they will shape the Earth's ecosystems. The forecasting models built with CCE data will help scientists to predict how this major coastal upwelling ecosystem will respond to these changes and to understand the consequences for the global carbon cycle.

Meet the researcher

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Dr Mark D. Ohman earned his PhD in Oceanography from the University of Washington, Seattle. He is a Distinguished Professor of Biological Oceanography in the Integrative Oceanography Division of Scripps Institution of Oceanography, UC San Diego, as well as Curator of the Scripps Pelagic Invertebrate Collection. As a specialist in marine zooplankton, Dr Ohman serves as the lead Principal Investigator of the *California Current Ecosystem* Long-Term Ecological Research (CCE-LTER) site, where he is currently working on multiple projects to quantify the effects of climate change on plankton populations and develop novel technologies for measuring marine ecosystems.

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http://cce.lternet.edu/about/personnel

FUNDING

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ECOLOGY

ARRESTING AND REVERSING ECOLOGICAL BREAKDOWN

Earlier this month (May, 2019), the United Nations released a landmark report, the *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Global Assessment*, detailing the most extensive evaluation of life on Earth ever performed. Created by world-leading specialists in biodiversity and conservation, the report describes unprecedented declines in wildlife due to human activity, through climate change, habitat destruction, overexploitation of the planet's resources, pollution and the introduction of invasive species.

From the planet's rapidly dying coral reefs, to the widespread conversion of rainforests into farmland, nature is being destroyed at a rate that is tens to hundreds of times higher than average. The overall mass of wild mammals has fallen by a terrifying 82%, natural ecosystems have lost about 50% of their area and a million species are at risk of extinction. The scientists call for a similar degree of urgency to the international response to climate change to arrest species loss, as the short timeframe to address the crisis is narrowing.

If we don't, our human societies are at risk of collapsing – a risk that is compounded by the increasingly severe effects of climate change, detailed in our previous section. 'The health of the ecosystems on which we and other species depend is deteriorating more rapidly than ever,' said Robert Watson, chair of IPBES. 'We are eroding the very foundations of economies, livelihoods, food security, health and quality of life worldwide. We have lost time. We must act now.'

The report is based on 15,000 academic papers and reports from indigenous groups, which show biodiversity losses and species extinctions across the globe. However, it is impossible to know the true magnitude of the crisis, since we don't currently know the actual number of species currently inhabiting the planet. Only around 1.5 million species have been documented, while estimates for the actual number vary wildly. Our conservation efforts can only be successful if we know about most of the species on Earth and which ones are in the greatest need of protection.

In order to save Earth's undocumented species from extinction, scientists are working hard to complete the inventory of our planet's biodiversity. This is the focus of our first article in this section, where we showcase the research of Dr Thomas Wilke of Justus Liebig University Giessen in Germany. His research team is developing a novel open-access and semi-automated taxonomy platform that will encourage global collaboration towards the common goal of documenting and describing Earth's currently-unnamed species.

On the topic of taxonomy, we then move on to theorise answers to an important taxonomic and existential question: what was Earth's first animal, from which all other animal species evolved? Here, we meet Dr Bernd Schierwater at the University of Veterinary Medicine Hannover, who has spent the past twenty years searching for the answer, which he now believes could rest on tiny, sticky creatures called placozoans. In line with the widespread declines in biodiversity discussed above, placozoans are highly sensitive to increasing ocean temperatures, and will likely exhibit population declines as global temperatures continue to rise.

Next, we shift our attention to declining biodiversity in cities and towns. Although urbanisation only takes up a small fraction of the planet's surface, the global human population is growing, causing urban areas to become overpopulated and green areas to be replaced with urban infrastructure. This is compounded by the fact that the global population is also becoming increasingly urbanised, with more than 54% of people living in towns and cities – a figure that was just 33% in 1960.

The loss of greenspace also means that an increasing number of people might rarely experience wildlife in their daily lives, reducing their connection with nature and their willingness to conserve it. This decreasing connection with the natural world, coupled with accelerated urbanisation, has undoubtedly contributed to declines in wildlife populations and extinctions.

To remedy this situation, Dr Ingo Kowarik of the Technical University of Berlin, who we'll meet in the next article of this section, is investigating ways to prevent such a crisis from continuing. Using evidence gathered over the past decade, his research team ultimately aims to design, develop and implement approaches that can effectively integrate biodiversity into urban environments, and are encouraging conservation policies that embrace wildlife within towns and cities.

From boosting biodiversity in cities, next we shift our attention to improving the health of forest ecosystems. Covering approximately 31% of the world's land surface, forests are one of the most important systems on Earth, supporting the majority of the planet's terrestrial wildlife, and acting as a vast carbon sink to offset the impact of our fossil fuel emissions. Therefore, it is essential that we protect the planet's remaining forests, as well as replacing those that have been destroyed, if we are to begin to reverse our disastrous impact on global biodiversity.

Towards this aim, detailed maps of the planet's forests are required, which provide information about the health of woodland ecosystems, so that we can develop the most effective management strategies to conserve and restore them. This is the focus of our next article, in which we showcase the work of Dr Peter Krzystek and his team at the Munich University of Applied Sciences. Dr Krzystek and his colleagues have developed innovative methods that combine laser scanning and aerial imagery to create extremely detailed, three-dimensional maps of the Earth's forests. The team's cutting-edge techniques can identify individual tree species and dead trees with remarkable accuracy and resolution.

Another scientist who develops technologies for monitoring the health of Earth's ecosystems is Dr Brian Glazer at the University of Hawai'i, whose research we'll showcase in the next article of this section. His team applies lower-cost electronic, computing, and sensor technologies to carry out remote coastal 'health checks' in real time, by monitoring water temperature, salinity, dissolved oxygen and weather events. These regular health checks can facilitate a faster response to environmental problems, meaning a better chance of reducing or even avoiding environmental damage.

In addition to forests and coastal areas, estuaries are also host to vital ecosystems that are under severe threat due to human activity. In many parts of the world, humans impact estuaries by extracting large amounts of freshwater from the rivers that flow into them, to accommodate urban, agricultural and industrial development. Reducing the amount of freshwater flowing into an estuary causes increased salinity – disrupting its delicate ecosystems.

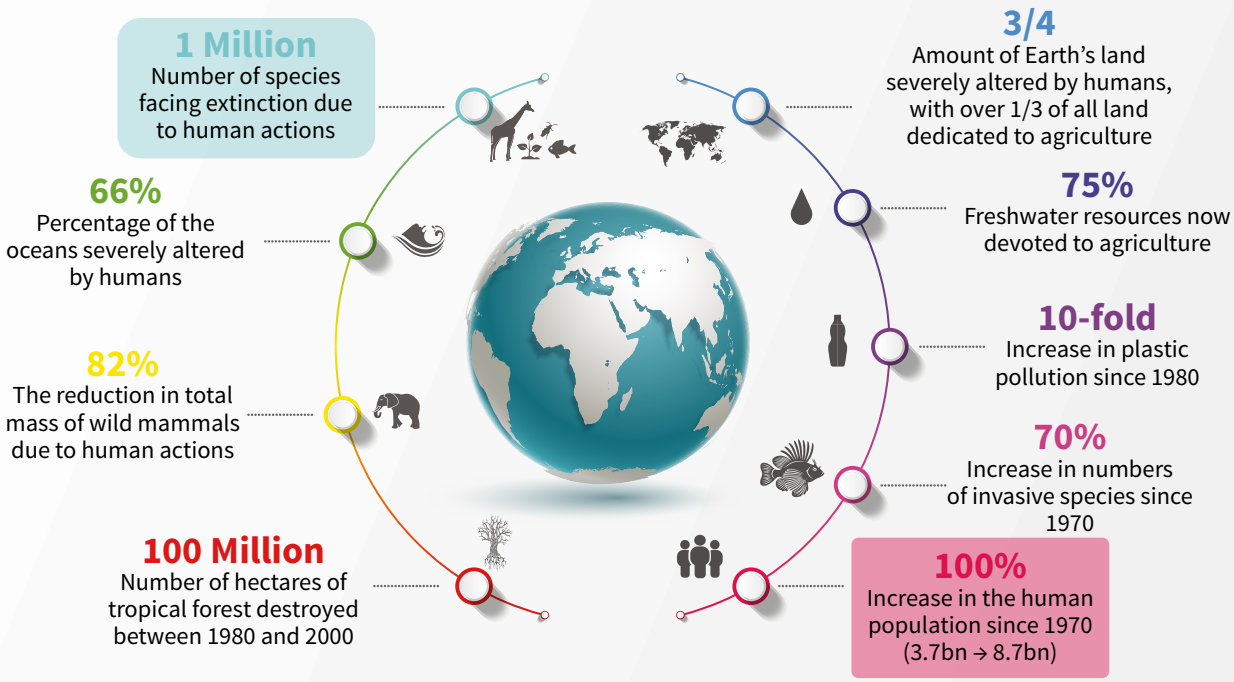
Salinity is one variable that Dr Paul Montagna at Texas A&M has identified as an effective measure of ecosystem health in estuaries around the Gulf of Mexico. In the next article of this section, we introduce his team's research into assessing estuarine health, and identifying so-called 'bioindicators' that can be used to easily measure it, such as salinity. By closely monitoring such estuarine bioindicators, resource managers can be much better equipped to effectively respond to environmental problems before they get out of hand.

Dr Jill Slinger of the Delft University of Technology is also passionate about maintaining and restoring the health of estuarine ecosystems across the globe. Her research focuses on gaining a better understanding of estuarine, coastal and river ecosystems, and how this improved knowledge translates into developing effective policies for improved environmental management. As we'll learn in the next article of this section, Dr Slinger also focuses on negotiating the complex issues that arise when the perspectives of affected stakeholders and community members intersect, and determining how, despite differences, long-term progress can be achieved.

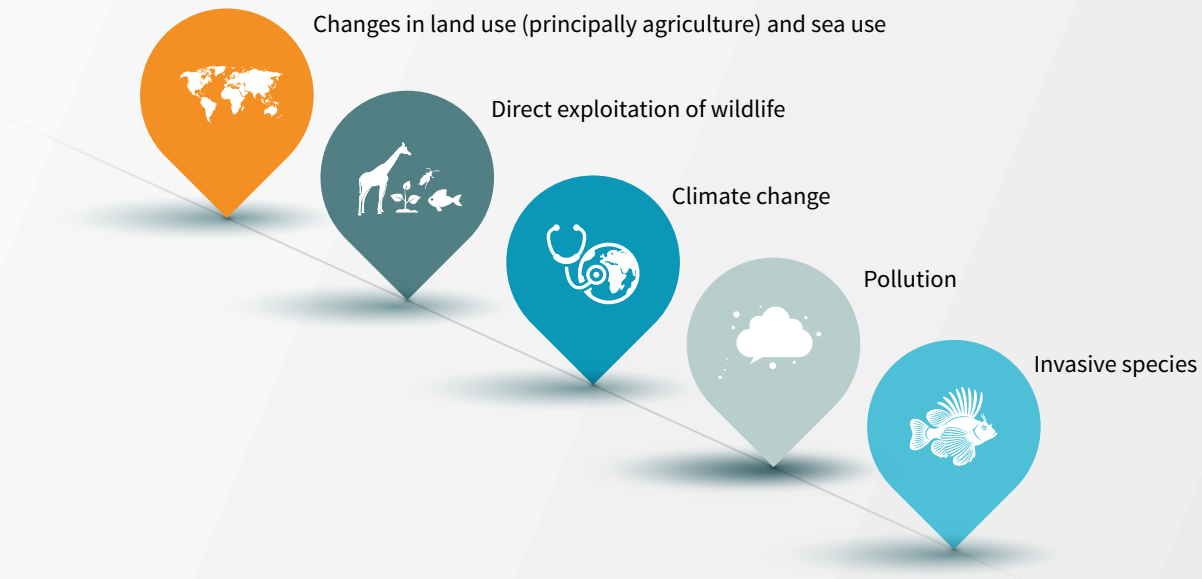
Our next article focuses specifically on the increasing threat of rising global temperatures on Earth's species, where we discuss one animal that is particularly vulnerable – the brown trout. Here, we meet Dr Thomas Wahli of the University of Bern, who has been exploring how global warming is leading to severely decreased populations of this important species. His team's research shows that in cold water, brown trout are less vulnerable to infection by the common parasite *Tetracapsuloides bryosalmonae*, and there is very low or no risk of death at temperatures between 8°C and 15°C. However, at temperatures above 15°C, which are becoming increasingly common in European rivers, Dr Wahli found that the parasite's life cycle is sped up and fish mortality can rise to over 80%.

As mentioned earlier, invasive species are yet another result of human activity that can decimate native populations. One incredibly problematic invader around the US and Central America is the lionfish. Native to the Indo-Pacific, this marine predator was first reported in the coastal waters of Florida in the 1980s, likely as a result of aquarium releases. They then rapidly proliferated, spreading to the south-eastern seaboard of the US, the Gulf of Mexico, and the greater Caribbean region. In the final article of this section, we meet Dr Mark Hixon and his colleagues, who have been working to understand the ecology and behaviour of this damaging species, so that the lionfish invasion can be better managed.

Findings from the IPBES Global Assessment



5 major drivers of wildlife declines:



A NOVEL TOOL TO BETTER UNDERSTAND THE DIVERSITY OF LIFE

Completing the inventory of the Earth's biodiversity is a huge challenge. Supported by the German Research Foundation (DFG), **Professor Thomas Wilke** and his research group at Justus Liebig University Giessen in Germany are addressing this challenge head on. The team is developing a novel open-access and semi-automated taxonomy platform that will encourage collaboration towards the common goal of documenting and describing as yet unnamed species.

An Incomplete Inventory of Earth's Biodiversity

Learning what species inhabit our planet is a fundamental quest for biology. Taxonomists are the stewards of knowledge about the world's living and fossil species – they discover, describe, and classify 'taxa' – groups of similar organisms. Despite the key role that taxonomy plays in the conservation and management of biodiversity, our taxonomic knowledge is far from complete. Even at the most conservative estimate, there are more unknown species than known ones.

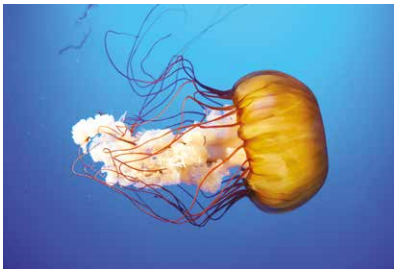
The science of taxonomy emerged in the 18th century with the Swedish botanist Carl Linnaeus. Linnaeus devised a two-part Latin-based naming system, whereby every organism has both a genus and a species name (*Homo sapiens*, for example). Linnaeus's biological classification system has been adapted by researchers for more than 250 years, and to date, around 1.5 million species have been validly described.

The actual number of species on Earth, however, remains uncertain – but estimates suggest that it is in the region of between 3 to over 100 million species. Therefore, there is a vast number of species that we know absolutely nothing about, and notably, the rate of species description per taxonomist has not increased in recent years.

Quality versus Speed

Significantly reducing the knowledge gap in the number of undescribed species is a weighty challenge. The speed at which species description can be documented by taxonomists is a factor, and with increasing extinction rates, this is especially important. There is an inherent conflict between the two main interests of taxonomy – the quality of description and delimitation (determining the boundaries between species) and the speed of description and delimitation. Each comes with its own set of specific issues.

There are several obstacles to high-quality species description. Examples include a lack of appropriate samples to make taxonomic comparisons, insufficient assessment of the range of character variation, neglecting to assess relevant characteristics, and disagreements on species concepts.



‘proSDS integrates various data sets, for example, anatomical, 3D-morphological, genetic, ecological, and biogeographical information, and uses supervised machine-learning approaches for dynamically delimitating species.’

In addition, there are also problems associated with the speed of description. These can be related to data (accessibility of information, differences in data formats, and issues with standards of coding of species’ characteristics) and to inference (lack of standardised algorithms, problems with missing data, and conflicts among datasets).

Compounding matters, current species delimitations tend to be ‘black and white’. That is, assignments are classified as either ‘no species’ or ‘species’. In reality, however, there are areas of grey. If we assume that the process of speciation (the formation of new and distinct species) is an evolutionary process that lasts hundreds of thousands or even million years, such discrete assignments can bias biodiversity estimations.

In addition, the current number of taxonomists is insufficient to document the remaining species within a reasonable time period. Many believe that taxonomy is in a state of crisis and scientists are concerned that numerous species will disappear before being named.

DFG ‘Taxon-Omics’ Priority Programme

The DFG is tackling this taxonomic crisis by establishing its Priority Programme (SPP) 1991 ‘*Taxon-Omics: New Approaches for Discovering and Naming Biodiversity*’. The €5.5 million initiative recognises the importance of developing innovative methods for dissemination and preservation of knowledge for future discoverability and re-use.

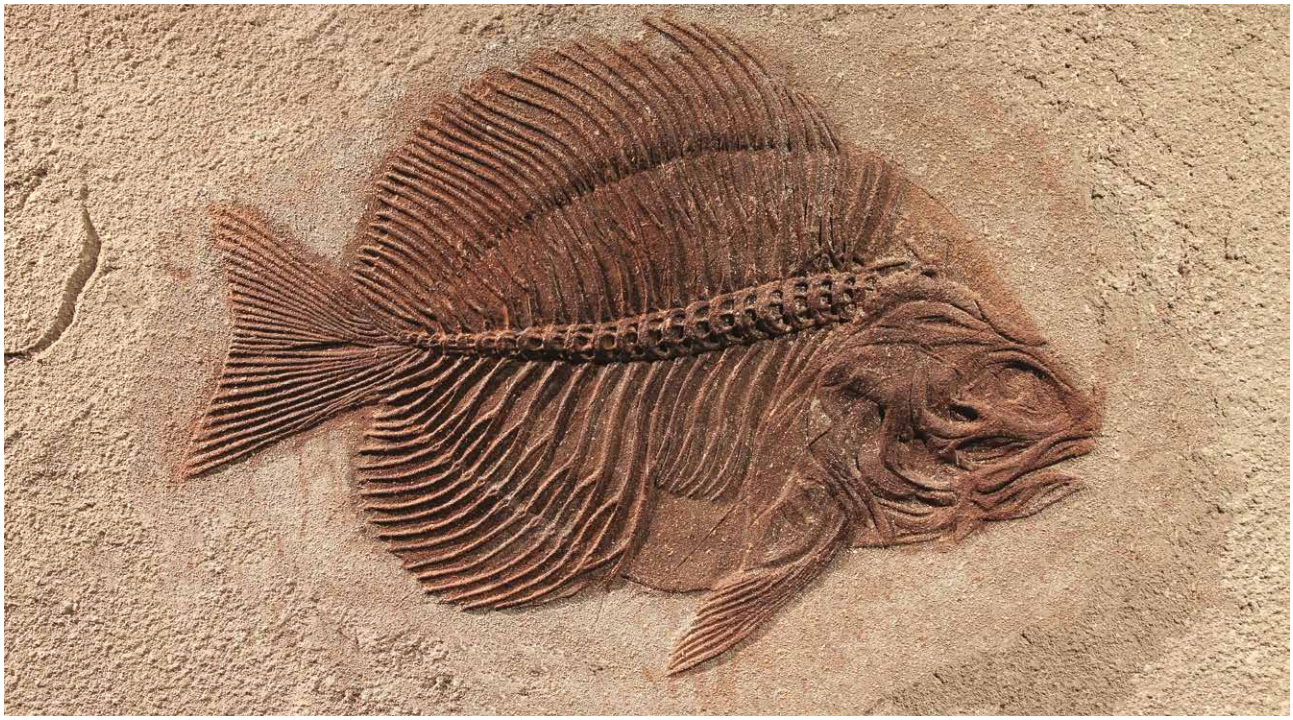
A promising solution to the taxonomic crisis is the integration of museum information with genetic data. DFG’s programme particularly supports new approaches that will increase the quality of species delimitation. It also aims to speed up the naming process, generate online identification tools, make novel use of natural history collections through ‘museomics’ (genomic data from historic specimens), and develop semi-automated analyses of specimens through machine learning.

A Novel Semi-Automated Species Discovery System

Professor Wilke and his team at the Institute of Animal Ecology and Systematics in Giessen hold one of 27 such research projects funded by the DFG’s Priority Programme. His team is developing a novel probabilistic and semi-automated species discovery system (or ‘proSDS’).

The ground-breaking tool will integrate non-genetic information with genetic data, utilising available information from museum collections and public databases. As Professor Wilke explains: ‘proSDS integrates various data sets, for example, anatomical, 3D-morphological, genetic, ecological, and biogeographical information, and uses supervised machine-learning approaches for dynamically delimitating species.’

Professor Wilke’s integrated approach was partly inspired by his postdoctoral experience at the Malacology Department of the Academy of Natural Sciences in Philadelphia, which boasts one of the largest mollusc collections worldwide. This work highlighted the huge value of these collections for making taxonomic decisions, but also the limitations of standard morphological approaches and the problem of missing genetic information. His experience led to a desire to better integrate museum materials with complex genetic (‘omics’) data sets.



The Snail Family Hydrobiidae

Professor Wilke and his team are drawing on a wealth of research expertise spanning 20 years into the taxonomy, systematics, and evolutionary biology of the microgastropod family Hydrobiidae. They are using this species-rich and taxonomically 'notoriously difficult' family as a model group with which to develop proSDS.

The tiny hydrobiid snails make up one of the largest gastropod families – with at least 900 valid species. Additionally, it's thought that the current number of named species may represent only one quarter of their actual diversity.

There are many gaps in the taxonomic knowledge of the hydrobiids. Genetic information is available only for a portion of species, and only a few large-scale comparative studies have been carried out. As Professor Wilke explains: 'The taxonomy of hydrobiids is clearly in need of revision in a comparative context using genetic, anatomical, ecological, and biogeographical information. Very likely, such integrated studies will further increase the number of described species.'

His team's first step will be to create a curated specimen-based reference database that includes a range of information on hydrobiid species (including genetic, biogeographic, ecological, anatomical, and 3D morphological data). As they will draw upon extensive previous research, only the 3D shell morphological scans will need to be generated from scratch. To obtain these scans, the team will take advantage of strong collaborations at European and North American museums, as well as the extensive collection of approximately 100,000 hydrobiid snails at the University of Giessen.

A Standardised and Scalable Tool

The proSDS team aims to address the problem of integrative species delimitation from a novel angle by utilising training datasets and a flexible machine-learning approach. Many of the system's features are innovative, including its ability to build on integrated data and to manage missing information. It can process mixed data types, retrieves information automatically from public databases and provides the user with probabilities that a specimen under investigation belongs to a known or novel species.

Initial evaluations of proSDS are very promising. The system demonstrates good performance, both for simulated and real data with high rates of correct species classifications over a wide range of variation within and between species.

An Open Source Resource

The team's aim is to assist scientists in making taxonomic decisions by estimating the probability that a specimen under investigation belongs to a known or novel species. The underlying machine-learning approach will also provide information for the individual contribution of the specific characteristics. Importantly, this may well alert taxonomists to potential conflicts among existing datasets.

In the future, proSDS will be applicable to a wide range of taxonomic groups. By providing open access to the tool, the team hopes that it will encourage collaboration towards the fundamental goal of furthering knowledge into the evolution, maintenance, and conservation of biological diversity.

Meet the researcher

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Professor Thomas Wilke graduated with a diploma in Biology with summa cum laude from Potsdam College and Humboldt University, Berlin, in 1989. He was awarded his PhD in Zoology from the University of Potsdam in 1994 and his habilitation in Zoology at Goethe University, Frankfurt am Main in 2001. Professor Wilke then held positions at the Academy of Natural Sciences, Philadelphia, and The George Washington University Medical Center, Washington DC, before taking a full professorship at Justus Liebig University Giessen in 2004. Here he is currently the Head of the Systematics and Biodiversity Group. Since 2005, he has also held the position of Vice President of the German Malacological Society (DMG).

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FUNDING

German Research Foundation
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German Ministry of Higher Education and Research

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JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

MOTHER OF ANIMALS: INTRODUCING THE PLACOZOA

Who are we? Why are we here? And where did we, as humans, come from? Each of these questions is fundamental to understanding our presence here on Earth, and have over time led to a split in opinion amongst scientists. One such example of this comes from theorising answers to another all-important question: what was Earth's first animal? **Professor Bernd Schierwater** at The University of Veterinary Medicine Hannover has spent the past twenty years searching for the answer, which he now believes could rest on tiny sticky and hairy creatures called Placozoa.

Understanding Evolution

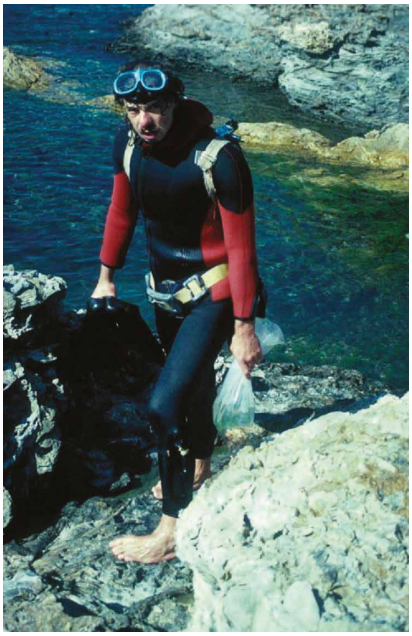
When asked to think of the term 'evolution', many people will automatically think of two things: firstly, monkeys – due to the widespread belief that humans evolved from apes (we actually evolved simultaneously from a common ancestor); and secondly, Rudolph Zallinger's *March of Progress* image. However, you have to go back a lot further in time to find the true ancestor that humans actually evolved from.

According to Professor Bernd Schierwater, a renowned zoologist at The University of Veterinary Medicine Hannover, and a leading expert in early-Earth animals, the first animals on Earth were tiny organisms with only six different cell types and the simplest animal body, called Placozoa. What are these, you ask? Well, as Professor Schierwater himself puts it: 'Placozoa are the most unique animals one can think of. They have no discrete organs, no clear nerve or muscle cells.' In fact, only six different cell types perform all of the animal's functions – from eating, smelling and seeing, to moving, growing and reproducing.

Understanding Placozoa

Placozoa crawl as flat, tiny plates over hard surfaces in most oceans. They were originally thought to only live in warm waters, but Professor Schierwater now predicts that they can be found in cooler waters as well. They also live relatively close to the surface, as their food (algae) relies on the sun's energy, so Professor Schierwater and his team rarely have to 'take their trousers off to collect them'.

Placozoans were first identified back in 1883 by the German zoologist Franz Eilhard Schulze, in an aquarium based in Graz, Austria. The Placozoa species that he discovered he labelled *Trichoplax adhaerens*, derived from the Greek 'thrix' (meaning 'hair') and 'plax' (meaning 'plate'). The term '*adhaerens*' came from the animal's tendency to 'stick' to glass, meaning that their name literally translates to 'sticky hairy plate' – which more or less tells you what they look like. In the field, the 'sticky hairy plate' creatures have been 'frequently overlooked' for more than a century, with no reported sightings even at highly active marine research stations where placozoans occur in high abundance.



Bernd Schierwater as a graduate student collecting at Banyuls-sur-Mer, France. Collecting placozoans from different depths can be exhausting, but fortunately placozoans can also be sampled in shallow waters with your trousers on. CREDIT: Professor Martin Wahl

But why are they so important to scientific research? And why has Professor Schierwater dedicated most of his academic career to understanding them? Mainly because they are incredible organisms that we can learn a lot from.

‘If we want to learn about animal evolution, why not start with the smallest, simplest and potentially most ancestral animal? If you can’t understand the simple, good luck with the complex!’

CREDIT: Svenja Danehl

Samples collected from the field are transferred to the laboratory in Hannover for microscopic inspection. Often several hundred samples from different oceans worldwide are cultured in the laboratory at the same time.
CREDIT: Kathrin Wysocki

Understanding Science

Everyone knows that you cannot run before you walk, yet that principle is sometimes overlooked within science – especially within this area of research. Genetics is a fascinating area of science, providing us with medicines for an array of different health conditions, yet it is also highly complex, and requires incredible precision in order to utilise effectively. With this in mind, understanding how the genetics of a complex organism, such as a human, works is no easy task – after all, you cannot build a house without laying the foundation first.

The average human contains over 30 trillion cells, each of which are encoded for by specific gene interactions. Given that there are more than 20,000 active genes in humans and an almost unlimited number of possible gene interactions, understanding how to put together a jigsaw puzzle this size is incredibly difficult. Yet this is, in essence, what many scientists are currently doing. So where are we going with this?

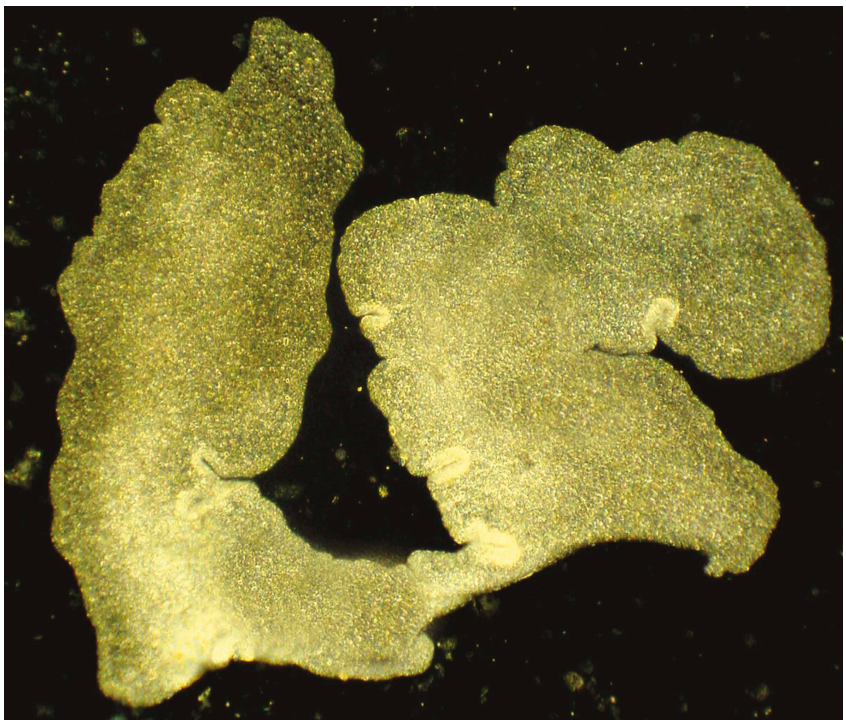
The placozoan *Trichoplax adhaerens* provides researchers with an organism that is much easier to study, understand and utilise in future drug design. As Professor Schierwater said in a recent *Current Biology Magazine* article: ‘If we want to learn about the evolution and structural organisation of genomes, why not start with the smallest, simplest and potentially most ancestral animal? As a rule of thumb, it is often helpful to first learn the basics before you analyse more complex entities. A lot can be learned from these tiny masters of morphological simplicity, especially in terms of cancer research, neurology and the evolution of organs.’

However, despite Professor Schierwater’s ongoing dedication and passion for Placozoa research, many other researchers in the field remain unconvinced. This has been mainly because of the biological controversy surrounding how the animal tree initially developed. To understand this requires a little biology lesson.

Understanding Family Trees

Welcome to Biology 101. There are five distinct groups that make up the metazoan animal tree of life. The most derived group is that of the ‘Bilaterians’, which includes most animals – humans, fish, insects, worms, etc. This group also differs to the other four groups, in that Bilaterians develop from three germ-cell layers (the layers of cells that form during reproduction), rather than two.

The other four groups are known as Diploblasts, due to forming from two germ-cell layers rather than three. These groups include Poriferan (sponges), Ctenophores (comb jellyfish), Cnidarians (corals and jellyfish) and Placozoa. We, as humans, evolved as a result of the relationship between these groups, yet it is not clear what the exact nature of that group relationship was.



A vegetatively reproducing placozoan specimen, which soon will divide into two daughter individuals of about the same size. CREDIT: Schierwater Lab

As Professor Schierwater sums it up: 'There are 105 ways that five taxa (groups) can be arranged in the animal tree, and nearly half of these have been offered as hypotheses for the relationships of these five taxa.' This, in turn, gives rise to one of zoology's longest-running and hotly-debated topics: which metazoan animal came first – Cnidarians, Ctenophores, Poriferans or Placozoa?

According to Professor Schierwater and his colleagues, the answer is 'Placozoa'. Following research at the American Museum of Natural History in New York and Yale University, Professor Schierwater's team examined genes and all other available data from several animal species representing the five critical animal groups.

The team developed a model capable of determining how and when each animal group evolved, i.e., they built an evidence-based animal tree that could then be used to test the different hypotheses. From this work, Professor Schierwater found that Placozoa were not only the first 'base' animal on the tree, but he also found evidence that Bilaterians (which include humans) actually evolved independently from Diploblasts (jellyfish, sponges, etc.) – going against a long-standing theory.

In other words, an ancestral sponge had long been believed to be the base animal, from which each of the five groups evolved in a certain order. Professor Schierwater's research has challenged that view, finding that animals such as jellyfish and sponges actually evolved in one route from a Placozoan base animal, while other animals such as insects and humans evolved at the same time in an entirely separate pathway.

Understanding Scepticism

Certain zoologists remain sceptical about this theory though, due to contradictory evidence surfacing from recent advances in DNA sequencing. However, such advances have regularly been shown to produce the most short-lived hypotheses that the natural sciences have ever seen. Thus Professor Schierwater remains unshaken and says, 'Placozoa are a "natural" fit at the base of the metazoan tree, especially when considering 'comparative organismal evidence and genuine biological knowledge'.

A lot more research remains to be done, but one thing is for certain – these tiny sticky hairy plate creatures require a lot more attention moving forward. Not only could they answer one of life's great questions, but they could also support research into the design and development of several drugs for a variety of diseases. It is no surprise that Professor Schierwater has such a passion for them.

He even remembers the first day he encountered Placozoa in incredible detail, citing an undergraduate presentation from his then-teacher, Professor Carl Hauenschild. Little did he know at the time, but that presentation would later go on to shape the rest of his academic career.

'It was on a Tuesday night, around 6 pm on 11 December 1979, when my most respected teacher, Carl Hauenschild, listed several reasons for Placozoa possibly being a basal metazoan phylum, i.e., the 'base' animal of the Metazoan animal tree,' he says. 'The black and white pictures thrown from the solid 30-year-old Leitz slide projector were not very impressive, yet they somehow fascinated me. Already I knew, I want to study Placozoa when I become a researcher.'

And that he did. Almost forty years on, and Professor Schierwater's dedication to the research of Placozoa is unparalleled. He is a highly renowned and respected zoologist and the leading expert for placozoans. Through his work at The Institute of Animal Ecology and Cell Biology at the University of Veterinary Science Hannover, he and his team have found that Earth's first animal could be none other than a 'sticky hairy plate'.

CREDIT: Martin Bühler

Meet the researcher

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Professor Bernd Schierwater is a German zoologist who has dedicated his academic career to the study of the Placozoa. Following his BSc in Biology at the Technical University Braunschweig in Germany, Prof Schierwater went on to study a BA in Psychology and an MSc in Biology, before conducting his PhD under the guidance of Carl Hauenschild and Fritz Wagner. He later went on to work as a Postdoctoral Research Fellow at Yale University before becoming an Assistant Professor at the University of Frankfurt, Germany, and Associate Professor at Freiberg University, Germany. He currently works as Professor of Zoology at the University of Veterinary Medicine Hannover and also as a Research Associate at both Yale University and the American Museum of Natural History New York.

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FUNDING

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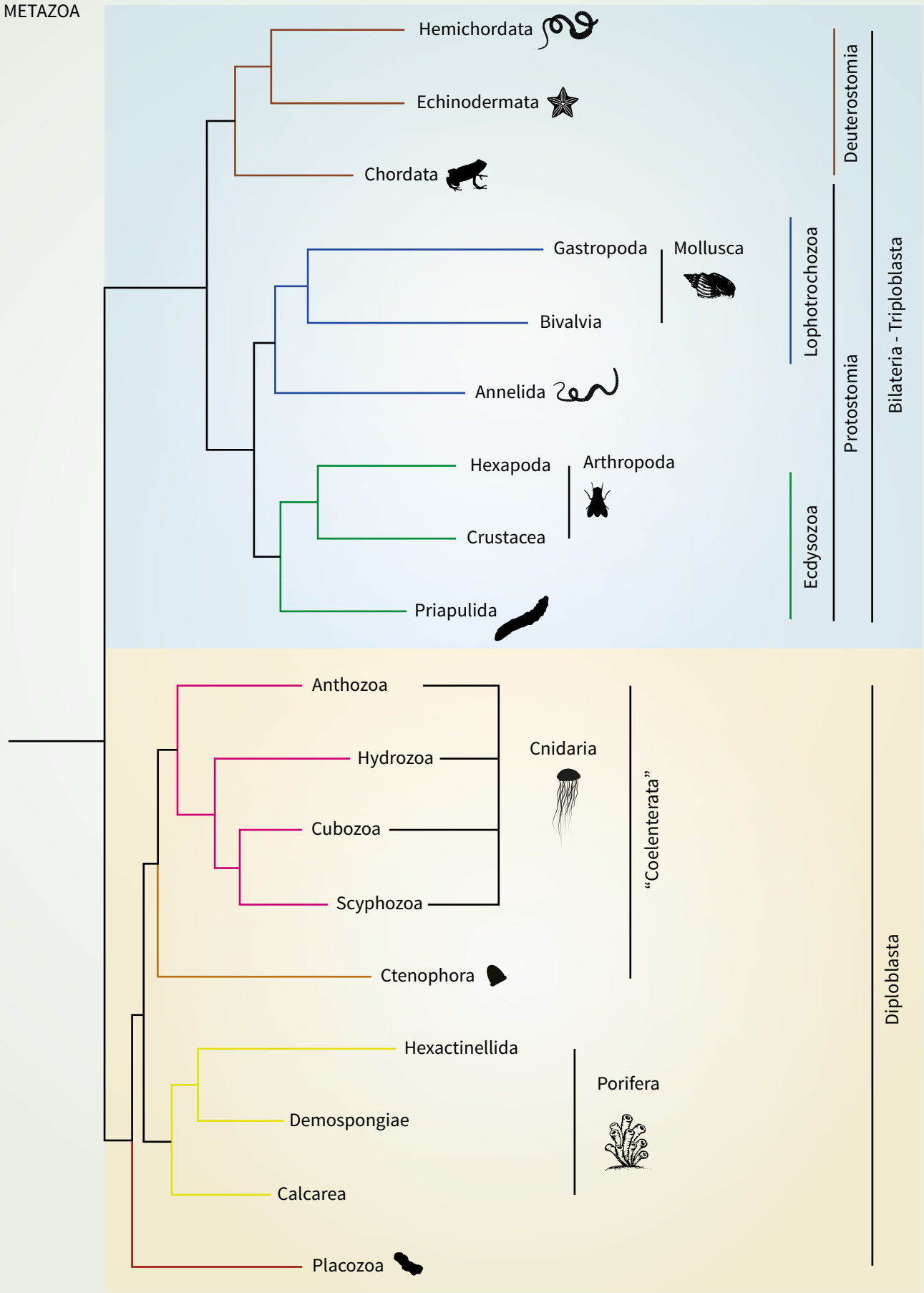
PHYLOGENETIC POSITION OF PLACOZOA



TACKLING THE URBAN BIODIVERSITY CRISIS

The planet's human population is becoming increasingly urbanised. This has led to reduced biodiversity in cities, which has brought all sorts of problems with it – from limited species variety to declining bee populations and decreasing opportunities for urban people to experience nature. **Professor Ingo Kowarik** and his team at the Technical University of Berlin are investigating ways to prevent such a crisis from continuing, and are encouraging conservation policies to embrace biodiversity within urban environments.

The world's population is growing at an unprecedented rate. There's no escaping that. In fact, only two centuries ago there were less than one billion humans living on Earth. Today there are more than seven billion. Of this seven billion people, more than 54% live in cities – a figure that was just 33% in 1960.

This large city-dwelling proportion of the global population is expected to climb further, due to the belief that cities are places where better standards of living can be found. Such accelerating urbanisation is one major driver behind the 'biodiversity crisis' – the loss of species across all ecosystems globally. But what exactly is meant by this? And why does a lack of biodiversity across urban areas represent a *crisis?*

Houston, We Have a Problem

To put it in simpler terms, imagine you were asked to draw an image of the Earth. Which two colour pens would you predominantly use? Blue for oceans and green for areas of land, right? Well, throw the impact of a growing human population into the mix and herein lies the biodiversity issue. It turns out you might not be needing that green pen as much as you think.

Cities across the world are becoming overpopulated, which leads to an increased need for urban growth. More people means an increased requirement for jobs and accommodation, which means more land taken up by skyscrapers, housing and transport networks. However, this loss of land and 'greenspace' from cities has an overarching effect on urban biodiversity – the plants and animals that exist within urban environments.

This loss of greenspace also means that an increasing number of people have no access to nature in cities, which is expected to change people's attitudes towards nature and reduce their willingness to conserve biodiversity, both inside and outside cities. In essence, the more our population continues to grow, the more our world's biodiversity will continue to suffer.

Tackling this issue is therefore a major global concern – one that Professor Ingo Kowarik and his team at the Technical University of Berlin are working to address. 'Understanding how biodiversity develops under novel urban conditions, and how plants can survive in urban environments, are both key questions to ask,' he says. 'Accelerating urban growth is a major threat to biodiversity.'

Asking the Expert

Ingo Kowarik has worked as a Professor of Ecosystem Science and Plant Ecology at the Technical University of Berlin for almost twenty years. However, his dedication to tackling the biodiversity crisis spans over a much longer time period, having first studied a Diploma in Landscape Planning back in 1981.

Professor Kowarik has largely focused on investigating biodiversity patterns

and their underlying mechanisms in a changing world, particularly centring on cities and 'biological invasions'. 'Biological invasions relate to the introduction and spread of animals and plants outside their native range and the associated consequences,' he explains. His research team ultimately aims to design, develop and implement approaches that can be effectively utilised to integrate biodiversity into urban environments. So, what has their research found over the years?

Biodiversity & Urbanisation

Back in 2011, Professor Kowarik published a paper reviewing the ways in which biodiversity was affected by urbanisation, discussing the potential consequences of using different approaches to conservation. This study found that a 'paradigm shift' was needed, arguing for conservation approaches to consider the benefits of plants and animals across all urban habitats for humans, thus highlighting the social benefits of urban biodiversity.

It also advocated for a 'differentiated valuation of risks and opportunities for alien species', which, in simpler terms, means that working with urban nature needs to embrace both native species (plants and animals common to that area) and non-native species (those originally from different areas).

Analysing this biodiversity impact on social perspectives has been of major interest to Professor Kowarik and his colleagues throughout the years. During a study published in early 2017, they investigated the way in which we as humans interact with environments and ecosystems. In essence, the team wanted to determine whether city-dwellers simply visited their local park for a picnic, or if they were actually interested in the nature they were surrounded by.

The researchers found that it was the latter, and that people use the surrounding biodiversity to eat, decorate themselves with, or simply enjoy the experience of immersing themselves in it. In fact, visitors were twice as likely to interact with the biodiversity in a park than they were to go jogging there. Gender and cultural diversity played a major role in this human-biodiversity interaction. Women, for example, were much more likely than men to interact with the surrounding biodiversity.

Analysing Social Perspectives

Research published in 2018 by Professor Kowarik and his colleagues looked further into this area, in a study called the European Green Surge Project. This was the first pan-European study of its type, and focused on investigating how urban-based people with different sociocultural backgrounds valued plant species richness across a range of urban greenspaces (areas of land partly or completely covered with grass, trees, shrubs, or other vegetation).

The results of this work found that biodiversity really does matter to us from a social perspective, with many of the study's respondents saying that they preferred a more varied presence of plant species within urban greenspaces. They also agreed with the suggestion that cities felt more desirable and liveable in areas that featured a higher richness of plant species.

As the team's research paper stated: 'This study can support policies on a biodiversity-friendly development and management of urban greenspaces, by highlighting social arguments for integrating biodiversity into urban development plans.' In other words,

conservation policies should ensure that biodiversity is a major feature of any future urban development plans.

Buzzing Biodiversity

The social connotations of supporting urban biodiversity is just one of the benefits to consider. The potential to protect plant and animal species on the brink of extinction is another.

According to research from Duke University in North Carolina, the world is currently losing species at a rate that is 100 to 1000 times faster than the natural extinction rate. From dodos to dinosaurs, to the scale tree and white rhinoceroses, plant and animal extinction is becoming a more and more common result of the planet's worsening biodiversity.

Take bees for example. Bees are vital to ensuring our world continues to thrive, through their ability to pollinate our plants. Without bees, many of the crops we eat and the plants we rely upon would either cease to exist entirely, or would exist in much smaller numbers. We really do owe a lot to our fuzzy black and yellow friends, yet their numbers are currently declining.

To this end, Professor Kowarik and his team decided to evaluate the impact of urban environments on bee species and bee populations. After collecting 1,706 specimens of 62 bee species across Berlin, the team's research found that the richness of plant species in greenspaces was not only an important factor for bees, but was especially enhanced when green areas were restored in urban environments. Similar to the team's previous research, this study again supported the notion that conservation approaches should incorporate a 'biodiversity-friendly management approach' within urban environments.

Looking to the Future

Looking to the future, Professor Kowarik and his team's research efforts will fundamentally focus on developing a deeper understanding of three key areas. Firstly, they wish to investigate how urbanisation affects interactions between plants and animals. Secondly, they plan to explore the survival of endangered species. And thirdly, they will assess how different scenarios of urban growth relate to biodiversity.

Professor Kowarik also currently acts as one of the Principal Investigators on the Bridging in Biodiversity Science (BIBS) Project. This project aims to provide a platform for collaboration across ecological-focused research disciplines, offering a multidisciplinary approach to future biodiversity research. In fact, the project, focused on investigating human-derived changes to ecological systems, is already proving effective.

'We have already successfully established a novel spread of CityScapeLabs across the city of Berlin,' said Professor Kowarik. 'These help us to perform experiments that provide a better understanding of how increasing urbanisation not only affects patterns in biodiversity, but also the interactions between plants and animals. The BIBS project ultimately allows us to support the development of biodiverse cities.'

With increasing worldwide urbanisation comes an underlying importance for cities to embrace biodiversity. Tackling this crisis is of fundamental importance, especially when considering the continual growth of the global population.

Moving forward, efforts should rely on altering our perspectives to current conservation policies, utilising the evidence gathered through Professor Kowarik and his team's research. After all, his work proves that we as humans love and respect biodiversity, so now is the time for us to stand together and protect it. Otherwise, mass species extinction could be waiting for us just around the corner.

Meet the researcher

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Professor Ingo Kowarik received a Diploma in Landscape Planning from the Technical University of Berlin (TUB), Germany, in 1981. He later went on to complete his PhD at TUB, before taking a position as a Full Professor for Applied Plant Ecology at the University of Hanover, where he worked between 1992 and 1999. Since then, he has been working as a Full Professor for Ecosystem Science and Plant Ecology at TUB. Professor Kowarik's research focuses on ecology – investigating biodiversity patterns and underlying mechanisms with a particular focus on cities and biological invasions. His research also focuses on the design and development of approaches to integrate biodiversity in urban environments.

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THE FUTURE OF FOREST MAPPING

Having good knowledge of forest structures forms the basis for planning and management, and assessing the overall health of a woodland ecosystem. Over the past 15 years, automated remote sensing techniques for monitoring forests have become more widespread, allowing us to map much larger areas at finer scales. By combining laser scanning, aerial imagery and advanced computational techniques, **Dr Peter Krzystek** of the Munich University of Applied Sciences and his colleagues are leading the way in 3D forest mapping.

Covering approximately 31% of the world's land surface, forest ecosystems are one of the most important living systems on Earth. They hold the vast majority of the world's terrestrial species, provide oxygen and watershed protection, store carbon, prevent soil erosion, and mitigate climate change. Within these ecosystems are forest structures such as individual species, single trees and fallen dead trees.

Dead trees are of particular significance. Approximately one third of all animals and plants living in forests rely on dead wood. As dead wood is decomposed by fungi, bacteria and other life forms, it facilitates new plant growth, by recycling nutrients such as nitrate and phosphorus back into the ecosystem. Furthermore, recent studies have estimated that up to 11% of all greenhouse gas emissions are sequestered by the world's forests, while 14% of total carbon stocks in forests are contained within dead wood.

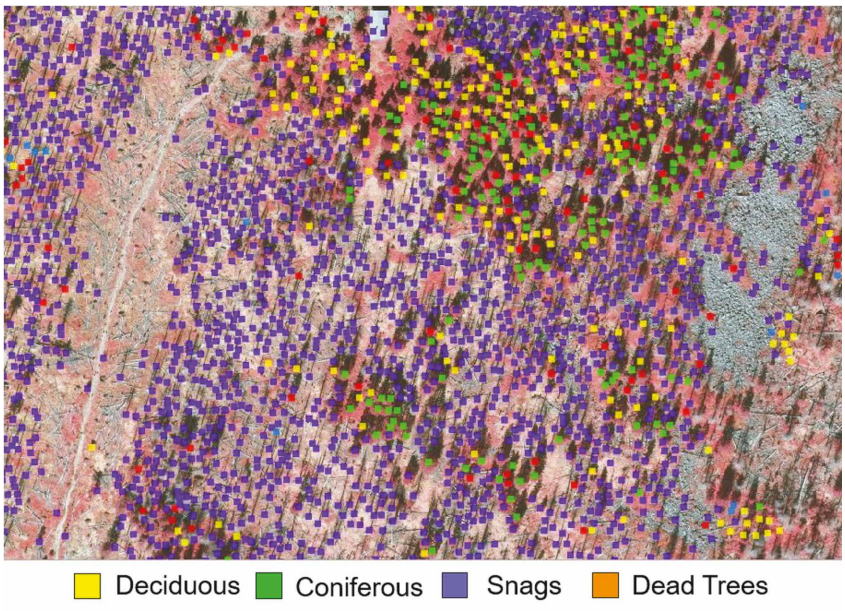
Knowledge of dead wood, and forest structures in general, is fundamental to understanding, protecting and preserving the biodiversity of our forests. As well as gaining a good understanding of ecological health, comprehensive environmental monitoring of our forests and the structures within are also important in disaster management. From monitoring entire forests in the case of wildfires, to tracking the spread of disease in single and dead trees – gaining accurate information on the status and distribution of these structures over various time scales is vital. This information is used by forest managers, researchers and governmental and inter-governmental institutions.

In the past, we relied on conventional forest inventory to monitor forests – vertical-view aerial photography for imaging, field studies and manual methods of subdividing the forest area into certain grid sizes, and the forest into circular plots. This meant high costs and limited spatial coverage. In the 1970s, with the launch of satellite technology and the advent of remote sensing and digital mapping technology, the way forests were mapped was changed forever, making it possible to map at very large scales.

Nowadays, a new technique called Light Detection and Ranging (LiDAR) is facilitating scientific discoveries at a phenomenal pace. LiDAR is a remote

Fallen dead trees

‘The innovative methods are also applicable to map urban objects (trees, cars, buildings, etc.) or just recently, vegetation and unknown graves of radioactive biomass in Chernobyl’s exclusion zone.’



Mapping of coniferous, deciduous, and dead trees (Image source: Bavarian Forest National Park)

sensing technique where pulses of visible or near-infrared laser light at a particular wavelength are used to create 3D images. Pulses are first emitted towards an object, such as a forest, and the reflected pulses are detected using a sensor. The return times of the reflected laser light can then be used to obtain accurate distances between the different parts of the object and the sensor, allowing a 3D image to be built. This 3D image is typically made up of a high density of data points, known as ‘point clouds’.

LiDAR is also known as laser scanning, and has aerial, terrestrial and mobile versions. In the aerial version, the system is fixed onto an aircraft, helicopter or drone, and is capable of scanning large swathes of land. Terrestrial LiDAR, on the other hand, is a stationary system where the sensor is usually mounted on a tripod. Mobile LiDAR is also a ground-based system, but is typically mounted on a moving vehicle.

In their recent research, Dr Peter Krzystek and his team at the Munich University of Applied Sciences have focused their efforts on developing innovative methods using LiDAR and aerial imagery for 3D mapping of trees in the Bavarian National Forest in Germany.

Capturing Remote Sensing Data

Over a ten-year period, Dr Krzystek and his team conducted numerous flight campaigns in the Bavarian National Forest – an excellent test site for the research. The flying height of the operation was between 400 and 600 metres, with the LiDAR system emitting more than 400,000 laser light pulses per second.

The team’s LiDAR sensor recorded in ‘full-waveform’ mode. Full-waveform technology adds significant value to the dataset, because it records the entire time series of received light and receives many more reflected signals from each emitted light pulse. This means that the data can be interrogated for more information about the composition of the objects in question, resulting in more precise maps.

The team combined their LIDAR data with aerial images obtained using cameras with multispectral sensors. The images collected with these cameras are often used along with LiDAR to generate radiometric data, which offers additional information on the intensity of the reflections of the tree species. This information can aid in the classification of tree species and the identification of standing dead trees.

In conjunction with LiDAR and aerial imagery, Dr Krzystek and his team also applied a series of advanced computer techniques known as machine learning and computer vision. Machine learning is a technique used to teach computers how to think for themselves, and in this situation the computer was taught how to find tree objects such as crowns and stems. Computer vision, on the other hand, is a type of machine learning designed specifically to analyse imagery.

‘My main research focus is on the application of machine learning methods and computer vision to detect and classify forest objects – like single trees, fallen or standing dead wood,’ says Dr Krzystek. ‘The overall goal is to develop techniques for automatic forest inventory using remote sensing data (that is, laser scanning data or image data) acquired from airborne platforms like planes, helicopters or drones.’

Detecting Forest Structures

The methods developed by Dr Krzystek and his team demonstrate that forest areas can be completely and automatically processed with LiDAR to produce 3D maps of individual trees, even at very large scales. ‘The results of our methods enable an area-wide 3D vegetation mapping and provide precise information about the percentage of tree species, stock of wood, wood growth, wood harvest in forests, and biomass,’ Dr Krzystek explains.

Segmented single trees

One of the team's methods offers the ability to detect single trees, and was one of the breakthroughs of this project. The team's newly patented approach takes advantage of a special segmentation technique adapted from image analysis. This technique involves labelling every point in the point cloud, and grouping these points. When combined with full waveform data, the detection rate is significantly improved. With this method, Dr Krzystek and his team found that they could classify coniferous and deciduous trees with excellent accuracy.

The team was then able to classify four tree species with fairly good accuracy by combining a large set of features generated from aerial imagery and multispectral LiDAR. Multispectral LiDAR acquires data at different wavelengths, and by using this, more data can be gained on the composition of the object, such as a single tree.

The team's methods are also particularly good at detecting fallen and standing dead trees. Accuracy is strongly dependent on the number of points collected by aerial and terrestrial LiDAR, but other factors such as the density of the forest canopy, the length of the stem and numbers of trees are also important. In training the computers to recognise fallen trees, Dr Krzystek and his team observed that there must be a minimum number of collected data points per tree – otherwise, the computer can't see the tree.

Using their new techniques, the research team found that they could also successfully detect standing trees with and without crowns – although trees without crowns were typically characterised using aerial LiDAR alone, as the trunks cannot be detected using aerial imagery alone. The team found that aerial LiDAR and aerial imagery perform equally well in the upper canopy, while aerial imagery performed less well in the medium to lower moving canopies.

The Future of 3D Forest Mapping

Mapping is critical for forest inventory, conservation and planning, and LiDAR technology offers researchers the opportunity to gain much more data in a short space of time. Furthermore, the use of LiDAR is increasing and the cost is declining. LiDAR sensors are becoming more powerful, allowing even more data points to be obtained. 'Since it is expected that new 3D measuring techniques will generate more 3D details of forest objects, existing methods need to be extended to take advantage of the higher point density,' adds Dr Krzystek.

The team now hopes to evaluate their methods that characterise fallen trees by incorporating mobile LiDAR technology such as wearable scanners, and photogrammetric point clouds – sets of 3D data points produced from images as opposed to laser pulses. The team also hopes to investigate tree species classification further by using multispectral laser scanning data.

LiDAR-based 3D data has wide applications beyond forestry. Dr Krzystek and his team assert that the methods they developed to characterise fallen trees could potentially be applied to urban features, or groupings of pipelines and road networks.

The team's methods have already been applied to hazard analysis for workers involved in remediation work: 'The innovative methods are also applicable to mapping urban objects (trees, cars, buildings, etc.) or just recently, vegetation and unknown graves of radioactive biomass in Chernobyl's exclusion zone,' concludes Dr Krzystek.

Meet the researcher

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Dr Peter Krzystek completed his PhD at the Institute of Applied Geodesy for Construction, University of Stuttgart in 1989. During this year, he moved to Inpho GmbH in Stuttgart for his second research assistant position in digital photogrammetry and software development. Dr Krzystek started his current position as Professor of Photogrammetry, Remote Sensing and Digital Image Processing at Munich University of Applied Sciences in 1998. Here, he specialises in a wide variety of research areas, including machine learning and computer vision, LiDAR-based 3D mapping and forest inventory. He is Head of the Photogrammetry and Remote Sensing Laboratory and has led the CORSNAV research group since 2012.

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German Research Foundation
European Science Agency

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UNIVERSITY OF APPLIED SCIENCES MÜNCHEN

EMERGING TECHNOLOGIES TO ENABLE AFFORDABLE OCEAN OBSERVING

Coastal environments have immense ecological, practical, recreational and cultural value, and are under threat from multiple natural and anthropogenic stressors. **Dr Brian Glazer** and his team at the University of Hawai'i use specialised equipment to conduct remote coastal 'health checks' (smartcoastlines.org). They are also working to put the data directly into the hands of the public to encourage community-based management initiatives.

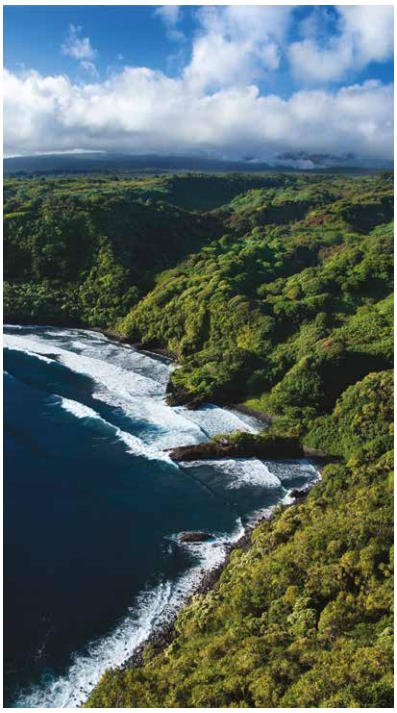
Coastal Zone Management

Government agencies and several community-based organisations are working tirelessly to ensure that our coastlines are resilient – and with good reason. We need to protect our environmental and natural assets for generations to come. Failure to do so could indeed have long-lasting effects as these finely tuned ecosystems could easily be ruined. Many of these sites also have cultural and practical fishing and aquaculture significance.

There are specific characteristics of the coastal environment that need to be monitored and managed more effectively, including indicators of water quality, coastal flooding and erosion, and environmental restoration activities. Each of these has an associated indicator of health that can be measured and monitored on a regular basis but doing so is typically cost-prohibitive for most community groups. Of course, scientists are always trying to find ways in which the monitoring process can be improved. This is especially true as the technology available to scientists is becoming increasingly powerful and diverse. Moreover, greater demands are being placed upon coastal areas by industry, economic development and an increasing population.

Dr Brian Glazer's lab at the University of Hawai'i's Department of Oceanography has been investigating the various applications of new lower-cost electronic, computing, and sensor technologies to carry out remote coastal 'health checks' in real time. Their work focuses on monitoring water temperature, salinity, dissolved oxygen and turbidity – as well as tidal variability, flooding and other meteorological events. In a nutshell, regular health checks and a faster response to environmental stressors means a better chance of mitigating environmental damage.

Dr Glazer is also working to ensure that the information gathered from these systems is available not only to researchers, but also to students and members of the public. Doing so allows them to participate in rigorous, crowd-sourced 'citizen science'. When students and community members have first-hand access to demystified sensor and instrument technology that provides data for their own local environments, they become more



informed about environmental issues that affect their community, and tend to become involved in conservation and management efforts. With funding from the National Science Foundation, NOAA Sea Grant, the University of Hawaii at Mānoa, and Schmidt Marine Technology Partners, Dr Glazer has established an open-source, expandable suite of hardware and online data-streaming platform for lower-cost, custom field observations (smartcoastlines.org).

A Foundation in Research

Dr Glazer's work is focused on the interface between chemistry and biology in the oceans. Much of his work has focused on processes at the seafloor, from nearshore sediment-water interface fluxes to deep-sea volcanoes. All of these features are part of complex ecosystems and food chains, and many of the fundamental interactions between chemistry and biology that happen at deep-sea volcanoes also happen along gradients in coastal zones. Changes or damage to these fundamental aspects of an oceanic environment could have serious negative flow-on effects.

Within this broader research context, Dr Glazer and his team are developing task-specific sensors and instrumentation for collecting and communicating data from remote locations. This practice is broadly referred to as telemetry. Telemetry is the automated communications process by which data is collected at remote locations, transmitted to receivers, processed and used for monitoring purposes.

The Benefits of Remote Oceanography

Of course, the information collected by scientists varies according to the research goals and nature of the monitoring site. There really is an amazing range of features that can be measured, and these measurements can tell scientists a whole range of different things about the site. As was mentioned at the outset, Dr Glazer focuses on tests that are most applicable to a given watershed, such as water quality parameters, tidal variability, flooding events and other meteorological events.

Consider how some of these tests could be beneficial to the public. Meteorological data may indicate impending weather events or how observed tidal fluctuations may differ from predicted tide levels, or in the longer-term, may be a commentary on a changing climate. Others are potential indicators of the relative waterway health. Turbidity (water cloudiness) or dropping levels of dissolved oxygen, for example, may be an indicator of pollution. For aquaculture communities, it could be a precursor to conditions that would lead to fish kills. Therefore, it is easy to see why measurements made at remote sensing sites would be beneficial, especially in terms of assisting communities in their quest to take care of their local environment.

Making Oceanographic Monitoring Accessible to All

Dr Glazer's *smartcoastlines.org* project provides a holistic approach to democratising access to ocean observing technology. Commonly, government initiatives may support large, expensive programs to monitor and understand environmental processes, but the expensive commercially-available instruments and complex data streams have really only been developed for use by highly-trained and cashed-up scientists. Even undergraduate research assistants, graduate students and postdoctoral fellows in highly productive marine science departments are intimidated by expensive and complex commercially-available sensors and instruments. Such technologies are as foreign to non-experts as Mars Rover technology. But they need not be.

Dr Glazer's group develops and tests inexpensive dataloggers with integrated telemetry capabilities and adapts an appropriate level of sensor accuracy, precision, expense for the appropriate application. There's little need to deploy expensive conductivity sensors that can measure four decimal places of accuracy in a location that may experience a 30% daily fluctuation, if lower-cost sensors can provide more measurements in more places to better understand spatial questions.

The *smartcoastline.org* project was initiated to address the situation described above. Its goals are: (1) to develop and deploy wireless coastal instrumentation to provide near-real-time web-based data from key environmental sites for both basic research and public engagement interests; (2) to provide open-source instrumentation and sensors, open-source software, and quality assured time-series data; (3) to develop a 'mentored citizen science' approach for training proactive local non-profit collaborators and enabling program participants to deploy, maintain, and use data from sensor packages and; (4) to coordinate state-wide coastal watershed restoration efforts by matching community-based efforts with previously unavailable spatial-scale sensor data.

smartcoastlines.org in Action

Dr Glazer highlights that with the increasing availability of low-cost, open-source and compact computers, sensors and supporting telemetry solutions, these goals are well within reach. In fact, it is well underway at sites around the Hawaiian Islands. The data being collected is available in real-time, providing web access to an amazing array of unique measurements and data sets on unprecedented spatial scales. Of course, the end goal is not just to arbitrarily capture data, but also to use the data to monitor and predict processes that affect the health of aquatic systems and inform decision-making processes.

Consider an example. As Dr Glazer highlights, Loko i'a (traditional coastal Hawaiian fishponds) represent a long-lasting example of one of the ancient world's more significant and successful aquaculture achievements. Today, they provide an ideal opportunity for coastal research and development of technological innovations. They are also an area of proactive community-based restoration projects. Unfortunately, most Hawaiian fishponds are largely in disrepair due to threats from land-use changes resulting in sediment and nutrient loading, encroaching development, and abundant invasive plant and animal species that have displaced native organisms.

In response, Dr Glazer and his team partnered with Paepae o He'eia – a private non-profit organisation dedicated to caring for the He'eia Fishpond, located in He'eia, Ko'olaupoko, O'ahu. Their goal was to implement this wireless coastal sensor network in the He'eia Fishpond to assist with measuring environmental restoration and management efforts, and to engage high-school and undergraduate students in related conservation. Initial work piloted at He'eia has now expanded to 18 other coastal restoration organisations throughout the state, and students have used the data captured in many research projects to quantify how contemporary threats to the coast are affecting pond restoration efforts.

Citizen Science and Community Involvement

'Understanding the dynamics of coastal systems from a basic research perspective requires a sustained measurement presence in situ; especially in the face of increasing threats from extreme weather events, climate hazards, and changing ocean conditions,' explains Dr Glazer. 'Verifiable, consistent, and comparable datasets and observations are the foundation of environmental science, and crucial for enabling science-based policy and management decisions. However, restoration and stewardship are often limited by inadequate water quality data and poor understanding of watershed-scale processes resulting from a limitation in collecting, analysing, compiling and comparing data.'

He concludes, 'having continuous time-series environmental datasets across wide spatial scales available to researchers and to non-scientists can help inform meaningful management decisions during restoration activities and as watersheds face differing environmental, land-use, or climate-related stressors.' And that's exactly what the *smartcoastlines.org* project achieves. It provides the tools, techniques and information for researching the coastal marine environment. Furthermore, it makes highly specialised equipment and real-time data available to anyone interested in the oceanographic and meteorological conditions across the Hawaiian Islands.

As for future work, Dr Glazer and his colleagues are set to make further additions and improvements to the program. They are expanding to additional field sites around the world. And to re-iterate, he wants to make sure that the data gathered is accessible to not only researchers, but also to students and the public for community-based management initiatives. This will have an immediate positive impact – helping local communities to conserve and manage their most precious assets.

Meet the researcher

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Dr Brian Glazer received his PhD in marine studies from the University of Delaware, USA, in 2004. He subsequently joined the NASA Astrobiology Institute at the University of Hawai'i at Mānoa. In 2006, he joined the Department of Oceanography, where he currently serves as Associate Professor. His research goals are to develop an understanding of the synergy between geochemical processes and biological diversity and function, and to develop in situ measurement techniques and instrumentation. He also wants to ensure that the information acquired is accessible to the global community – especially those engaged in undergraduate, postgraduate and community-based research and conservation projects. His current focus, *smartcoastlines.org*, is facilitating democratisation of environmental monitoring and data dissemination with funding support from the National Science Foundation, NOAA Sea Grant, Schmidt Marine Technology Partners, and a UH Manoa Strategic Investment Initiative.

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Hui Mālama Loko I'a (http://kuahawaii.org/huimalamalokoia/)
Paepae o He'eia (https://paepaeoheeia.org)
Purple Maia Foundation (http://www.purplemaia.org)

FUNDING

US National Science Foundation (NSF)
NOAA Sea Grant
Schmidt Marine Technology Partners
UH Manoa Strategic Investment Initiative
Posner Family Foundation

UNIVERSITY of HAWAI'I® MĀNOA

NATURE'S VITAL SIGNS: USING BIOINDICATORS TO UNDERSTAND ECOSYSTEM HEALTH

The 2010 Deepwater Horizon Oil Spill was an environmental disaster in the Gulf of Mexico that may take decades to recover. In the immediate wake of the crisis, scientists began to study the developing effects of the spill. **Dr Paul Montagna** at Texas A&M, Corpus Christi studies bioindicators from the ecosystems around the Gulf of Mexico. His team's work focuses on topics that identify the outcomes of human activities. The results of their studies on these local systems are significant for ecosystems worldwide.

Estuarine Bioindicators

To understand biological health, key indicators and normative levels must be identified and measured. Just as a doctor takes a patient's vital signs – temperature, pulse, heart rate – scientists must also understand the vital signs of a healthy ecosystem.

These vital signs of an ecosystem are known as 'bioindicators'. A healthy ecosystem should, ideally, fall within an acceptable range of measured values. However, defining acceptable ranges for these indicators is challenging because there is rarely sufficient data to define a healthy or unhealthy ecosystem, and metrics vary quite a lot over space and time. Disturbances in an ecosystem can be chronic or short-term, and the means of assessing the changes may vary. The ultimate measure of an ecosystem's health is its ability to maintain a balanced, resilient, diverse community of organisms.

As vitally important ecosystems, estuaries are under severe threat due to human activity. Estuaries are semi-enclosed bodies of water that are connected to the open sea and diluted with freshwater from land. They act as storm barriers, allow fisheries to thrive and improve marine water quality. Changes to natural water flow in an estuary can compromise all of these functions. In many areas of the world, humans are impacting estuaries by re-engineering coastlines and extracting large amounts of freshwater, reducing the natural flow downstream, to accommodate urban, agricultural, and industrial development and an expanding human population.

Without intervention to address such chronic disturbances, these important ecosystems may collapse to the point where it is impossible for them to return to their former health. Short-term disturbances in ecosystems create unique possibilities for measuring ecological health by focusing on bioindicators.

Oil spills serve as an example of a 'pulse event', a short term, sudden occurrence that causes a short-term disturbance, but they are sometimes not a chronic issue. On April 20, 2010, the Deepwater Horizon offshore drilling rig erupted off the Gulf of Mexico causing the largest oil spill in US history. The spill released an estimated 731 million litres into the Gulf of Mexico over a three-month period. Although sudden, the effects of large pulse event can be long lasting. Continued research and management of these areas, using bioindicators to assess health over time, is critical.

Dr Paul Montagna leads a team of researchers who are working to define ecological health and understand the best ways to measure the health of important natural resources, such as estuarine and deep-sea ecosystems along the Gulf of Mexico.

Nature's Vital Signs

'What is ecological health? How do we define it and measure it?' These are the major questions Dr Montagna aims to answer as the Endowed Chair for Ecosystems and Modelling at the Harte Research Institute for Gulf of Mexico Studies at Texas A&M, Corpus Christi. His team's work highlights the need to understand disturbances to ecosystems, such as short-term and long-term effects of freshwater diverted from estuaries, and the Deepwater Horizon oil spill.

Dr Montagna's research attempts to more clearly understand the complex relationships between humans and our environment. 'We identify the normal ranges of bioindicators, and then compare these to areas where we suspect environmental impairment due to human activities,' explains Dr Montagna. 'We can then base our assessment on the response of the bioindicators.'

Using this approach, Dr Montagna and his team have published extensively in research journals on estuarine health and the impact of oil spills. Dr Montagna has also served on critical committees to advise the National Oceanic and Atmospheric Administration on the Deepwater Horizon oil spill.

Exploring the Deepwater of the Horizon Oil Spill

When the Deepwater Horizon oil spill occurred in April 2010, Dr Montagna led a series of studies to examine the impacts of the oil spill on communities of organisms on the seafloor. Animals in these communities are often sedentary, and are therefore unable to avoid exposure to the oil particles. They are vital to the health of deep-sea ecosystems where they decompose matter, regenerate nutrients, and serve as primary food resources for animals higher up on the food chain.

Dr Montagna, along with a team of researchers across the United States, set out on large research cruises to investigate differences in communities in 'impact' zones, within the oil spill's disturbance area, and those well outside the limits of the spill. The first cruise took place two months after the oil spill and subsequent cruises were conducted the following year and again in 2014.

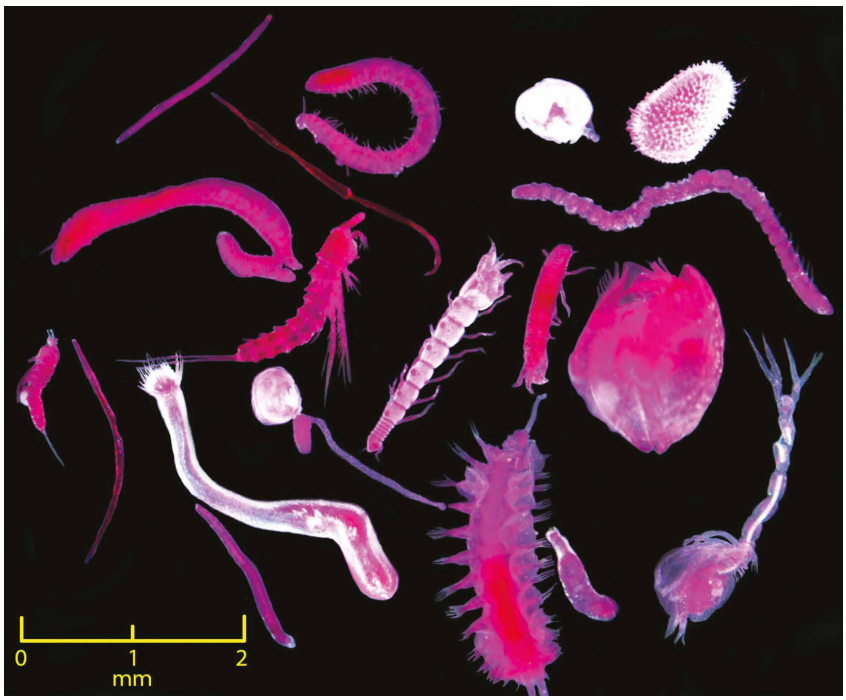
The team found that community richness and diversity were significantly lower in the 'impact' zones where oil particles from the spill were still present. Both larger animals (macrofauna) and smaller organisms (meiofauna) were impacted for years after the oil spill, although the macrofauna recovered more rapidly than other benthic organisms (those found on the seafloor).

Their research indicated that the oil spill reached the seafloor and negatively impacted communities on the soft-bottom depth and even deeper in the deep-sea. Four years after the spill, these ecosystems still had not fully recovered, likely due to the toxicity of contaminants associated with the spill. The temperatures and nutrient conditions on the seafloor limit the oil's ability to degrade, which can greatly affect benthic communities.

These communities are critical to understanding the lasting effects of pulse events, serving as 'the "canaries in the coal mine" and can indicate when something is happening that needs our attention,' explains Dr Montagna. In a subsequent study, he and his colleagues found that these communities, particularly in the deep sea, will take decades or longer to recover from the spill.

Salt as an Indicator for Life

Using a similar approach to his work on the Deepwater Horizon oil spill, Dr Montagna's research also focuses on understanding bioindicators in estuarine systems in his local Gulf of Mexico waters. One major bioindicator of the health of an estuary is the average salinity. Salinity in an estuary reflects the degree



to which freshwater dilutes seawater. If too much water is diverted for human purposes, the average salinity of the system will be higher than healthy thresholds for estuary ecosystems. Many of the Gulf's estuaries are becoming saltier. Salinity is increasing as less freshwater makes it downstream when it is diverted for human consumption. In addition, many coastlines are suffering from land sinking. This is a phenomenon that occurs when too much groundwater is extracted. The dry soil then behaves like a sink hole, and salt water creeps into the surface water and groundwater from the sea, increasing the salinity of the freshwater.

To make matters worse, climate change will likely cause more frequent and severe droughts and floods, which will further divert freshwater. This can cause a reduction in organic matter and nutrients in the water, deaths in keystone species, and increased phytoplankton blooms.

Dr Montagna and his colleague, Amanda Van Diggelen, have been studying salinity variance (how much the salinity deviates from the average) and how this may serve as an indicator of the disturbance of benthic species. They have found that salinity variance is in fact a better indicator of benthic community diversity than average salinity, which is typically used to understand the health of an estuarine ecosystem.
By measuring the health of benthic communities over time, Dr Montagna and others are able to understand whether an ecosystem has the ability to resist or recover from disturbances, both chronic and short-term. Dr Montagna focuses on benthic organisms 'because they are fixed in place and don't move if an environmental injury occurs in their vicinity, and because of gravity they are always the first affected.' This work will help scientists and water resource managers to create mathematical models to predict changes to the structure and function of the estuaries.

A diverse ecosystem is considered healthier because there are more species to offset the stress caused by disturbance. 'A change in diversity is a sensitive indicator that something has changed,' Dr Montagna emphasises. Community diversity is a strong indicator of ecosystem health, but it is much more difficult to measure than salinity variance. Therefore, Dr Montagna's team has recommended that water resource managers and scientists instead use salinity variance as a key bioindicator in future studies. Their research reinforces the idea that freshwater flow in areas with high human populations is essential to allow both human and estuarine communities to thrive.

Repurposing our Consumption

Ultimately, water resource managers working with estuarine ecosystems must strike a balance between the amount of water taken from a freshwater system then returned to the system from wastewater and industry waste. However, managing this balance has proven difficult, as human consumption takes priority.

One solution, implemented across the United States in places such as The Everglades and Mississippi River, is to strategically time the release of freshwater to estuaries. This solution requires careful evaluation of the water requirements needed from both humans and the natural environment. This approach has caused some backlash, as some similar projects have caused negative impacts on the oyster industry in the past.

Another solution involves using existing river diversions to divert water back into the freshwater ecosystem. As a result, conservationists can deliver nutrient-rich sediment downstream, regulate salinity, and improve the growth of vegetation. By nursing the ecosystem back to health, managers are also supporting thriving fisheries and oyster industries.

All of these solutions are dependent on understanding the needs and health of the water system by tracking a water system's vital signs over time.

Meet the researcher

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Dr Paul Montagna was awarded his PhD from the University of South Carolina in 1983. After working as a postdoctoral researcher at the University of California's Lawrence Livermore National Laboratory, he worked as a professor at The University of Texas at Austin for 20 years. Dr Montagna currently serves as the Endowed Chair for Ecosystems and Modelling at the Harte Research Institute for Gulf of Mexico Studies at Texas A&M, where he has been based since 2006. Dr Montagna is committed to preserving the Gulf of Mexico, by serving on the Texas Environmental Flows Science Advisory Committee and the National Oceanic and Atmospheric Administration advisory after the devastating 2010 Deepwater Horizon oil spill. In 2009, he helped to launch an oyster recycling program, Shell Bank, which works with local restaurants to reclaim used oyster shells to restore lost reef habitat. He recently won the 2017 Coastal Bend Bays Foundation Environmental Stewardship Awards for his accomplishments with the initiative. Dr Montagna is Co-Editor in Chief for the journal Estuaries and Coasts.

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National Oceanic and Atmospheric Administration
National Fish and Wildlife Foundation

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PROMOTING INCLUSION IN ENVIRONMENTAL POLICY DEVELOPMENT

Responding to global environmental change requires ongoing effort, and long-term success depends heavily upon the input of local communities. Moreover, if diverse viewpoints are included in policy development, then shared solutions and common goals are achieved. **Dr Jill Slinger** from the Delft University of Technology is committed to this cause. She also brings a wealth of research experience on estuarine and coastal systems to the policy discussion table.

Tackling Environmental Issues – A Melting Pot of Viewpoints

Humankind is certainly at a momentous point in history. Environmental issues and disasters continue to threaten our lives, livelihoods and potential to flourish as a human race. It is easy to see why, then, scientific research, public discussion and policy development surrounding environmental issues generates a range of different views. Indeed, the necessity for locally relevant, applicable and supported solutions to complex multi-level environmental and engineering challenges is becoming more and more evident. But of course, negotiating this challenge is difficult, to say the least.

Central to confronting this challenge is the input of experienced and skilful scientists. Dr Jill Slinger, environmental systems engineer from the Delft University of Technology (TU Delft) is one such scientist. Her research work focuses on the understanding of coastal and water systems, and how that translates into effective policy development for improved environmental management. Not only that, she also focuses on negotiating the complex issues that arise when the perspectives of affected stakeholders and community members intersect, and determining how, despite differences, long-term progress can be achieved.

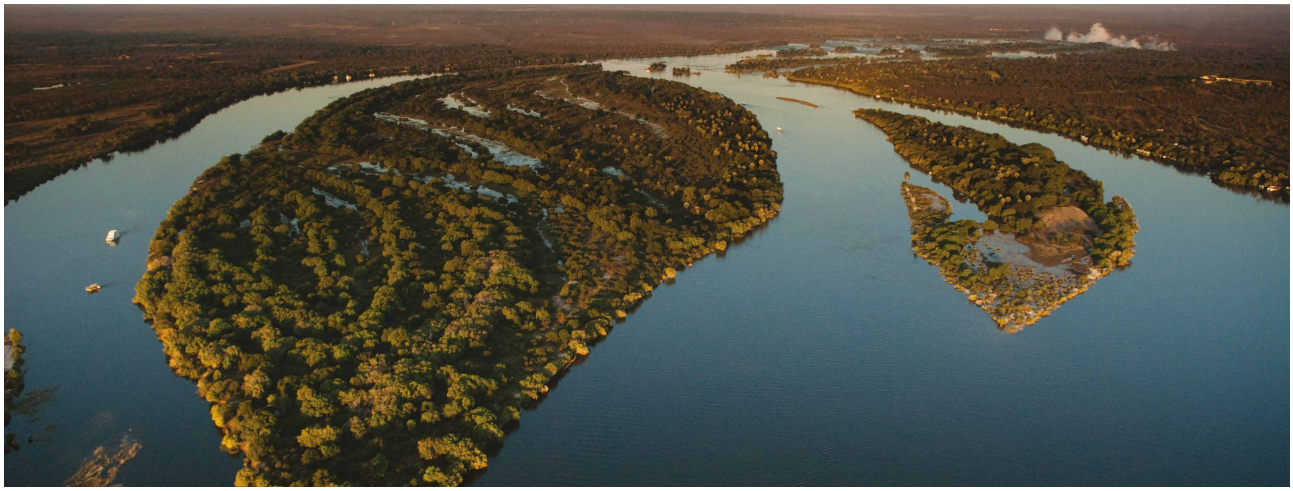
Dr Slinger brings scientific rigour – not just in water and coastal management, but also in policy analytical methods – to social-ecological problems, and creates platforms and workshops to encourage people to be socially innovative and to negotiate shared solutions in an ongoing fashion. She states, 'I don't believe in one-off solutions, but in designing and building multi-actor spaces where people can co-design solutions together.'

The Valuable Input of Experienced Scientists

Dr Slinger is first and foremost an inspired scientist, and her portfolio of research is certainly rich. It all began in 1985 with the 'Inland Water Ecosystems National Scientific Programme' at the University of KwaZulu-Natal in Pietermaritzburg, South Africa. In this project, Dr Slinger developed a mathematical model of a freshwater wetland on the Pongola River floodplain to investigate the efficacy of flood releases in maintaining the ecosystem and associated grazing function.

Over a relatively short period of time, Dr Slinger gained much knowledge and expertise in the management of coastal and estuarine systems. She worked on several projects in the areas of oceanography and estuary dynamics, with an emphasis on understanding, quantifying, modelling, and managing water movements and water quality in these complex environmental

'I bring scientific rigour – not just in water and coastal management, but also in policy analytical methods – to social-ecological problems, and I create platforms and workshops to encourage people to be socially innovative and to negotiate shared solutions in an ongoing fashion. I don't believe in one-off solutions, but in designing and building multi-actor spaces where people can co-design solutions together.'



systems. In time, however, she began to merge her scientific expertise on rivers, estuaries and coasts with the development and implementation of effective policy. In fact, this marriage of robust science and policy development is something that would define Dr Slinger's career in the years to come.

The Importance of Inclusion in Policy Development

At the core of effective policy development and decision making is effective collaboration and communication with all concerned. Of course, this includes scientists, stakeholders, the public and the private sector. A positive relationship between these stakeholders is vital. But it is something that will not develop and flourish of its own accord. It needs to be cultivated.

In 1995, Dr Slinger was working on an interdisciplinary national research programme for the conservation and management of South African estuaries. It was at this time that she became involved in the discourse on new policy for the allocation of freshwater to South African estuaries. She devoted much time and energy to making sure that the related policy development was effective.

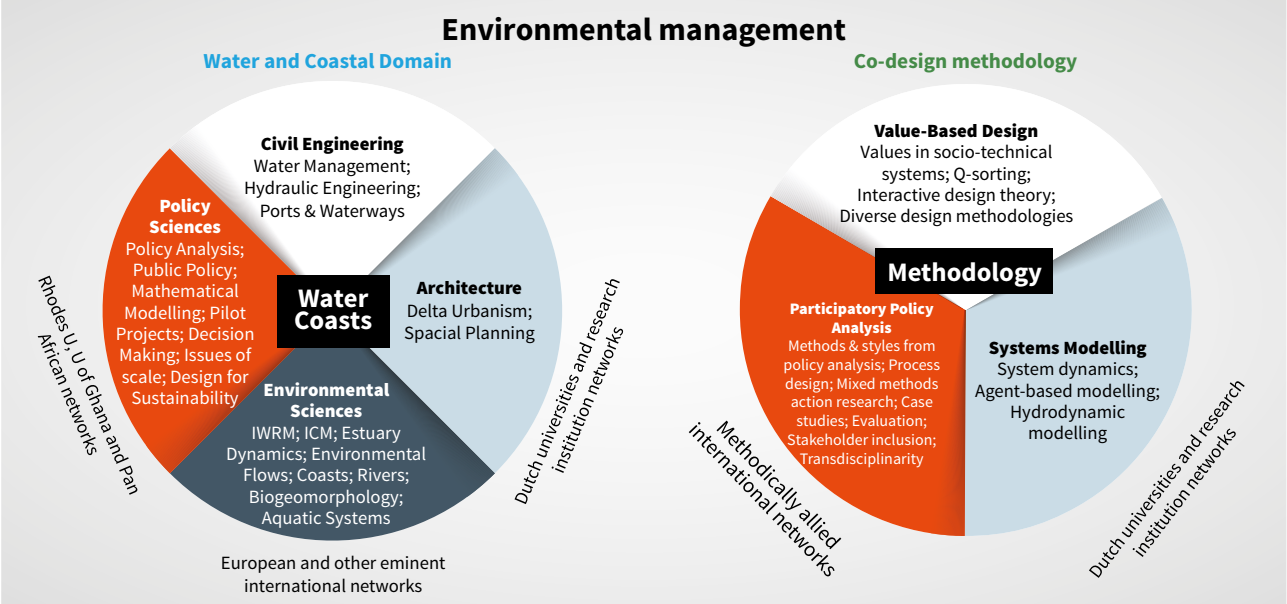
In 1998, Dr Slinger began working on the Scheldt Estuary, which runs through the Netherlands and Belgium. Initial research involved designing and developing a linked system of 3D hydrodynamic model results, spatial and temporal data processing and a rapid assessment model to indicate how physical changes would affect biological responses in the estuary. From 2005 to 2008, however, the focus shifted to the role of policy makers, scientists and citizens in flood risk management. She explored the role of new model-based knowledge in informing the policy debate between affected stakeholders through in-depth interviews, workshops and a quantitative survey. During this research, it became evident that the inclusion of diverse viewpoints, particularly those of local communities, is a prerequisite for successful policy development.

In an associated research paper of 2007, Dr Slinger and her colleagues compared local knowledge and interpretations with that of policy makers. The study concluded: 'People's insights regarding the consequences of flooding and the recovery thereafter went deeper than a purely scientific understanding... In fact, the policy advisors were also surprised by the high quality of the information derived from the study and felt challenged by the request for precautionary post-flood planning measures.' Clearly, local knowledge and viewpoints are vital.

In 2008, Dr Slinger and her team explicitly examined the role of new knowledge and an enhanced understanding of the opinions of fellow citizens in influencing policy preferences in relation to the findings of the Scheldt Estuary project. The related research paper concluded: 'In this study, we have demonstrated that it is possible to engage in meaningful scientifically-based discussions on flooding related issues with local citizens and policy makers.' Indeed, inclusion of diverse perspectives in policy development and decision making is both necessary and possible. But the question remained, how could these insights be applied in practice?

Practical and Innovative Strategies for Inclusion

Dr Slinger's efforts to pioneer and implement practical strategies to incorporate stakeholder viewpoints and local knowledge is well illustrated through her work on the Great Brak Estuary in South Africa. She has been involved with the Great Brak since the construction of the Wolwedans Dam more than 30 years ago. Recently, an approach taken by Dr Slinger and



her team was once again to 'engage with stakeholders… to generate a common understanding of the water resource issues and management processes...' The project highlighted that ongoing societal and environmental changes have altered the relationship between the community, their environment and their environmental management representatives. This means that old management arrangements will have to be replaced by new, relevant procedures.

A subsequent research project of 2016 delineated an effective approach for tackling this challenge. Dr Slinger and her team suggested utilising 'a progression from collecting and exploring individual experiences of stakeholder's problems; to connecting individual's experiences to their broader sector's problems; and finally, to cross-connecting the sector's impacts and requirements to one another under different scenarios of change.' In a paper published in 2017, she also suggested that structurally embedding the practice of learning from the experiences of local people, in a well-timed and thoughtful manner, is extremely important.

In summary, Dr Slinger's approach is multi-disciplinary, includes embedded opportunities for contributions from all concerned parties, and is centred on the principles of environmentally sound, inclusive design. This overarching approach is being applied, for example, in the 'Integrated and Sustainable Port Development in Africa' project. In this case, Dr Slinger and her colleagues report a 'significant step forward in enhancing knowledge synergy not only for sustainable port development but also for sustainable large-scale infrastructure development in general.' This is certainly a step forward in the holistic management of natural resources and sites of environmental significance.

Continuing to Incorporate Diversity into Planning and Policy

Dr Slinger continues to work on the Netherlands Organization for Scientific Research's 'Integrated and Sustainable Port Development in Africa' project. This project is focused on planning, designing and enabling green ports in Africa – with the Port of Tema, Ghana, as the central case study. Collaboration and Inputs from local stakeholders are core to this research endeavour. She is also developing the co-design method further in a project called 'Co-designing Coasts in Nested Channel Shoal Systems', or 'CoCoChannel', focusing on Texel Inlet in The Netherlands. Over the last three years, groups of Dutch and Texan students have tested the co-design methods further in a series of Living Labs. These authentic learning experiences have been funded by a Partnership in Education and Research grant from the National Science Foundation of the United States of America.

Of course, Dr Slinger's work continues to involve pioneering and testing new ways to ensure inclusive and sound policy decision making. All the while, she conducts rigorous scientific research and acquires funding for the many, varied projects aimed at managing coastal and estuarine systems. She has also spearheaded the development of a Massive Open Online Course (MOOC) on the topic of 'Engineering: Building with Nature' to teach engineers to consider the environment in their designs. To invest time and energy into all these areas concurrently is truly an outstanding achievement. Furthermore, her work has brought together scholars, citizens and professionals from around the globe.

Overall, Dr Slinger has 30 years international experience in applied consultancy and research leadership. Without a doubt, she is committed to the sustainable management of water and coastal systems. She is also committed to promoting inclusion in the related planning and policy development. And there are many more projects and ventures on the horizon.

Meet the researcher

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BROWN TROUT & ITS PARASITE: A COMPLICATED RELATIONSHIP

The brown trout and *Tetracapsuloides bryosalmonae* are two animals with a close connection: that of a host and its parasite. The brown trout represents an important native species in many parts of Europe for fishing activities. Thus, declines in brown trout populations make *Tetracapsuloides bryosalmonae* an economic liability. Working within the University of Bern's Faculty of Veterinary Medicine, **Dr Thomas Wahli** and his team focus on this unique relationship and the best ways to handle it.

Proliferative Kidney Disease of Salmonids

Closely related to salmon, the brown trout is a native European fish widely sought after in angling communities. A common parasite of the brown trout, *Tetracapsuloides bryosalmonae* (*T. bryosalmonae*), is a minute aquatic animal closely related to jellyfish.

T. bryosalmonae can cause the spread of proliferative kidney disease in many freshwater fish, causing huge losses in European and North American trout populations every year. Mortality associated with this parasite is generally low (at around 20%), but often, poor environmental conditions worsen its effects and death rates can reach up to 95–100%.

Proliferative kidney disease has been strongly implicated in the recent decline of wild brown trout in Switzerland. Furthermore, large European farms of non-native rainbow trout, which are also susceptible to the parasite, are heavily affected, leading to huge financial consequences. Thus, with both high environmental and economic losses at stake, any new research investigating proliferative kidney disease is highly prized.

For over 30 years, Dr Thomas Wahli has been a leading figure in researching the damaging effects of fish diseases in Switzerland. He now sits as Associate Professor in the Faculty of Veterinary Medicine at Bern University, and is Deputy Head at its Centre for Fish and Wildlife Health. Dr Wahli and his team try to understand the relationships between pathogens and fish hosts in Swiss fish populations. Their aim is to develop measures to protect both wild and stocked populations. In recent years, their work has heavily revolved around understanding the brown trout (also native to Switzerland) and its precarious relationship with *T. bryosalmonae*.

The Influence of Climate Change

It is now well understood that human-induced climate change is a growing threat to countless species around the world. For the brown trout, the higher temperatures associated with climate change could spell greater risk of disease. As a freshwater fish, the brown trout's immune response is correlated with heat, and so even a minor change in the temperature can lead to a significantly increased investment in immune function if infected with *T. bryosalmonae*.

PKD-affected kidney in comparison with a healthy kidney

For some context, at the beginning of its life cycle, the *T. bryosalmonae* parasite first infects a bryozoan (invertebrate filter feeders). The affected animal subsequently releases spores, which go on to infect fish, most commonly brown trout in Europe. The parasite develops in the kidney, producing spores that are released through the trout's urine. If these spores then come in contact with another bryozoan, the life cycle begins anew.

Dr Wahli's studies into this unique circle of life have shown that the parasitic infection occurs at a very slow rate in cold water (8–15°C), with low or no fish mortality. However, at temperatures above 15°C, the *T. bryosalmonae* life cycle appears to be quickened and fish mortality may rise to over 80%.

To better understand what impacts climate change could have on brown trout populations – and to help minimise parasite-induced deaths in general – Dr Wahli and his team studied how different temperatures affect the spread of proliferative kidney disease. The team developed three hypotheses: (1) that temperature has an effect on a parasite's ability to infect brown trout; (2) that temperature has an effect on the parasite's intensity in the fish host; and (3) that temperature has an effect on the release of the parasite.

To confirm or reject these hypotheses, the team infected groups of brown trout with *T. bryosalmonae* at 12°C and 15°C. They measured the rate of the parasite's development by looking at the amounts of spores produced in the fish and released into the water. The researchers found that the onset of release was delayed at the lower temperature, but the amount of spores released appeared to be independent of temperature.

Just as Dr Wahli's hypotheses had stated, the elevated temperature shortened the parasite's life cycle and increased its chances of spreading to other fish. The team's research thus highlighted yet another negative effect that climate change and rising water temperatures could have on aquaculture and natural ecosystems. As populations of Swiss brown trout have already seen significant declines, this finding is especially pertinent towards understanding the adverse effects of climate change.

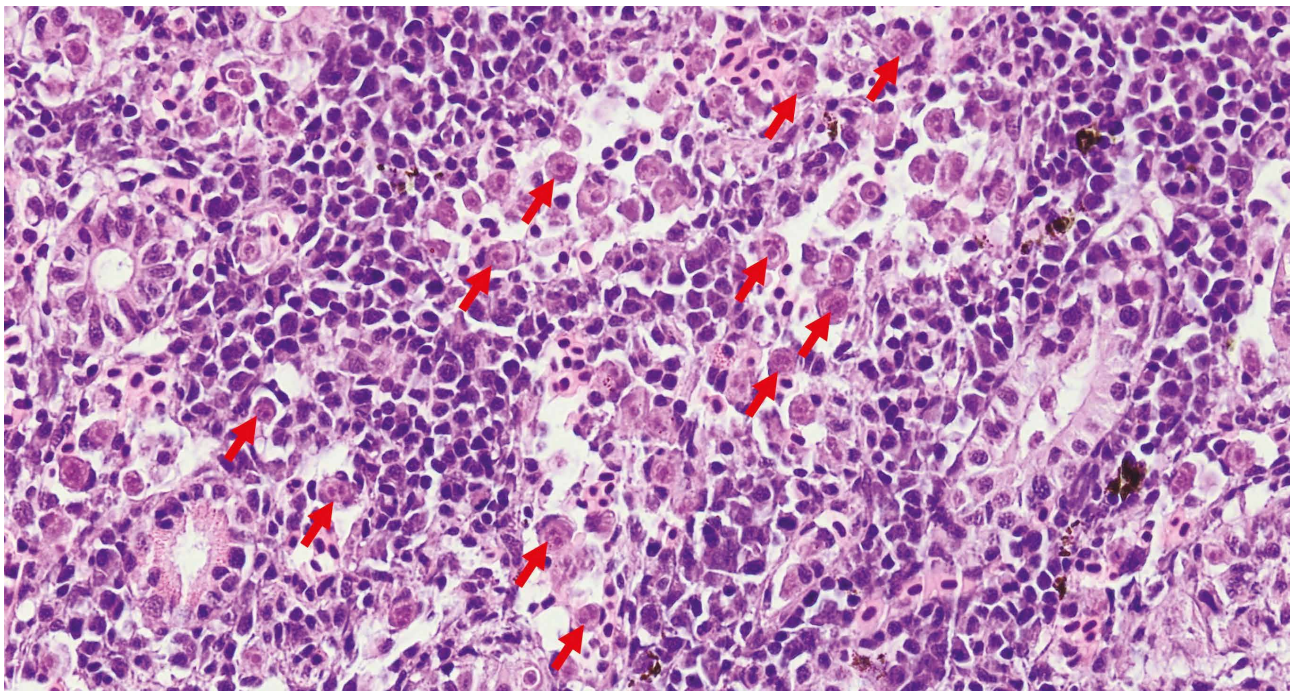
Parasite Concentration

While high temperatures may stimulate a parasite's life cycle within a host, they don't assist it during its most crucial stage: entry into the host. At this moment, the number of parasitic organisms present is the most important factor. Expanding on their previous research, Dr Wahli and his team endeavoured to understand what impact different parasite concentrations have on the spread of proliferative kidney disease in brown trout.

To do this, the team exposed groups of trout to three different concentrations of parasites (high, low and multiple exposures of low concentrations). Using this experimental design, the team confirmed two of their hypotheses: the initial concentration influenced the resulting parasite concentration in the fish, leading to different degrees of kidney damage, while the onset of spore release was the same in all groups.

It is important to note that during this study, the team tightly restricted the period of parasite exposure to one hour on one day for low and high concentrations, and to one hour on three consecutive days each for those undergoing multiple exposures. The infections could take place only during this period, meaning that significant rises in parasite intensity could not be due to re-exposure. In this respect, it is noteworthy that direct infection from fish to fish is not possible.

Through their experiment, Dr Wahli and his team proved that a combination of high and multiple doses of *T. bryosalmonae* parasites significantly worsened the state of the infected fish, caused dramatic tissue damage, and slowed down the recovery time. These results highlight the impact of initial infection concentrations and demonstrate the importance of minimising contact between economically valuable trout and high concentrations of parasites.



Histological section of a kidney that is a heavily infected with T. bryosalmonae

Acquired Immunity

Shedding some hope onto the plight of infected fish, previous research has shown that rainbow trout that are re-exposed to *T. bryosalmonae* can develop partial resistance – a form of immunity that one-year-old 'naïve fish' lack. Wishing to know more about this potentially vital area, Dr Wahli and his team designed an experiment to test the effects of the age of brown trout on the spread of proliferative kidney disease.

Prior to this work, nothing was known as to whether older fish might be more tolerant to the disease or whether the European brown trout reacted in a similar way to re-exposure. Thus, by expanding on the understanding of the field, the researchers hoped to identify new ways of managing the disease and protecting brown trout populations.

By exposing the different groups of brown trout with parasites, the team found that the prevalence and parasite intensity were significantly higher in the younger fish. Older trout were still susceptible to infection by *T. bryosalmonae*, but at lower prevalence, and suffered less kidney damage in comparison.

Just as Dr Wahli had predicted, the results of their trials where previously infected fish were exposed to parasites suggest that there might be a mechanism of resistance preventing the parasite from re-entering the fish or establishing itself in the kidneys. This proposed 'acquired immunity' mechanism still requires further investigation to prove its existence, but if accurate, the team's research would be the among the first to shed light on the possibility of managing proliferative kidney disease in wild freshwater fish populations – a goal crucially needed when rising water temperatures are concerned.

The Future for European Brown Trout

Proliferative kidney disease has been a growing threat to fish species for decades. In Switzerland, mass outbreaks of the infection have devastated the country's brown trout populations, creating economic and environmental fallout. Thanks to the research of Dr Wahli and his colleagues, it is now clearer than ever that higher water temperatures facilitate the life cycle of the *T. bryosalmonae* parasite and its infection. Thus, it can be reasoned that for Switzerland and other countries home to brown trout, the fight against the disease will only intensify as the effects of human-induced climate change become more apparent.

This stark warning is compounded with Dr Wahli's other research, which has highlighted the dangers of high concentrations of the *T. bryosalmonae* parasite in freshwater fish populations. As *T. bryosalmonae* is widespread among Swiss rivers and watercourses, the team's recent efforts further prove the present and incoming risks to native brown trout.

Fortunately, Dr Wahli's recent work showing that previously infected trout are partially protected against proliferative kidney disease reveals an avenue that could be exploited to safeguard fish populations. Demonstrating that re-exposed trout are less susceptible to infection and suffer less kidney damage than their 'naïve' siblings, Dr Wahli and his collaborators have given hope to the future of Switzerland's brown trout.

The team now intends to continue this research and further assess its practical possibilities in managing host pathogen interactions, disease surveillance, and fish welfare.

Meet the researcher

Dr Thomas Wahli
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Dr Thomas Wahli received his PhD fish diseases from the University of Basel in 1985. At present, he serves as Associate Professor in the Faculty of Veterinary Medicine at the University of Bern, where he is also Deputy Head for the Centre for Fish and Wildlife Health (FIWI). For the past 20 years, he has also headed the National Fish Disease Laboratory and Reference Laboratory for notifiable Fish diseases. Over the past 10 years, Dr Wahli's research has focused on ascertaining the effects of temperature, parasites and disease on Swiss fish populations. His current research is focused on diagnosing and counselling fish diseases, host pathogen interactions, disease surveillance, and fish welfare. At the core of his research is the goal to better understand the populations of Swiss fish in the hope of better preserving them.

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UNIVERSITÄT BERN

COMBATTING THE LIONFISH INVASION

Lionfish are predators that typically inhabit Pacific and Indian Ocean coral reefs. In areas where they have been introduced, they have become troublesome invaders. Populations have spread and grown in some regions to the extent that they are wreaking havoc on local marine ecosystems. **Dr Mark Hixon** and his team are working hard to combat the lionfish invasion.

Introduced Invasive Species – A Threat to Global Ecosystems

Biological invasions are a leading cause of biodiversity loss. In the United States alone, according to the Nature Conservancy, invasive species have contributed directly to the decline of 42% of threatened and endangered species. The annual cost of managing the impacts of invasive species is more than 120 billion USD per year. Sadly, invasive species have been introduced both intentionally and unintentionally by humans, and in many cases these introductions have proven to be devastating.

One incredibly problematic invader is the lionfish. Lionfish were first reported in the coastal waters of Florida in the 1980s, likely the result of aquarium releases. They then rapidly spread to the south-eastern seaboard of the United States, the Gulf of Mexico, and the greater Caribbean region. Lionfish are predators that target small fish and some invertebrates on coral reefs and other coastal habitats. Given that the invaded ecosystems are not equipped to deal with lionfish, their presence is causing significant damage. To compound the issue, larger predators which could keep lionfish populations under control tend to steer clear because lionfish have venomous spines. As a result, lionfish are proliferating and the damage is continuing.

Dr Mark Hixon is a marine biologist from the University of Hawai'i at Mānoa. Funded by the US National Science Foundation at Oregon State University, he, his team of graduate students, and postdoctoral researcher Dr Stephanie Green, have worked to understand the ecology and behaviour of lionfish so that the lionfish invasion can be managed. The team focuses their attention on Atlantic areas with substantial populations of invasive lionfish, such as the Bahamas and the Cayman Islands, and on Pacific regions with native lionfish populations, such as the Philippines and the Marianas Islands.

Specifically, the research of Dr Hixon and his team seeks to find answers to two key questions: What are the main ecological effects of lionfish on invaded coral reefs? And, do any native coral-reef species provide biotic resistance, that is, the ability to naturally control invasive lionfish populations? With the answers to these questions in hand, they aim to help develop an effective strategy to manage the lionfish threat.

Effects of Invasive Lionfish on Native Species

Dr Hixon and his colleagues have conducted multiple field experiments to investigate the effects of invasive lionfish on native species. Specifically, they have been manipulating the number of lionfish on coral reefs, and then examining the impact of these fluctuations on local ecosystems. These experiments have clearly shown that lionfish cause decreases in the populations of many native fishes. In extreme cases, some species are even driven to local extinction.

Mark Hixon and lionfish. CREDIT: Carl Safina

CREDIT: Mark Albins, OSU

Dr Hixon and PhD student Mark Albins first studied relocated coral and artificial reefs that had been populated with lionfish in order to examine the subsequent recruitment of native reef fishes. They found that lionfish caused,

‘The lionfish invasion has been recognised as one of the major ocean conservation threats worldwide. Our work has already benefited reef managers and the public by documenting the negative effects of lionfish and conveying the importance of control efforts.’

CREDIT: Jens Petersen

on average, a 79% reduction in the appearance of newly settled larvae over a five-week period. Critically, the study suggested that invasive lionfish could negatively impact Atlantic coral reefs both strongly and quickly – which later investigations confirmed to be correct.

PhD student Kurt Ingeman found that populations of fairy basslet – a native coral reef species and popular aquarium fish – are especially impacted by lionfish. Specifically, he observed local extinction of fairy basslet populations on reefs with lionfish but not on reefs with native predators only. Additional studies by PhD student Tye Kindinger showed that lionfish preferentially attack fairy basslet over blackcap basslet, which alters the level of competition between these species, leading to broader impacts within the ecosystem.

Importantly, native fishes do not recognise invasive lionfish as a threat. PhD student Casey Benkwitt found that, although larvae of some native reef fishes avoid settling where native predators are present, they do not avoid settling near lionfish. This behaviour further jeopardises these small prey.

In addition to direct predation effects and loss of biodiversity, lionfish can have flow-on indirect effects. For example, PhD students Tye Kindinger and Mark Albins found that lionfish reduce both the populations and the individual feeding rates of herbivorous fishes, which are species that remove seaweed and algae. Grazers are vital to reef ecosystems because excess seaweed and algal growth can smother and kill corals. As lionfish are responsible for reducing grazing, they are indirectly hastening the demise of already stressed coral reefs in invaded regions.

Lack of Biotic Resistance and Lionfish Proliferation

Clearly, large, invasive lionfish populations pose a significant threat to marine ecosystems and they need to be controlled. Albins and Hixon commented in 2008, ‘while complete eradication of lionfish in the Atlantic is likely impossible, it would be prudent to initiate focused lionfish control efforts in strategic locations.’ To understand how best to control lionfish populations, the team has been assessing the factors that contribute to their proliferation. Primarily, the success of lionfish is associated with a lack of biotic resistance.

The term ‘biotic resistance’ refers to the ability of local species to keep populations of invasive species in check, or to eradicate them completely from an affected area. PhD students Mark Albins, Alex Davis, and Tye Kindinger

CREDIT: Rich Carey

found that native species, including potential competitors such as territorial damselfishes and ecologically similar groupers, do not inhibit invasive lionfish in any substantial way. This lack of biotic resistance has provided lionfish a free reign to multiply and cause further damage. But could parasites offer a solution?

The team specifically examined the role of parasites in controlling lionfish abundance. In a study led by PhD student Lillian Tuttle, in collaboration with former PhD student Dr Paul Sikkel and colleagues, they found that fewer lionfish were parasitised in their Atlantic habitats, where they are invaders, compared with Pacific habitats where they are native. Unfortunately, the relatively low infection rates of lionfish in the Atlantic indicate that parasites are not likely sources of biotic resistance to lionfish invasion. Indeed, finding an effective biological solution for lionfish population control has proven impossible thus far, so other options are being considered.

Options for Population Control

Surprisingly, towards the end of the team's decade-long study, lionfish abundances in the central Bahamas were declining despite there being no lionfish control efforts in the region. Joined by former PhD students Tim Pusack and Chris Stallings, the team investigated the possible reasons behind this trend. They suggested that some combination of poor larval supply and survival rates, hurricanes, and new interactions with native species may be accountable. While the team acknowledges that further studies are required to determine whether the declines will persist, as well as the exact cause, getting to the bottom of this observation will likely assist future conservation efforts.

In the meantime, human consumption has been suggested as the best method of lionfish population control, and lionfish derbies and fisheries are appearing throughout the invaded range. However, some have expressed concern that lionfish may be poisonous to humans. The specific toxin of concern is ciguatoxin, which some marine species acquire by ingesting certain marine microorganisms, which are concentrated up the food chain.

Some tests have indicated that lionfish may be ciguatoxic. However, research by Dr Christie Wilcox and Dr Hixon suggests that ciguatera tests on raw lionfish flesh are likely to be inaccurate, so human consumption as a means of dealing with lionfish should not be ruled out. The solution is to test lionfish flesh for ciguatoxin after cooking, which will provide an accurate test. In any case, there have been no cases reported to date of lionfish causing ciguatera.

Communicating Their Findings to the Public

Considering the environmental and economic impacts of increasing lionfish populations, the issue should be of global concern. As Dr Hixon relates, 'the lionfish invasion has been recognised as one of the major ocean conservation threats worldwide.' As such, communicating their findings to the public is one of the team's primary goals. To that end, they have utilised several methods of public communication.

To date, dissemination of their lionfish research has included numerous public presentations, a television episode (Saving the Ocean), a TEDx talk and over 30 peer-reviewed publications in scientific journals (available at http://hixon.science.oregonstate.edu/content/highlight-lionfish-invasion). The results of these efforts are promising. 'Our work has already benefited reef managers and the public by documenting the negative effects of lionfish and conveying the importance of control efforts,' Dr Hixon explains.

In conclusion, given that invasive lionfish pose a significant threat to the environment and the economy, understanding their ecological effects is critical to conservation strategies. Furthermore, supporting the collaboration between scientists and the public to combat the problem is vital. Thankfully, the work of Dr Hixon and his team reflects significant progress in meeting these challenges.

From left to right: Postdoctoral researcher Steph Green*, PhD students Kurt Ingeman**, Tim Pusack, Lil Tuttle**, Alex Davis**, Casey Benkwitt**, and Tye Kindinger**

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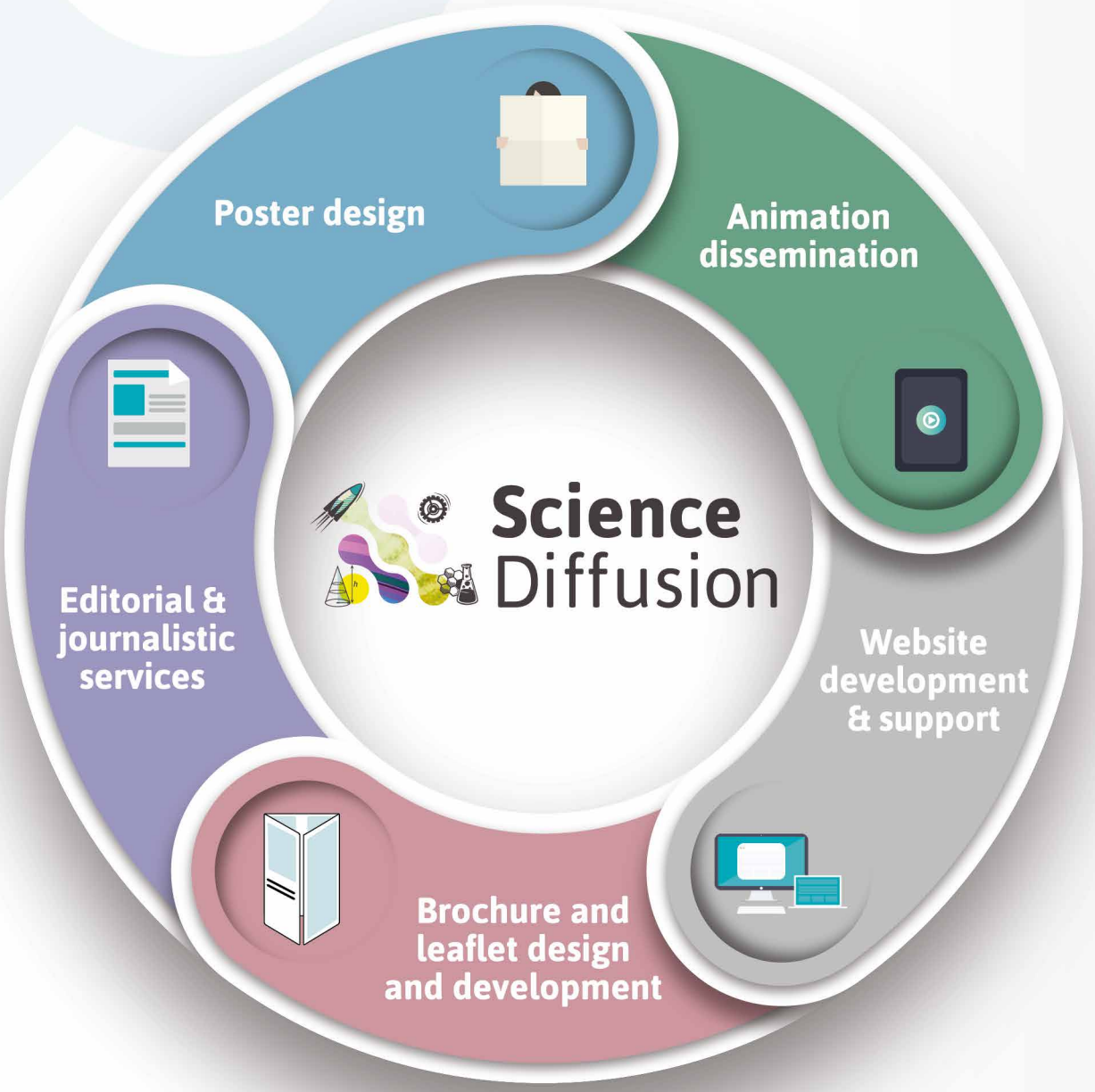

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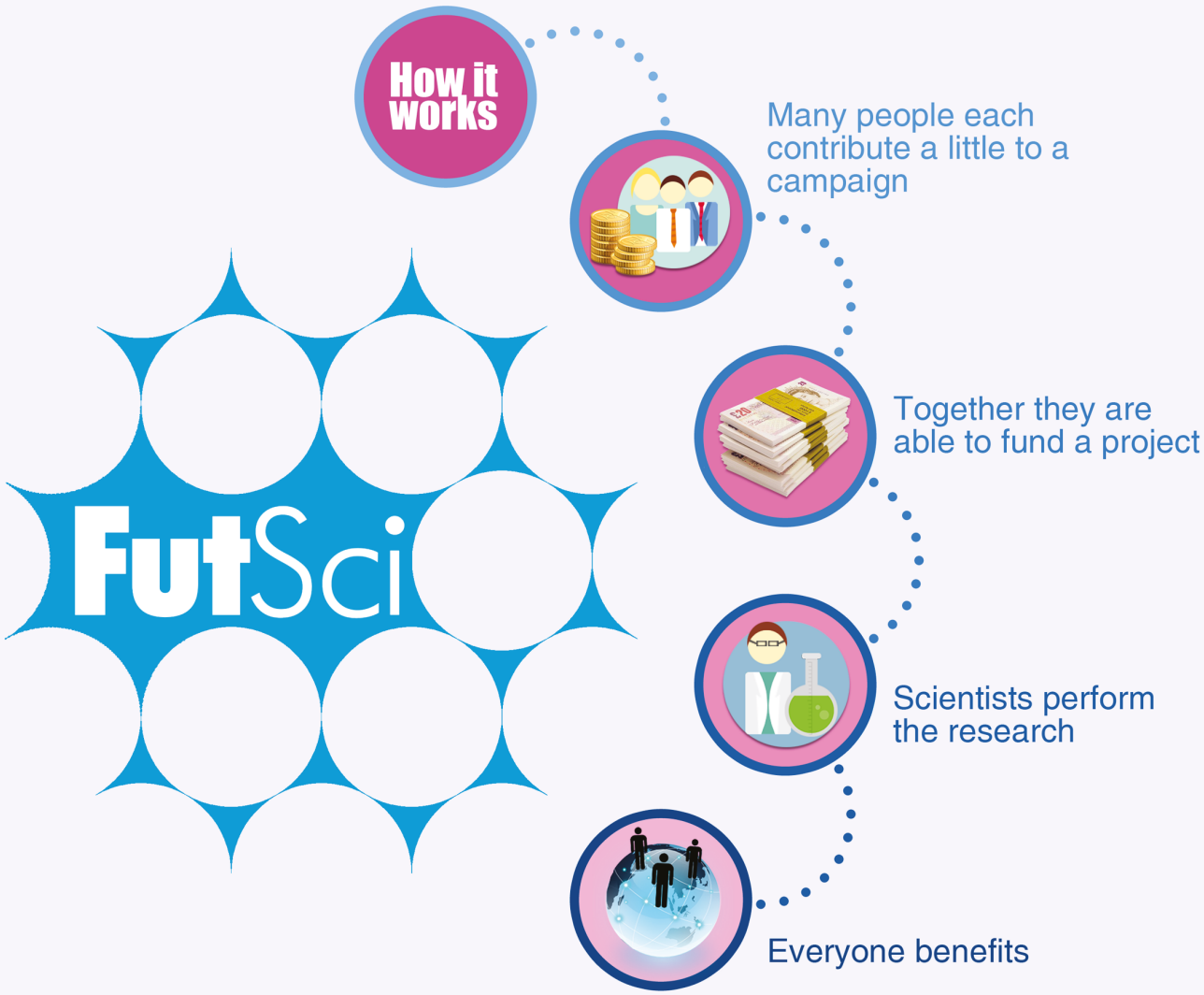

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