IGB

Leibniz Institute of
Freshwater Ecology
and Inland Fisheries

One Year of Freshwater Research

Annual Research Report 2019

Freshwater biodiversity

The silent crisis of aquatic biodiversity is taking place beneath the surface – in two senses.

Greenhouse gases in inland waters

From CO_2 storage to methane polluter? Inland waters and climate change influence each other.

Water in the landscape

The types of vegetation and land use play an important role for the water regime.

Protection and use, a conflict of objectives?

Managing and conserving freshwaters for the welfare of mankind and nature – with research knowledge.

Angling

Aquaculture and Aquaponics

Biodiversity

Dialogue and Transfer

Freshwater Ecosystems

Use and Management

Multiple Stressors and Pollutants

Environmental Change

Behavioural Ecology and Swarm Intelligence

Water and Matter Cycles

Research for the future of our freshwaters

IGB is Germany's largest research centre for freshwaters. At IGB, scientists from a whole range of disciplines work under one roof. They are working together to investigate the fundamental processes in rivers, lakes and wetlands, and join forces to develop measures conductive to sustainable water management.

On the following pages we present selected research results, projects and events from 2019. The content is allocated to ten topics in which we bundle the results of our research work that could be of interest to you. For each topic, you will find further information, materials, experts as well as background information and current news on our website.

We hope you enjoy reading and exploring!

Contents

Dear Reader,

I am new to IGB. This implies that in 2019 I did not contribute anything to IGB's research. And yet I am very glad to now have the opportunity to recommend looking at our research and its contribution to tackling the challenges of our time. In 2019, IGB and its outstanding scientists once again addressed highly relevant research questions at the highest level of excellence.

What is it that we at IGB do in the field, on the lake, in the laboratory or at our desks? Roughly spoken, we explore the basic processes governing freshwater ecosystems and their communities, how they respond to environmental change, including human-induced changes such as climate warming and urbanisation, and study the effectiveness of restoration or mitigation actions. By sharing this knowledge, the institute facilitates the development of scenarios and measures for achieving sustainable water management, for maintaining aquatic biodiversity, and for the preservation of freshwater ecosystems as a vital resource and a valuable habitat.

"The basis for wise decision-making – in freshwater management, biodiversity protection and elsewhere – is excellent science, which is both dedicated to the elucidation of fundamental principles and mechanisms as well as to current societal challenges, and which is the foundation for a proper factual discourse on controversial issues."

In this annual research report, we present four overarching topics we were particularly engaged with in 2019. They show key scientific insights that we gained into how natural systems function and how they respond to stressors and management. They also illustrate how important these insights are to achieving the goals of sustainability.

Starting on page 9, you can read how the pressure on aquatic biodiversity is increasing and what solutions research

Photo: Portrait De Meester © David Ausserhofer

can offer – but also which political steps are needed. The biodiversity crisis is less abundantly reported upon in the news than the climate crisis, yet is dramatic, with equally far-reaching consequences. Let us not forget that our society vitally depends on the resources offered by natural habitats – and very much so also by aquatic ecosystems. Research on the diversity of life forms, how this diversity originates and is maintained, and how it affects the functioning of ecosystems and its links to society, is therefore of crucial importance.

From page 15 onwards, we can learn how water bodies affect greenhouse gas emissions, and how this is impacted by climate change, leading to an unpleasant feedback. Our researchers are trying to fully understand no less than the global methane cycle in order to improve predictions about climate change – and possible countermeasures. From page 22, the focus is on the amount of water itself. The relationships between vegetation, soil and water regimes are complex. Here too, the question arises of how global warming will affect the water balance in various ecosystems. It is clear that some systems will get hit particularly hard.

I am not only new to IGB, I am also new to the German and Berlin science system. I am very happy to see that in 2019, as before, many partners accompanied, supported and inspired our research, teaching and transfer activities. In particular, I would like to mention our close university partners – Freie Universität Berlin, Humboldt-Universität zu Berlin, Technische Universität Berlin and the University of Potsdam – as well as the many research institutes with which we collaborate. I also want to thank the institute's Scientific Advisory Board, which showed great commitment during the period of interim directorship, the Forschungsverbund Berlin for its professional administrative support, the Leibniz Association, and the authorities and associations that maintain close links with us. And it is only thanks to the financial and practical support of Berlin's Senate Chancellery for Higher Education and Research, and of the Federal Ministry of Education and Research (BMBF), that IGB can function in the first place.

"True to IGB's guiding principle – Research for the future of our freshwaters – our research findings empower society and decision-makers to respond to a changing global environment more effectively and to strike the right balance between protecting aquatic ecosystems and using freshwater-based resources, knowing that sufficient protection is often crucial to enable sustainable use."

An interview with Luc De Meester. Meet the new director – on the last → **pages 49-50**

I also sincerely thank my dedicated predecessors. Thanks to the effective leadership of Klement Tockner and Mark Gessner, in synergy with the thriving community of researchers and supporting staff at the institute, IGB has continuously grown in excellence, relevance and international reputation. I am very grateful for their great work, and together with the institute's staff, I am eager to develop IGB's vision for the future building on their achievements.

I am – you might have gotten a feeling of this by now – very proud of IGB and its interdisciplinary research approach, its diverse collaborative activities and the outstanding transfer work undertaken at the interface of science and society. True to IGB's guiding principle – Research for the future of our freshwaters – our research findings empower society and decision-makers to respond to a changing global environment more effectively and to strike the right balance between protecting aquatic ecosystems and using freshwater-based resources, knowing that sufficient protection is often crucial to enable sustainable use. Take a look at page 27 to read more on this.

The basis for wise decision-making – in freshwater management, biodiversity protection and elsewhere – is excellent science, which is both dedicated to the elucidation of fundamental principles and mechanisms as well as to current societal challenges, and which is the foundation for a proper factual discourse on controversial issues. Following this discourse, it is also essential that responsibility is taken by everybody involved to translate the generated knowledge into action. I hope that this annual research report contributes to that inspiration. Enjoy the read!

Yours,

Luc De Meester
Director

Artificial intelligence for sustainable development

Can AI contribute to the implementation of the UN sustainability goals? Yes, especially at the ecological level. But AI can also impede the implementation of measures, especially at the social level. The 17 Sustainable Development Goals (SDG) of the United Nations take aim at 169 individual targets running the gamut from economy and society to environment. 134 of these targets could benefit from AI, while 59 could also be impacted negatively. AI has the greatest potential to positively support the achievement of the environmental goals. One example: AI-based technologies could better capture biodiversity.

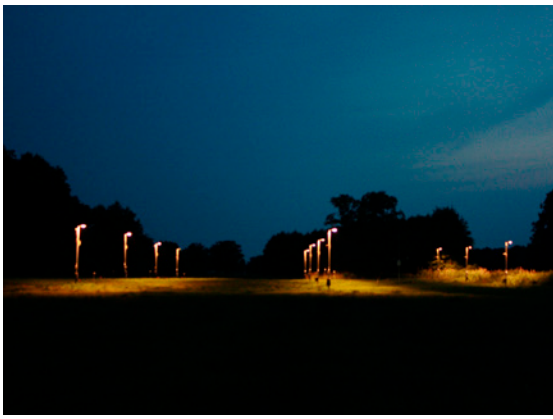
Read more
→ www.igb-berlin.de/en/news/ki

Vinuesa, R. et al. (2020). The role of artificial intelligence in archieving the sustainable development goals. **Nature Communications**, 11, art. 233. doi:10.1038/s41467-019-14108-y

On a journey...

...as a microorganism on microplastic. Unlike natural substances such as wood or colonies of algae, microplastic particles decay extremely slowly, and may therefore transport the organisms they host over long distances. Floating plastic could therefore play a role in the dispersion of various organisms, including invasive, parasitic or pathogenic species. More for fans of microorganisms → **page 19**.

Kettner, M. T. et al. (2019). The eukaryotic life on microplastics in brackish ecosystems. **Frontiers in Microbiology**, 10, 538. doi:10.3389/fmicb.2019.00538



The experimental fields in the Westhavelland Nature Park in Brandenburg. Here IGB scientists are testing the ecological effects of street lighting.

Against light pollution

The light pollution research at IGB, together with the German Federal Agency for Nature Conservation (BfN) and the University of Münster, has published a guideline for redesigning and converting outdoor lighting. The guideline offers those responsible in local authorities as well as lighting, urban and regional planners a free professional decision-making aid on how to make street and building lighting more efficient in order to minimise light pollution.

In the absence of explicit regulations for outdoor lighting, industry standards for lighting are often treated as legal regulations in practice. In many cases, even the minimum requirements of the technical standards are far exceeded in order to exclude possible claims for damages (f.i. in the case of traffic accidents). As a result, outdoor spaces are often illuminated much more than necessary, with possible negative effects on people and nature. However, it is possible to minimise the ecological damage caused by artificial lighting while at the same time meeting social requirements such as safety and aesthetics.

Guideline for redesigning and converting outdoor lighting (in German) → bit.ly/bfn-543

M.Sc. Fish Biology, Fisheries and Aquaculture

The international master programme educates fish experts for science, practice and nature conservation and provides them with the skills to work in pioneering jobs at the interface of the aquatic sciences, sustainable ecosystem management and food production. The course of study is covering the three domains Fish Biology and Evolution of Fishes, Fisheries Management and Conservation as well as Aquaculture – making it unique in its orientation.

Apply → www.igb-berlin.de/en/master-programme

Funded to foster

The research training group Urban Water Interfaces (UWI), conducted in close cooperation with the Technische Universität Berlin, focuses on the role of natural and technical boundary zones in the urban water cycle. In 2019, the German Research Foundation (DFG) has extended funding for UWI for another four and a half years. The aim now is to intensify interdisciplinary cooperation and to transfer the results of basic research more effectively into water management practice.

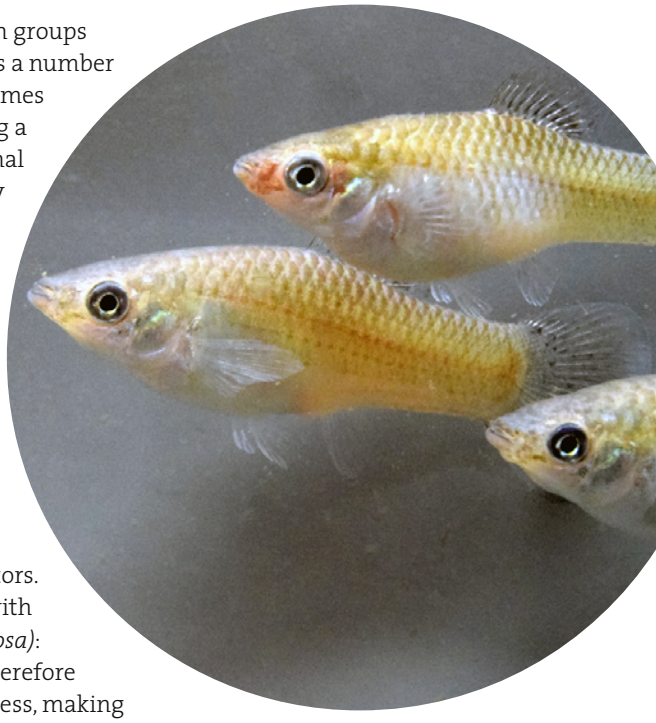
About UWI
→ www.uwi.tu-berlin.de

Tips for finding food

Tips for a successful foraging are best obtained from female guppies. In the rainforest of Trinidad, it can be observed that male guppies are more likely to find new feeding grounds in the presence of females than in pure male cliques. However, in females, the success of the foraging is independent of the gender composition of the group. Who – except male guppies – benefits from this information? For example, nature park administrations and conservationists: understanding social networks of animals is a prerequisite for successful conservation measures.

Snijders, L. et al. (2019). Females facilitate male food patch discovery in a wild fish population. **Journal of Animal Ecology,** 88(12), 1950-1960. doi:10.1111/1365-2656.13086

Familiarity breeds aggression



Many animal species live in groups because cohabitation offers a number of advantages, such as when it comes to foraging, defence, and selecting a mate. Finding out how such animal groups form and function is a key issue in behavioural ecology. IGB researchers have found out – in a group – that group composition is dependent not only on environmental factors such as the availability of food, but also on the level of familiarity among group mates. This factor has often been neglected so far, because familiarity is often linked to kinship, making it difficult to disentangle these two factors. Fortunately, this is not the case with the Amazon molly *(Poecilia formosa)*: they reproduce by cloning and therefore exhibit identical genetic relatedness, making them ideal for researching the influence of familiarity. A central finding of the current study: the fish with the highest level of familiarity acted most aggressively towards each other. This surprised the researchers.

Read here why
→ www.igb-berlin.de/en/news/familiarity-breeds-aggression

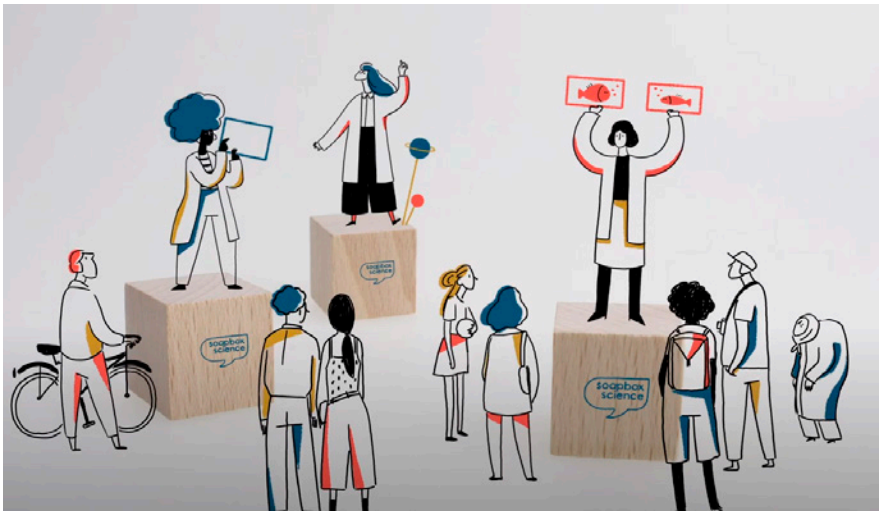
Laskowski, K. L. et al. (2019). Naturally clonal vertebrates are an untapped resource in ecology and evolution research. **Nature Ecology & Evolution**, 3(2), 161-169. doi:10.1038/s41559-018-0775-0

Doran, C. et al. (2019). Familiarity increases aggressiveness among clonal fish. **Animal Behaviour**, 148, 153-159. doi:10.1016/j.anbehav.2018.12.013

Revised: Aquakulturinfo.de

Aquaculture is the fastest growing area of food production in the world – one of the reasons why it is the subject of controversial debate in society and politics. What is often overlooked, however, is that there is no all-encompassing definition of the aquaculture. In fact, aquaculture encompasses very different forms of the controlled production of fish, crustaceans, mussels or algae. With our research-based information portal Aquakulturinfo we want to support the personal opinion-forming and the public discussion about aquaculture. Consumers, trade, associations, industry and politics can use the website to obtain objective and scientifically sound information on topics such as animal welfare and animal health, husbandry or product quality as well as important aquaculture animal species. It is envisaged to translate Aqualkulturinfo into English.

Get informed
→ www.aquakulturinfo.de



Soapbox Science

The Soapbox Science initiative promotes more female role models in science and aims to break stereotypes about how female scientists look or work. The events transform public places into venues for scientific discussions. They provide a platform for female researchers to share their passion for experimentation, discovery and innovation with the public and to exchange research results with citizens. The IGB is a proud co-organiser of the events in Berlin.

Watch the video
→ youtu.be/wmBj_Houb_w

FRESHWATER NEWS

Are you interested in freshwater research and would like to learn about new activities at IGB? Then simply subscribe to our newsletter, which will be sent to your mailbox every two months, packed with information about IGB and our topics.

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Photos: Screenshot © IGB; Video © Soapbox Science

Freshwater biodiversity

More public attention and conservation efforts for biodiversity in freshwaters are needed

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The silent crisis of aquatic biodiversity is taking place beneath the surface – in two senses –, often unnoticed by society, industry and politics. The decline in biodiversity, i.e. the disappearance of species, populations, habitats or even entire ecosystems, occurs much more rapidly in inland waters than on land or in the sea. Climate change, introduced pathogens and invasive species further exacerbate the crisis.

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Fitness training for sturgeons

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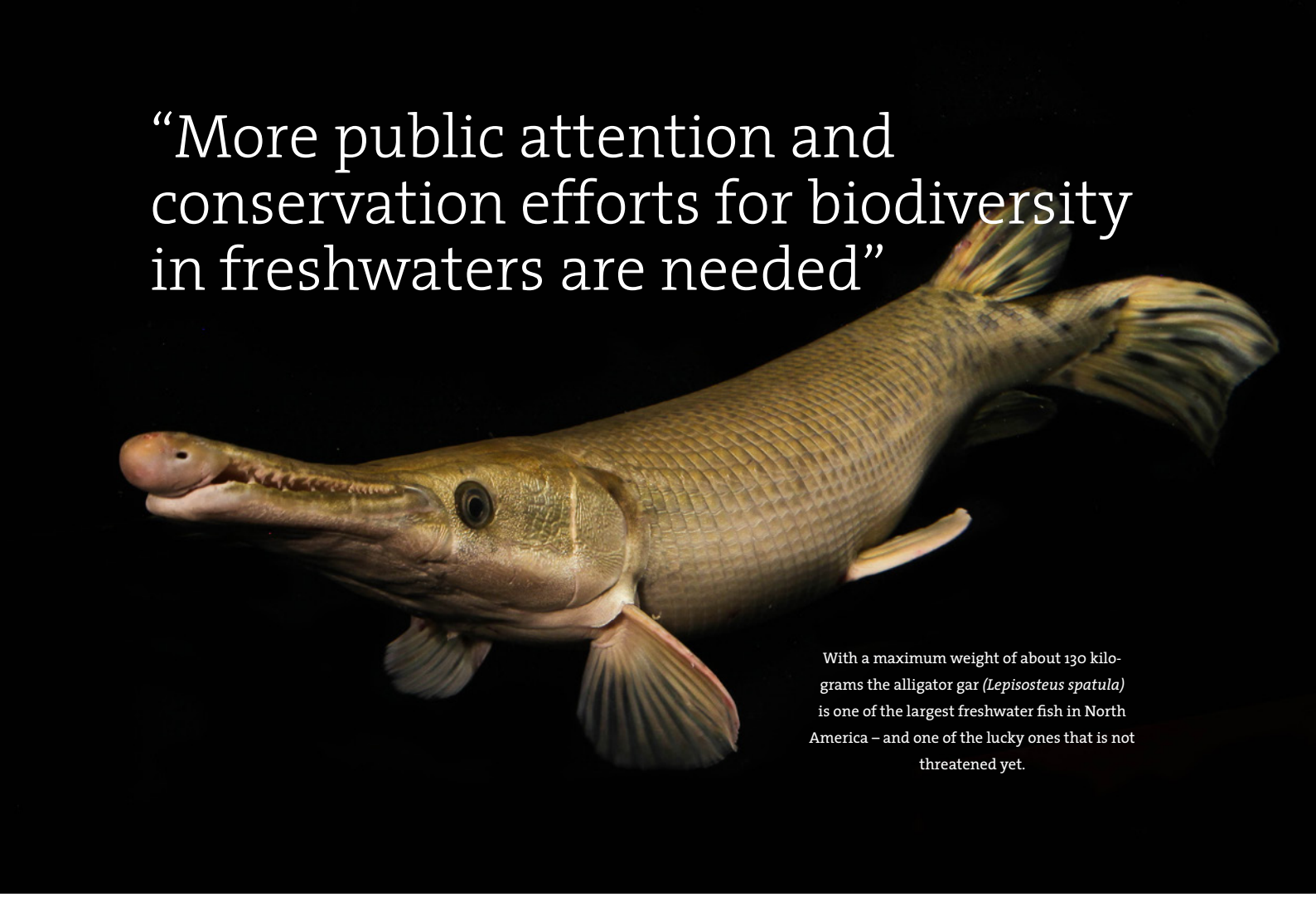
“More public attention and conservation efforts for biodiversity in freshwaters are needed”



With a maximum weight of about 130 kilograms the alligator gar *(Lepisosteus spatula)* is one of the largest freshwater fish in North America – and one of the lucky ones that is not threatened yet.

Rivers and lakes cover just about one percent of Earth’s surface, but are home to one third of all vertebrate species worldwide. At the same time, freshwater life is highly threatened. Sonja Jähnig and Fengzhi He together with international colleagues have found out that global populations of large freshwater animals – freshwater megafauna – have shrunk by 88 percent within a few decades. In this interview, Jähnig and He explain why and describe how the decline in freshwater species can be tackled. A first important step is to put the biodiversity crisis in freshwaters on the public and political agenda.

For the first time you have quantified the global population trend of the largest vertebrate species in inland waters. What have you learned?

Fengzhi He: We have shown that from 1970 to 2012, global populations of freshwater megafauna declined by 88 percent. The decline is thus twice as high as that of vertebrates on land or in the ocean. Freshwater megafauna include all freshwater animals that can reach a body mass of 30 kilograms or more, such as river dolphins, beavers, crocodiles, giant turtles, and sturgeons.

Sonja Jähnig: For the study we compiled available time series data for 126 freshwater megafauna species worldwide, as well as the historical and contemporary geographic distribution data of 44 species in Europe and the USA. Large fish species such as sturgeons, salmonids, and giant catfish are particularly affected, with a decline of 94 percent. In addition, 42 percent of all freshwater megafauna species in Europe lost more than 40 percent of their historical distributions.

How did this happen?

Sonja Jähnig: Overexploitation of these large animals for meat and caviar consumption and traditional medicine is one of the main threats to them.

Fengzhi He: Moreover, the habitats of freshwater megafauna have been increasingly destroyed: The decline of large fish species like the sturgeons and giant catfish is also attributed to the loss of free-flowing rivers as their access to spawning and feeding grounds are often blocked by dams. Although many of the world’s large rivers have already been highly fragmented, another 3700 large dams are planned or under construction – this will exacerbate the river fragmentation even further. More than 800 of these planned dams are located in diversity hotspots of freshwater megafauna, including Amazon, Congo, Mekong, and Ganges river basins.

Photos: Alligator gar © Zeb Hogan; Portrait He © private; Portrait Jähnig © David Ausserhofer

Are there also successful protection efforts?

Fengzhi He: Yes. Thanks to targeted conservation actions, populations of 13 megafauna species including the white sturgeon and the American beaver have been stable or even increasing in the USA according to the Red List of Threatened Species of the International Union for Conservation of Nature (IUCN). In Asia, the population of the Irrawaddy river dolphin in the Mekong basin has increased for the first time in twenty years. In Europe, efficient and large-scale conservation strategies seem to be more difficult to implement, arguably due to politic boarders and differences in environmental protection efforts among countries. Nevertheless, the Eurasian beaver, for example, has now been reintroduced to many regions where it was extirpated.

Nevertheless, the current protection measures seem to be insufficient.

Sonja Jähnig: Correct. According to the IUCN Red List, over half of all assessed freshwater megafauna species are considered as threatened. Nonetheless, they receive less research and conservation attention than megafauna in terrestrial or marine ecosystems.

In May 2019, the World Biodiversity Council IPBES published a summary for decision-makers on the Biodiversity Report. It shows that biodiversity is declining at an alarming rate and to an alarming extent – but here too the biodiversity crisis in inland waters remains a marginal note.

Sonja Jähnig: Yes, sadly. The document shows that 75 percent of freshwater resources are "consumed" for agriculture – just one example of the enormous pressure on inland waters and their biodiversity. We need more attention to biological diversity in freshwaters and hope that we can put the issue of the biodiversity crisis in inland waters on the social and political agenda. With the "Living Waters" research agenda, which we handed over to the Federal Ministry of Education and Research in May 2019, we have taken another small step forward (→ **page 14**).

What concrete measures do you demand to stop the loss of species?

Fengzhi He: It is important to improve the monitoring of population trends and distributions of freshwater species in regions such as Asia, Africa and South America. After all, changes in abundance and distribution are more informative about the condition of ecosystems and their living organisms than the extinction of species.

Sonja Jähnig: For the European Union's Biodiversity Strategy 2030, we consider it essential that the value of inland water ecosystems is considered for itself and that water is not only seen as a resource. It is equally important to recognise the role that biodiversity plays in ecosystem functions such as the provision of drinking water. An important step would be to set separate targets and indicators for inland waters and their biodiversity. It would make sense for these measures to take into account the mechanisms of aquatic-terrestrial coupling – the success of restoration will largely depend on this. This is because freshwater ecosystems do not exist in isolation, but are closely linked to their environment and vice versa. For example, many species change from one ecosystem type to another during their life cycle. Therefore, holistic management approaches must be applied to halt the decline of biodiversity.

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Dr. Fengzhi He, fengzhi.he@igb-berlin.de

He, F. (2019). The global decline of freshwater megafauna. **Global Change Biology,** 25(11), 3883-3892. doi:10.1111/gcb.14753

He, F., & Jähnig, S. C. (2019). Put freshwater megafauna on the table before they are eaten to extinction. **Conservation Letters**, 12(5), e12662. doi:10.1111/conl.12662

Zarfl, C. (2019). Future large hydropower dams impact global freshwater megafauna. **Scientific Reports**, 9, 18531. doi:10.1038/s41598-019-54980-8

Fitness training for sturgeons

IGB researchers have provided one of the first proofs of the complex learning behaviour of fish. They investigated whether sturgeons can increase their fitness for the wild by training. An important factor is their feeding behaviour: Even a two-week "learning lead" already rendered food finding more efficient.

Sturgeons are among the most endangered fish species in the world. The IGB develops the scientific basis for the reintroduction of the Baltic and European sturgeons. This also includes releases of juvenile fish reared under controlled conditions. Many of these fish die in the wild during the first days following release. The faster the animals adapt to the new environmental conditions, the higher the chance of survival. For this reason, the IGB researchers have developed out a "fitness training" in order to optimally prepare the animals for the reintroduction.

Compared to mammals, the formation of nerve cells in the brain in fish is very dynamic and remains active throughout life. This enables fish to react very well to changes in their environment. In the behavioural studies, the sturgeons were divided into two groups, one of which underwent feeding training under near-natural conditions, while the other group was given food that was readily available. After two weeks, both groups had to search for their prey under near-natural conditions. The trained fish found the food twice as fast as their untrained conspecifics, while also showing differences in the brain structure.

The complicated search for food thus caused the animals' brains to be more active and to process learning experiences. The results are significant from a scientific point of view, since there is little evidence to date for complex learning behaviour of fish. From the point of view of species protection, the results are also very important: Based on the results, the IGB can further optimise the rearing conditions for sturgeons prone to be released.

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Dr. Jörn Geßner, sturgeon@igb-berlin.de

Cámara-Ruiz, M. et al. (2019). How to improve foraging efficiency for restocking measures of juvenile Baltic sturgeon *(Acipenser oxyrinchus)*. **Aquaculture**, 502, 12-17. doi:10.1016/j.aquaculture.2018.12.021

Protecting insects through environmentally friendly lighting

Three questions to Sibylle Schroer, who coordinates the six-year joint project "Species conservation through environmentally friendly lighting" in the Federal Biodiversity Programme. The team develops special lamps and includes citizens in the project work..

What is the aim of the project?
Sibylle Schroer: To better protect insects. Lighting is an important factor here. We develop a more environmentally friendly street lighting design with less impact on nocturnal insects and other animals.

How do the new luminaires differ from street lighting as we know it?
In cooperation with the Department of Lighting Technology at the Technical University of Berlin, we develop a street lighting design that minimizes the emission of light onto the trajectories of insects. The light will then no longer be visible on the luminaire itself, but only on the pavements and streets. Following a scientific evaluation in an experimental field in Westhavelland, the new street lighting design is expected to be installed and tested in four German communities in autumn 2021.

Are you investigating the attraction and behavior of insects on the street lights?
Yes, over two years before and after the installation of the new street lighting. Volunteer entomologists from all over Europe are involved in this project, as are pupils who can learn the taxonomic classification of insects and their importance for ecosystems. We also involve citizens in the project because private lighting in gardens and on house facades is increasing.

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→ www.tatort-strassenbeleuchtung.de/en

Project: AuBe, **Duration:** 06/2019-05/2025, **Funded by:** Federal Agency for Nature Conservation (BfN) with funds of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) in the Federal Biodiversity Programme, **Lead:** PD Dr. Franz Hölker, Dr. Sibylle Schroer, **Research group:** Light pollution and ecophysiology, Dept. Ecohydrology

Photos: Sturgeon © Marco Prosch; Light pollution © Sophia Dehn/NABU Westhavelland; Frogs © James Harding

Tracking the consequences of invasive species

Invasive species can bring native animal and plant species to the brink of extinction. They often go undetected for a long time, or their damaging impacts are not immediately clear. This phenomenon – referred to as crypticity – represents a huge challenge for the management of species communities and the conservation of biodiversity. IGB researchers are also looking at the costs caused by invasive species and the future impacts of biological invasions.

"Same same but different": Gray tree frog (*Hyla versicolor*, right) and Cope's gray tree frog (*Hyla chrysoscelis*, left) – indistinguishable based on external morphology.

The impacts of invasive species on native fauna and flora can be devastating. A major problem in dealing with invasive species is that their introductions often go unnoticed, or their damaging effects are only detected with a delay. Since these processes are often hard to predict, it is difficult to assess the extent, impacts and risks of biological invasions, and to plan effective control measures. The researchers have therefore developed a conceptual framework to deal with these aspects of uncertainty.

Whether an invasive species is quickly detected depends on its ecological properties, its new habitat and the circumstances of its introduction. If, for instance, the imported species closely resembles a native species, genetic analyses are often necessary to tell them apart. Many species also go undetected for a long time because they occur only rarely or populate habitats that are difficult to access – examples include belowground and aquatic ecosystems.

In order to identify detrimental species and their properties more effectively, as well as spatial and temporal changes, our research is also supported by citizen scientists. Long-term monitoring should help to flag critical developments in good time.

IGB researchers aim to gain a more comprehensive understanding of the multi-faceted effects of invasive alien species on biodiversity and ecosystem services, and to better assess future developments. In particular, the European wide InvasiBES project focuses on the costs caused by invasive species and examines ecosystem services. The AlienScenarios project, which is like InvasiBES carried out jointly with Freie Universität Berlin and other partner institutions, focuses on the future impacts of biological invasions on biodiversity and human livelihoods. Seven international project teams evaluate for the first time the future trajectories of biological invasions in the 21st century on different spatial scales and for a wide range of species communities. These scenarios will support decision-makers to assess which measures are necessary for the conservation of biological diversity.

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Dr. Wolf-Christian Saul, saul@igb-berlin.de

Projects: InvasiBES, AlienScenarios, **Duration:** 2019-2022, **Funded by:** Federal Ministry of Education and Research (BMBF), BiodivERsA-Belmont Forum Call 2017/2018, **Research group:** Ecological Novelty, Dept. Ecosystem Research

→ alien-scenarios.org

Jarić, I. et al. (2019). Crypticity in biological invasions. **Trends in Ecology and Evolution**, 34(4), 291-302. doi:10.1016/j.tree.2018.12.008

Living Waters: A Research Agenda for the Biodiversity of Inland and Coastal Waters

Inland and coastal waters are among the hotspots of biodiversity.

Inland and coastal waters are home to a unique diversity of life. At the same time, streams, rivers, lakes, small still waters, wetlands, estuaries and groundwater in Germany – and worldwide – are among the most threatened ecosystems. In contrast to terrestrial or marine ecosystems, however, the loss of biological diversity in inland waters has so far hardly been the focus of public attention. Coordinated by Sonja Jähnig, researchers from 20 German scientific institutions have therefore written the "Living Waters" research agenda and presented it to the German Federal Ministry of Education and Research in May 2019 at the 15th BMBF Forum for Sustainability (FONA).

In future, this loss of biological diversity could also become a problem for humans. This could happen when water bodies are no longer able to perform important functions such as supplying drinking water, providing fishery resources, degrading pollutants or serving as recreational areas. Because of these essential ecosystem services, they should actually be granted special protection and sustainable use. But the silent crisis of aquatic biodiversity is taking place beneath the surface – in two senses –, often unnoticed by society, industry and politics. Meanwhile, the pressure of use from agriculture, industry, transport, drinking water and energy production, wastewater disposal and leisure activities continues to increase. Climate change, introduced pathogens and invasive species further exacerbate the crisis.

The research agenda aims to document the status and development of water biodiversity, to better understand influencing factors, to derive forecasts and to develop strategies and measures for sustainable biodiversity management for water bodies in Germany – and to further develop German biodiversity research in the water sector in a targeted manner. As an important cross-sectional task, the researchers would like to develop, bundle and make available free of charge data sources which document the state and change of biodiversity.

Four central research areas shall support environmental policy and are intended to ensure the conservation and improvement of water biodiversity and its sustainable use:

1 Research on the development of a central aquatic biodiversity monitoring system that uses innovative methods such as eDNA and thus enables new findings on species, ecosystems and sources of pollution.

2 Substantial ecological analyses, e.g. on influencing factors and interactions in ecosystems, the effects of extreme events and the extension of model approaches.

3 The consideration of human motives and actions as well as the development of methods for the presentation and weighing of ecological, economic and social needs; and the development of new forms of communication and sensitisation for biological diversity in inland and coastal waters.

4 The evaluation and optimisation of environmental policy measures and management options as well as the development of further options for action to protect and promote water biodiversity in Germany and worldwide.

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Read the research agenda
→ bit.ly/FreshwaterBiodiversity-ResearchAgenda2019

Jähnig, S.C. et al. (2019). Living Waters: A Research Agenda for the Biodiversity of Inland and Coastal Waters.
doi: 10.4126/FRL01-006418180

Greenhouse gases in inland waters

From CO_2 storage to methane polluter? Inland waters and climate change influence each other also in terms of methane formation, their "new" role as methane producers should not be underestimated. Another trend that not only endangers drinking water reserves and important ecosystems: Water bodies are temporarily drying out, shrinking or disappearing permanently and are becoming an increasingly important player in the global carbon cycle.

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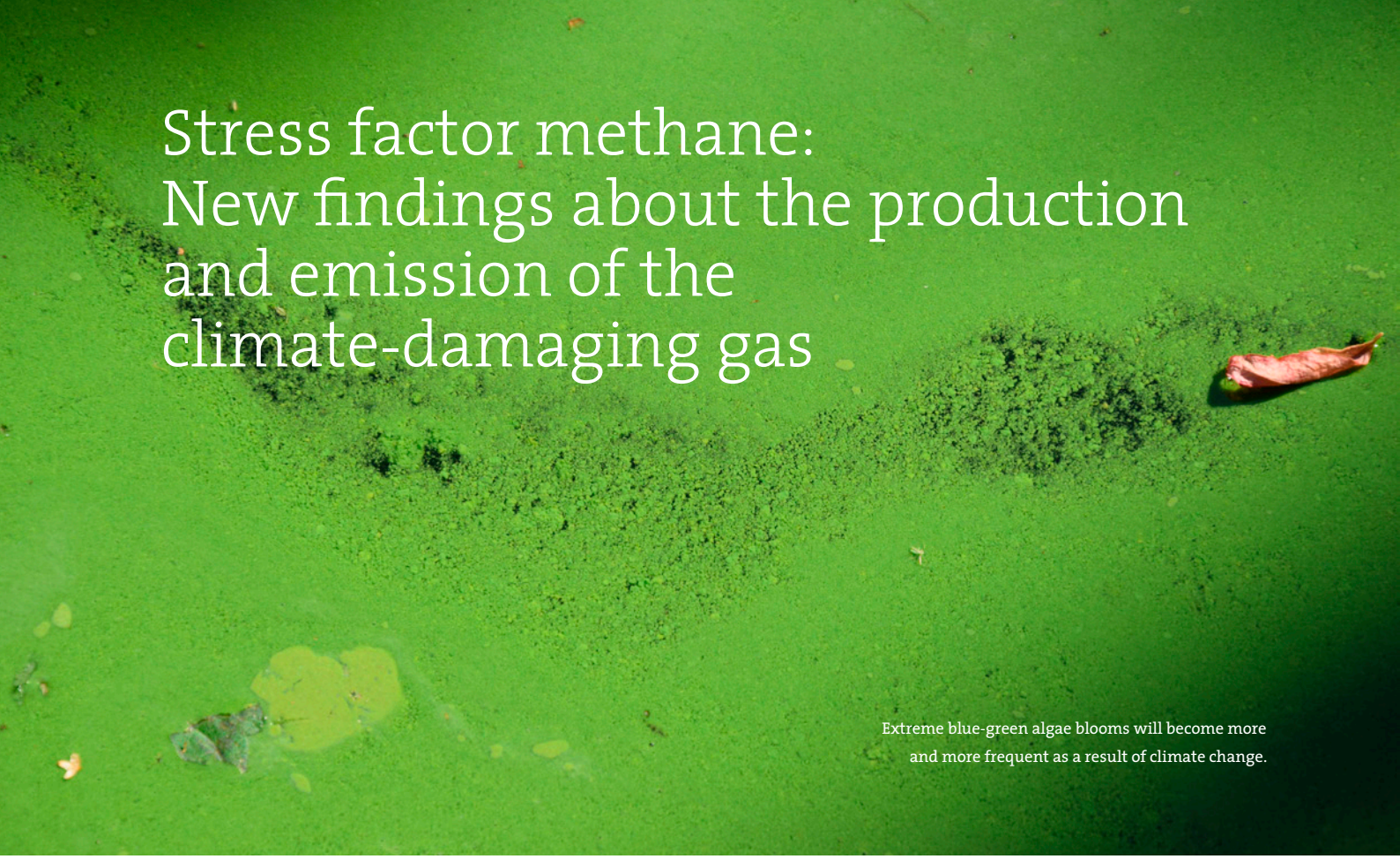
Stress factor methane: New findings about the production and emission of the climate-damaging gas



Extreme blue-green algae blooms will become more and more frequent as a result of climate change.

Water bodies and climate change mutually affect each other, for example in terms of methane emission. Mina Bižić, Hans-Peter Grossart and colleagues have discovered that, contrary to previous assumptions, oxygen-rich lakes emit more methane than ever considered, and cyanobacteria play a previously unknown role as methane producers. Since blue-green algae blooms will increase as a result of climate change, this is not good news for the global methane budget, as the two researchers explain in the interview.

Methane is a harmful greenhouse gas. Two studies in which the IGB was involved have now uncovered two previously unknown sources of methane. The first of them shows that oxygen-rich lakes with good water quality are an underestimated source of methane. How did you come across this discovery?

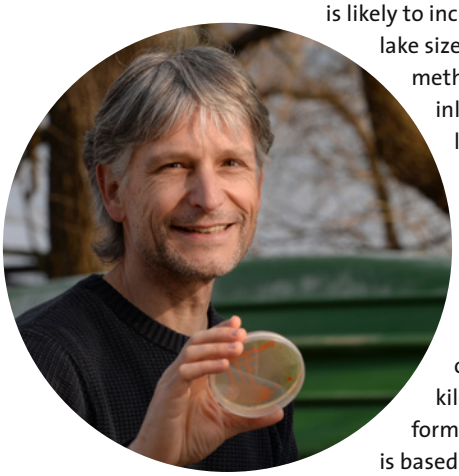
Hans-Peter Grossart: We investigated how methane forms in Lake Stechlin. For this purpose, we took water samples from the lake, which has a high oxygen concentration in the upper water body due to the photosynthesis of the algae. We discovered that methane can be produced in the upper mixed water layer which is in direct contact with the atmosphere. The climate-relevant gas can therefore be released directly into the atmosphere without first being oxidized to carbon dioxide.

What does this mean?

Hans-Peter Grossart: A significant amount of methane can be produced in the oxygen-rich upper layer of a lake. And unfortunately, methane harms our climate more severely and faster than carbon dioxide. This result refutes a scientific paradigm that has been valid up to now, including in the current assessments of the Intergovernmental Panel on Climate Change (IPCC), where experts assumed that methane in inland waters is mainly produced in oxygen-depleted environments such as lake sediments, wetlands and swamps.

Can we conclude that all lakes emit methane – also in the presence of oxygen?

Hans-Peter Grossart: Yes, but we assume that the fraction of methane emissions from oxic waters is likely to increase with the lake size. Half of the methane formed in inland waters is likely to come from methane production in the oxygenated water body of large lakes with a surface area of over one square kilometer. Methane formation in lakes is based on a complex interaction of biochemical and physical processes, some of which are still poorly understood or unknown.



Photos: Blue-green algae bloom © Angelina Tittmann/IGB; Portrait Bižić © Duan Ionescu; Portrait Grossart © David Ausserhofer

Another element for a better understanding of how the methane cycle and climate change are connected was found when you took a closer look at cyanobacteria.

Mina Bižić: We investigated 17 species of cyanobacteria that occur in the sea, in freshwater or on land. Cyanobacteria or blue-green algae, as they are often called, are among the most common organisms on earth, and we wanted to know whether these bacteria, when present in lakes, are involved in methane production and are therefore a previously unknown source of methane.

How did you go about it?

Mina Bižić: We were able to show for the first time that cyanobacteria produce the greenhouse gas during photosynthesis. A colleague from the University of Heidelberg used isotopically labelled carbon to confirm that methane is formed in the cell during the conversion of light energy into chemical energy. In parallel at IGB, we measured methane production rates during multiple day night cycles. We compared the amount of methane produced by cyanobacteria with the amounts produced by methanogenic archaea and eukaryotes like algae, plants and fungi: For the same biomass, cyanobacteria produce less methane than archaea, but more methane than fungi or plants and hence, relevant amounts of methane.

Again, you have debunked a scientific paradigm...

Mina Bižić: ...which states that organisms can only produce methane under oxygen-free conditions. Until now, among bacteria, methane formation could only be detected in the domain archaea. These two assumptions are refuted by the results of our study.

How does this affect the methane cycle?

Mina Bižić: The increasing number, duration and intensity of blue-green algae blooms resulting from global warming will most likely increase the release of methane from inland waters and oceans into the atmosphere. However, it is difficult to estimate the global proportion of methane from cyanobacteria, as there is a severe lack of detailed data on the biomass of these organisms in freshwater and soil.

Can you describe the relationship between cyanobacteria and methane formation more precisely?

Mina Bižić: It may be that cyanobacteria have been producing the greenhouse gas methane already since the early days of Earth. Cyanobacteria are well known for the Great Oxygenation event that took place 2.5 billion years ago, but the oldest known fossils, stromatolites, are deposits of cyanobacterialike organism found in 3.5 billion-year-old rocks in Western Australia. Today, cyanobacteria are spread all over the world. Some species develop particularly well in seawater or freshwater with high nutrient loads and high temperatures. As a result of climate change, mass developments, the so called blue-green algae blooms, will therefore occur more frequently and will do so to a greater extent in the future.

Hans-Peter Grossart: According to our current findings, this will also increase the emission of the greenhouse gas methane from various aquatic systems, which forms an important positive feedback mechanism for global climate. However, in order to fully understand the global methane cycle and to be able to improve climate change predictions, we still have a lot of work to do.

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Project: Aquameth I+II, **Duration:** 11/2013-12/2016, 01/2019-12/2021, **Funded by:** Deutsche Forschungsgemeinschaft (DFG), **Lead:** Prof. Dr. Hans-Peter Grossart, **Research group:** Aquatic microbial ecology, Dept. Experimental Limnology

Günthel, M. et al. (2019). Contribution of oxic methane production to surface methane emission in lakes and its global importance. **Nature Communications**, 10, art. 5497. doi:10.1038/s41467-019-13320-0

Bižić, M. et al. (2020). Aquatic and terrestrial cyanobacteria produce methane. **Science Advances**, 6(3), eaax5343. doi:10.1126/sciadv.aax5343

New insights into carbon cycling in flowing waters

Cycling of carbon in rivers and their riparian zones is crucial for the functioning of river ecosystems and their food webs up to the global carbon cycle. Since this process is determined by climatic factors such as temperature and humidity, pronounced changes are to be expected in the course of climate change.

Large amounts of organic carbon are released into streams and rivers from the surrounding landscape, for example in the form of plant residues, which are either degraded or transported further downstream. River ecosystems play a significant role in the global carbon cycle by regulating decomposition rates and transport of organic matter to the oceans. On the other hand, there is a limited knowledge on patterns of how decomposition rates vary from river to river on a global scale and with the respective climatic zone.

153 researchers from 40 countries used a simple, strictly standardised method to analyse more than 1000 watercourses worldwide. The results not only provide basic information on the functioning of river ecosystems and their riparian zones, but also new insights into their responses to global warming and other factors of climate change, as the turnover of carbon from plant residues strongly depends on microbial activity. This is determined not only by environmental factors, but also by the composition of microbial communities and, therefore, varies from location to location. Irrespective of temperature conditions, slow microbial turnover rates were observed at sites of all latitudes, while very high turnover rates were limited exclusively to lower latitudes. In the course of global warming, it is likely that microbial turnover will also be significantly accelerated at the higher latitudes.

Prof. Dr. Mark Gessner, gessner@igb-berlin.de

Tiegs, S. D. et al. (2019). Global patterns and drivers of ecosystem functioning in rivers and riparian zones. **Science Advances**, 5(1), eaav0486. doi:10.1126/sciadv.aav0486

Dry inland waters and their role in climate change

Due to climate change, more and more freshwaters will at least temporarily run dry, and many lakes are shrinking or have disappeared completely. This trend is not only a threat to drinking water reserves and major ecosystems: Dried freshwaters also play an important role in the global carbon cycle, as they can release CO2 and other climate-relevant gases and thus intensify climate change.

Gabriel Singer and his team found that rivers, lakes, ponds and streams that fall partially or completely dry may have significant CO_2 emissions. Freshwaters therefore play a more important role in the global carbon cycle than was previously assumed. They analysed numerous publications from recent years that have reported CO_2 emissions from permanent and drying freshwaters and their contribution to the carbon cycle.
It is true that lakes also emit CO_2 under normal conditions, but they also act as so-called C sinks – long-term carbon accumulation occurs in their sediments. When water levels fall, however, an increasing share of the lake bottom is exposed to the oxygen in the air. The drier sediments become, the more aerobic respiration increases – dead organic matter in the lake bottom is used by bacteria, which leads in turn to the production of CO_2. Streams and rivers are already known as CO_2 sources as they respire organic carbon from the catchment that is continuously delivered with the flowing water. But quite surprisingly, CO_2 emissions remain high from dry and exposed streambeds.
It is difficult to estimate the extent to which anthropogenic influences are responsible for permanent water bodies to become seasonally dry, and those that used to be only seasonally dry to turn into permanently dry ecosystems. Potential influences are attributed to land use changes in catchments, including water removal and alteration of flow regimes. Local drying may also be a consequence of changes in temperature and rainfall associated with global climate change.

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Project: Fluvial meta-ecosystem functioning: unravelling regional ecological controls behind fluvial carbon fluxes (FLUFLUX), **Duration:** 04/2017-03/2021, **Funded by:** ERC Starting Grant, **Lead:** Prof. Dr. Gabriel Singer, **Research group:** Fluvial Ecosystem Ecology, Dept. Ecosystem Research

Marce, R. et al. (2019). Emissions from dry inland waters are a blind spot in the global carbon cycle. **Earth-Science Reviews**, 188, 240-248. doi:10.1016/j.earscirev.2018.11.012

Del Campo, R. et al. (2019). Dry phase conditions prime wet-phase dissolved organic matter dynamics in intermittent rivers. **Limnology and Oceanography**, 64(5), 1966-1979. doi:10.1002/lno.11163

Fungicides as an underestimated hazard for freshwater organisms

Fungicides from agriculture can leak into nearby surface waters. Although aquatic fungi have important ecological functions in aquatic systems, these microorganisms have not yet been considered in the risk assessment of fungicides.

Ramsy Agha and Justyna Wolinska have investigated how fungicides used in agriculture such as tebuconazole or azoxystrobin influence the growth of aquatic fungi. For example, the concentrations of fungicides found in natural water bodies reduced the infection of potentially toxic cyanobacteria by parasitic fungi. But pathogens and parasites are an important component of ecosystems and – despite their negative image – can also have positive effects. Parasitic fungi can keep cyanobacteria in check and thus reduce blue-green algae blooms (→ **page 16**). Pollution by fungicides can interfere with this natural process.

In aquatic ecosystems, fungi represent up to 50 per cent of the microorganisms with cell nuclei and hold many important ecological roles. The EU regulatory frameworks for protecting the ecology of waters from adverse effects of pesticides have so far not addressed aquatic fungi – despite their importance. One reason for this is the lack of standardised bioassays using aquatic fungi as test species. Methods of cultivation and identification of aquatic fungi are continuously improving, so that risk evaluations could in future consider the impact of fungicides on aquatic fungi more adequately.

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Prof. Dr. Justyna Wolinska, wolinska@igb-berlin.de

Project: Integrating fungal parasites into plankton ecology, **Duration:** 08/2014-03/2022, **Funded by:** Alexander von Humboldt Foundation, IGB, Deutsche Forschungsgemeinschaft (DFG), **Lead:** Dr. Ramsy Agha, **Research group:** Disease Evolutionary Ecology, Dept. Ecosystem Research

Ortiz-Canavate, B. K. et al. (2019). Fungicides at environmentally relevant concentrations can promote the proliferation of toxic bloom-forming cyanobacteria by inhibiting natural fungal parasite epidemics. **Chemosphere**, 229, 18-21. doi:10.1016/j.chemosphere.2019.04.203

Excursus: 10 fascinating facts about aquatic fungi

1 Hardly any group of organisms on our planet has been as little characterized as lentic fungi. Researchers also call aquatic fungi "microbial black matter" if they cannot be cultivated and propagated in the laboratory so far.

2 Aquatic fungi occur in all types of water, in small puddles, large oceans, even in ice and snow. There are islands of unfrozen water in the ice, where fungi can survive and even reproduce with the help of sophisticated protective mechanisms known as cryoprotectors.

3 There are only rough estimates of the fungal proportion of all microorganisms for the various types of water – in freshwaters they can contribute to as much as 50 percent of all microorganisms with cell nucleus.

4 Fungi also colonize plastic particles and can actively contribute to their degradation. In 2012, for the first time, biologists discovered a fungus in the Amazon that is able to decompose plastics.

5 Aquatic fungi are underestimated key players in aquatic food webs.

6 Fungi can act as symbionts and parasites, and thus are in constant contact with other organisms in the aquatic environment.

7 Aquatic fungi play an important role in the turnover of organic matter in the water and are able to produce greenhouse gases such as carbon dioxide and methane.

8 Together with other microorganisms, they are an important component of the "Oceanic Carbon Pump", as they affect sinking of organic matter to the seabed. Organisms on the seabed can use this material for their growth, mainly with the help of fungi - otherwise life in the dark deep sea would hardly be possible.

9 Aquatic fungi break down organic matter and nutrients from dead plant material and thus make them more readily available for other living organisms in the ambient water.

10 Fungi are virtually everywhere in the water: even aquatic insects harbor fungi in their intestines that support their digestion.

Prof. Dr. Hans-Peter Grossart,
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Grossart, H.-P. et al. (2019). Fungi in aquatic ecosystems. **Nature Reviews Microbiology**, 17(6), 339-354. doi:10.1038/s41579-019-0175-8

"Remote sensing data could make it easier to monitor and protect lakes in the future"

The project, coordinated by IGB and involving seven partner institutions, started out in May 2019 with the collection of data, expected to take until the end of 2020. In an interview, Stella Berger and Sabine Wollrab report on the first results, and explain why it is particularly interesting to work in a multidisciplinary team, and how this benefits the project.

The CONNECT project revolves around lakes connected together along river systems. You intend to collect and analyse data that should make it easier in future to implement monitoring and protection measures for these lakes. Why focus on connected lakes?

Stella Berger: The project involves us investigating a total of 19 lakes in Mecklenburg-West Pomerania and Brandenburg. These include the relatively strongly connected lakes along the Upper Havel, several lakes that form part of Feldberg Lake District that are not so strongly connected, and Lake Stechlin. Although the latter is only slightly connected to the surrounding lakes, the lake is home to the LakeLab, where we conduct experimental studies on the connectivity of lake systems. Lakes suffer disproportionately from anthropogenic pressures and the effects of climate change – for example, from extreme weather events such as heat waves, storms and warmer winters. In fact, most lakes along river systems are currently in a moderate to poor ecological state, and may not be able to meet the expectations of the European Water Framework Directive.

Which data is being collected and analysed?

Stella Berger: We collect multiple physical, chemical and biological data both above and below the water – from Secchi depth and optical calibration measurements to nutrients and organisms such as bacteria, phyto- and zooplankton, to exchange rates of greenhouse gases. Our measurements also include chlorophyll a and phycocyanin. These are pigments that indicate the occurrence of algae, of which cyanobacteria are a particularly important indicator for water quality. Measuring buoys that we installed in all 19 lakes provide us with continuous measurements. Our team additionally takes samples from the lakes at regular intervals, timed to coordinate with satellite overflights. The exciting thing is that we can match all the data we have collected on site with remote sensing data. This gives us a basis to improve bio-optical models to calculate chlorophyll concentrations from remote sensing data.

Sabine Wollrab: The remote sensing data originate from the optical earth observation satellites Sentinel 2A and 2B. Both satellites are equipped with multispectral cameras with a sufficiently high spatial resolution for medium-sized lakes. The satellites practically record the colour of the lake in specific spectral bands, the colour being dependent on factors such as water constituents and organisms. The state of freshwaters can then be assessed from these data. The Sentinels fly over our study area every two to three days. The problem is that there are often too many clouds in the sky, even when the weather is fine. Then the satellite images produced cannot be used. This is why taking our own ground-level spectral measurements is an important part of the project, because we then get data even when the sky is overcast.

How do you harness the data?

Sabine Wollrab: We want to determine chlorophyll concentrations from the optical measurements. To do this, the bio-optical models are being

The CONNECT team after passing the powerboat certificate!

calibrated by comparing values with data collected on site. Once calibrated successfully, the remote sensing data can be used on a larger scale to support the monitoring and protection of freshwaters. You can see how representative a measuring point is for the whole lake, and can then, in principle, observe how a lake develops even between sampling dates. This is of interest for nature conservation authorities, for instance, which can then plan their measurement campaigns more accurately. After all, the remote sensing data can give an indication of when it makes sense to take on-site measurements.

Can you not do without them then?

Stella Berger: No, there is still a need to take on-site measurements of water constituents and to analyse the samples in the lab so as to obtain basic values for comparison with remote sensing data and ground-truthing. Satellite data enable us to optically record large areas, and therefore several freshwaters, simultaneously, but they are definitely not able to replace on-site measurements at present. Lake Stechlin, for example, has a low chlorophyll concentration, according to the satellite images, and is considered to be an oligotrophic lake. But this is only a reflection of the algae levels in the upper layers of water. In this lake, phytoplankton is hidden in the depths, which shows that the vertical distribution of algae – and of nutrients – is important to be able to assess water quality. In future, a combination of strategically positioned measuring buoys that also take vertical profiles and remote sensing could pave the way for targeted, optimally timed on-site sampling.

You started collecting data in May 2019. Do you have any preliminary results?

Stella Berger: Initial findings confirm our expectations that connectivity has an impact on lake systems. For instance, both remote sensing data and our own measurements show that the relatively strongly connected Havel lakes are similar and seasonally synchronised. We can infer this from the algae level, the composition of phytoplankton, and Secchi depth. The remote sensing data reveal a chlorophyll gradient along the flow direction of the Upper Havel, for example from the Zotzensee through the Labussee to the Ellbogensee. The type of lake – whether it is deep or shallow – also influences algae concentrations and composition. In contrast, less connected lakes tend at the same time to have a more individual character.

Sabine Wollrab: In the CONNECT project, we also analyse the exchange of greenhouse gases between water and the atmosphere. The aim is to determine whether there is a connection between algae blooms and the emission of climate-relevant gases such as methane and carbon dioxide. To do this, we use flux chambers to record the quantities of these gases released or absorbed by the lake. Initial results point to a high degree of seasonal variability, as well as showing major differences among lakes. We are currently looking into why that could be. Another important interim finding is that we managed to find out which of the various bio-optical models works best, and to calibrate it so as to provide excellent readings. It all worked out really well!

CONNECT brings together experts from all kinds of disciplines, ranging from chemistry and physics to ecology and earth sciences. What was it like collaborating on such a scale?

Stella Berger: A challenge, by all means; we first had to agree on a common language. However, we found collaboration to be enormously exciting and motivating from the very beginning. Since various disciplines are involved, we produce all kinds of ideas that bring added value to the project. It takes such a diverse team to conduct a study in which so many parameters can be recorded in parallel and linked to each other.

Sabine Wollrab: It is also fascinating, for example, to explore standing and running waters using a combined approach. They tend to be separate disciplines in freshwater ecology. You learn a great deal from each other when you plan and implement such a project together, because it enables you to combine a variety of approaches and broaden your perspective.

The interview was conducted by Wiebke Peters.

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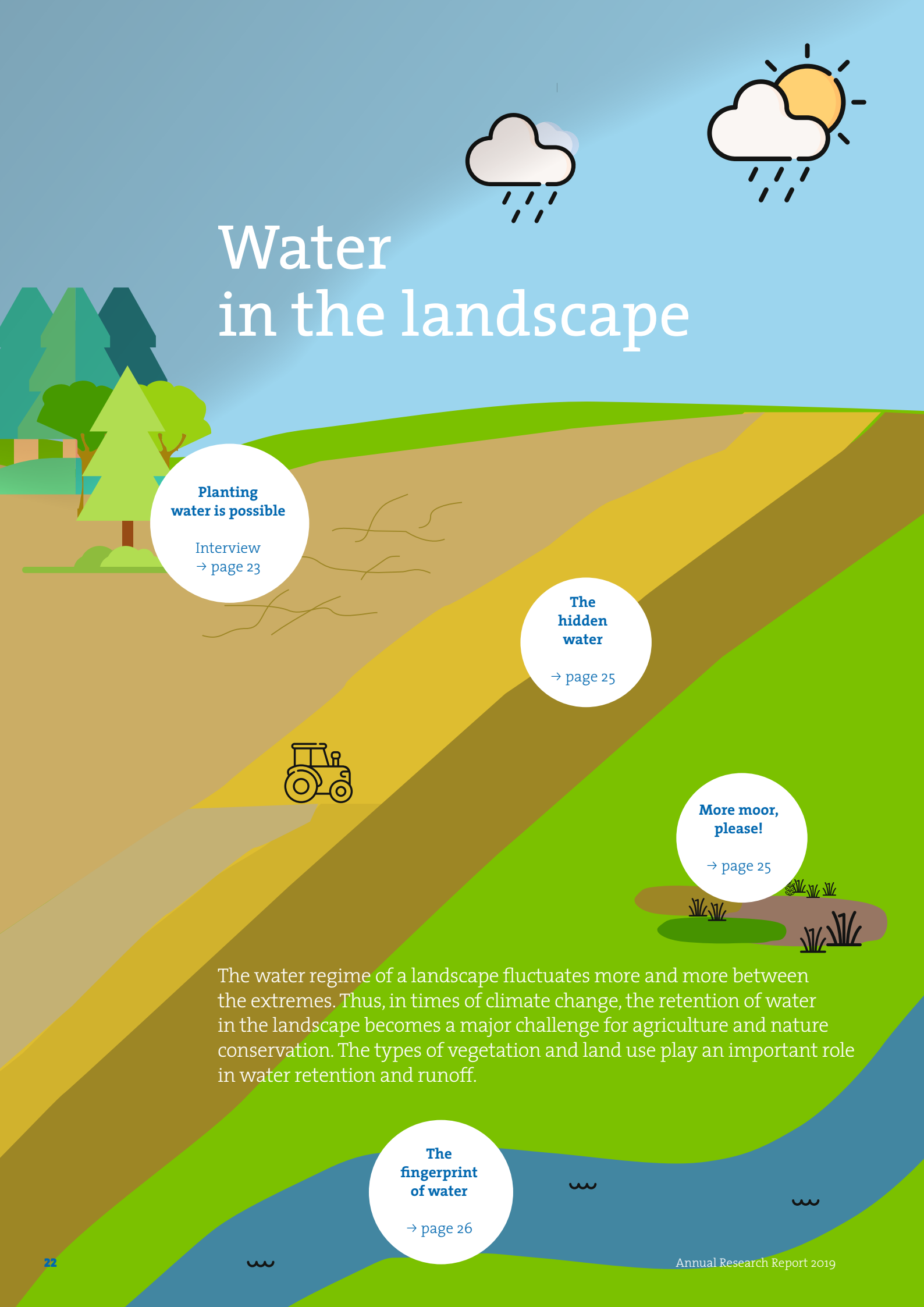
Dr. Sabine Wollrab, wollrab@igb-berlin.de

Project: CONNECT, **Duration:** 05/2018-04/2021, **Funded by:** Leibniz-Competition Collaborative Excellence, **Lead:** Dr. Stella A. Berger, Dr. Sabine Wollrab, **Research groups:** Experimental phytoplankton ecology, Ecological modelling, Dept. Experimental Limnology

How to explore the water quality of lakes from a distance
→ bit.ly/lakelab-remote-sensing

Water in the landscape



Planting water is possible

Interview
→ page 23

The hidden water

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More moor, please!

→ page 25

The water regime of a landscape fluctuates more and more between the extremes. Thus, in times of climate change, the retention of water in the landscape becomes a major challenge for agriculture and nature conservation. The types of vegetation and land use play an important role in water retention and runoff.

The fingerprint of water

→ page 26

“Planting water is possible”

Dörthe Tetzlaff’s research focuses on the storage and movement of water in landscapes. Her team has developed mathematical models that can reflect the relationships between vegetation, soil and water regimes. She has also analysed the influence of climate change on the coupling of vegetation and water balance in northern regions: Global warming will have a particularly strong impact on the water balance in these ecosystems.

What actually constitutes the water balance and what role does it play in the ecosystem?

Dörthe Tetzlaff: The water balance of a landscape refers to water retention and runoff, for which the type of vegetation and land use play an important role. And, of course, the climate, whose change has already had a major impact: The water regime of a landscape commutes more and more between the extremes drought and flooding. We need water for food production, drinking water supply, and other ecosystem services. Before we can ensure water security for all these ecosystem services we need to understand the processes of water supply and distribution.

Together with colleagues from Scotland and the USA, you have developed ecohydrological mathematical models. What can these models do?

We wanted to develop models that can reflect the complex relationships between vegetation, soil and water balance. They show, for example, that in beech forests water is increasingly cycled between soil and vegetation to increase evaporation to the atmosphere, while grass cover promotes groundwater recharge. With our EcH2o-iso model we can quantify where, how and for how long water is stored and released in the landscape. More specifically, we can quantify “blue” water fluxes like groundwater recharge and surface runoff, but also “green” water fluxes such as evaporation and transpiration.

What is special about the EcH2o-iso model?

Previous hydrological models often capture vegetation as a static element. They have been unable to adequately capture the complex interactions between evapotranspiration – the evaporation of water by plants and of soil and water surfaces – and the physiological processes of plants. Furthermore, we could also use long-term data from direct vegetation measures such as biomass production and transpiration. This improved the reliability of the model and its transferability. Finally, and most uniquely, we incorporated stable isotopes (→ **page 26**) into the model which allowed us to constrain parameter sets and reduce model uncertainties, and really quantify not just the different ecohydrological fluxes but determine their ages and temporal dynamics of those.

And how can it be used?

The model helps to better predict the effects of vegetation dynamics and land-use changes on the water balance under changing climatic conditions. In drought-prone areas in particular, this knowledge can help to develop land use strategies that increase the landscape’s resistance to climate change and protect water resources. So far, the type of vegetation has been considered primarily with a view to preventing soil erosion and maximising food or timber production. In view of more frequent extreme weather events such as droughts and floods, however, it is increasingly a question of which plants can be cultivated to control the retention or loss of water in the landscape.

In the region around Lake Stechlinsee in northern Germany, you validated the model using field studies. What was the result?

We compared land areas with representative deciduous forest and grass cover. Our results show that grassland use leads to more groundwater recharge and that in forests more water is returned to the atmosphere by evapotranspiration. However, the effects are site-specific and depend on the respective hydroclimate, biogeography and

landscape ecology. With the help of the EcH2o-iso model, however, these differences can be taken into account in the future and local as well as large scale forecast models can be created.

According to the Intergovernmental Panel on Climate Change, global warming is expected to be particularly high in the northern latitudes in the future. Together with the Scottish University of Aberdeen, you investigated the influence of climate change on the coupling of vegetation and water regime in northern regions. What have you found out?

We evaluated hydroclimatic data from six intensively studied river basins in Scotland, Canada and Sweden along a climatic gradient in the North and combined them with remote sensing data on vegetation. These regions are particularly sensitive to climate change as even small temperature changes determine if precipitation falls as rain or snow, and effect rate and amount of snowmelt as well as snow accumulation. Our results show that in these higher latitudes pre-season temperature has a greater influence on vegetation growth than precipitation. Furthermore, an earlier beginning and a longer duration of the vegetation period leads to a decline in streamflows due to rising temperatures. This is important to know, as some of these cold regions are very dry regions as well, with very limited precipitation amounts.

What does this mean?

Our data analyses support the statement that global warming particularly affects the water regime of ecosystems in cold, energy limited northern regions. In the project we have learned a lot about the important role of vegetation for water distribution and the water cycle in the landscape. Uniquely, we have explored this along a spatial gradient that encompasses different ecological and climatic conditions – from dry sub-boreal areas to subarctic regions. We hope that the methods and models developed will allow us to better predict the effects of climate change in these regions.

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Project: Vegetation effects on water flow and mixing in high-latitude ecosystems (VeWa), **Duration:** 10/2013-03/2019, **Funded by:** European Research Council (ERC), **Lead:** Prof. Dr. Dörthe Tetzlaff, **Research group:** Landscape ecohydrology, Dept. Ecohydrology

Smith, A. A. et al. (2019). Assessing the influence of soil freeze-thaw cycles on catchment water storage-flux-age interactions using a tracer-aided ecohydrological model. Hydrology and Earth System Sciences, 23(8), 3319-3334. doi:10.5194/hess-23-3319-2019

Piovano, T. I. et al. (2019). Spatially distributed tracer-aided runoff modelling and dynamics of storage and water ages in a permafrost-influenced catchment. Hydrology and Earth System Sciences, 23(6), 2507-2523. doi:10.5194/hess-23-2507-2019

Douinot, A. et al. (2019). Ecohydrological modelling with EcH2O-iso to quantify forest and grassland effects on water partitioning and flux ages. **Hydrological Processes,** 33(16), 2174-2191. doi:10.1002/hyp.13480

Wang, H. et al. (2019). Climate-phenology-hydrology interactions in northern high latitudes: assessing the value of remote sensing data in catchment ecohydrological studies. **Science of the Total Environment**, 656, 19-28. doi:10.1016/j.scitotenv.2018.11.361

More moor, please!

The retention of water in the landscape is a major challenge for agriculture and nature conservation in times of climate change. The restoration of formerly drained wetlands and the recolonisation of rivers by beavers have an influence on the water balance of a landscape – but the water quality only improves after decades.

The landscape-ecohydrologists at IGB have investigated the long-term changes (30 years) of the water regime and water quality of watercourses in the agricultural region in a tributary of the River Spree in the north-eastern lowlands of Germany.

Restoration measures and the recolonisation of the beaver along the investigated river network have led to an increase in the groundwater level since 2000. With moors being rewetted, wetland restoration, greatly enhanced by increasing beaver populations, resulted in longer water transit times in the stream network, less linear storage-discharge relationships and a loss of daily stream variability. The proportion of rewetted moorland areas compared to agricultural land is, however, still too low to significantly affect the discharge of water in the landscape. The researchers recommend that in future larger former moor areas and above all interconnected sections should be rewetted in order to improve the retention and storage of water in agriculturally shaped landscapes in the long term.

Despite the wetland rehabilitation, there was surprisingly limited water quality improvement over the past decades. This probably reflects the long-term legacy of fertiliser use on nutrient reserves in soils, groundwater and waters in this catchment area. It shows that changes in land use and restoration measures often take several decades to take effect.

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Smith, A. et al. (2020). Riparian wetland rehabilitation and beaver re-colonization impacts on hydrological processes and water quality in a lowland agricultural catchment. **Science of the Total Environment**, 699, 134302. doi.org/10.1016/j.scitotenv.2019.134302

The hidden water

Jörg Lewandowski explores groundwater–surface water interactions, and has published a Special Issue on the topic, containing 21 studies.

Each article highlights the importance of the hidden hyporheic zone between groundwater on the one hand and streams, rivers, lakes, oceans or wetlands on the other. In the interface, biogeochemical turnover processes reduce nutrient loads to lakes; microorganisms remove trace substances from rivers; and microplastics and other particles are filtered out of the water. The hyporheic zone provides habitat and refuge for countless organisms, and the inflow of groundwater through the hyporheic zone feeds entire streams.

The Special Issue provides an overview of recent advances in research and innovative approaches. It covers a wide range of issues and scales, and also contains experimental and modelling studies. The groundwater–surface water interface is explored by many different specialist disciplines, such as hydrology, aquatic ecology, biogeochemistry and microbiology. The collection of research papers in this Special Issue identifies current knowledge gaps and sets out the challenges in the establishment of standardised measurements and assessment approaches. The aim is for improved water management and near-natural freshwater ecosystems to help optimise ecosystem services, ultimately enhancing water quality.

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All 21 studies on the topic of "groundwater–surface water interactions"
→ www.mdpi.com/journal/water/special_issues/Groundwater-Surface_Water

Lewandowski, J. et al. (2020). Groundwater-surface water interactions: recent advances and interdisciplinary challenges, **Water**, 12(1), 296. doi:10.3390/w12010296

The fingerprint of water

Without water, nothing works in IGB research. In landscape ecohydrology, researchers deal with this vital substance in a special way: They use isotope techniques to precisely determine the origin and pathways of a water molecule in the water balance of a landscape. This not only allows analysing the transformation of precipitation into plant, ground or surface water, but even the "fingerprint" of water in hurricanes.

Isotopes are variants of a chemical element with the same number of protons in the atomic nucleus, but with different numbers of neutrons. Therefore, they have different physical properties, for example in the absorption of light. Within laser spectroscopy, this effect is used by projecting a laser beam into a chamber and recording the change in intensity over time. Each sample measured in IGB's modern isotope laboratory thereby produces a unique, characteristic record.

The researchers analyse stable hydrogen and oxygen isotopes that form heavy or light water molecules in various combinations. These molecules are influenced differently by phase state changes such as evaporation or condensation and as a result the ratio changes from heavy to light. Thus, the water molecules get their own "fingerprint" and can be measured in our laboratory in liquid samples like rain or stream, or groundwater samples as well as in complex samples like soil or plants.

At IGB, stable hydrogen and oxygen isotopes, which form heavy or light water molecules in various combinations, are analysed. These molecules are affected differently by phase changes such as evaporation or condensation, and as a result the ratio changes from heavy to light. In this way, the water molecules get their own "fingerprint" and can be measured in the laboratory in liquid samples such as rain or water samples as well as in complex samples such as soil or plants. The techniques make it possible to better understand the paths of water through the water cycle.

Green and Blue

In the research field of ecohydrology a distinction is made between green water in terrestrial systems, which is influenced by plants, and blue water from lakes, rivers and aquifers, which is directly available for water supply.

For a comprehensive understanding, it is not only the absolute quantities of water in the landscape that are important, but also how long the water remains on site, how old that water is and which paths it takes. The researchers also analyse how climate change and urbanisation affect the water balance and what role plants play in this.

Another field of application for isotope analyses is, for example, the investigation of extreme storms like tropical cyclones. Such extreme events will continue to increase in the future, with far-reaching consequences for the populations and economies of the affected countries. The IGB research group landscape ecohydrology wants to find out more about the origin and consequences of tropical cyclones in times of global environmental change and thus contribute to improving adaptation measures to these extreme hydro-climatic events. They investigate heavy rainfalls in real time using state-of-the-art isotope analysis: stable isotopes are being used as the fingerprints of the water. The researchers are thus able to quantify where the water for the precipitation during the hurricanes came from and which paths it took.

Isotope analysis can also be used to compare the frequency and intensity of past storms. For these retrospective analyses, traces of water immortalised in caves, corals and tree rings can be used. In this way, the distribution of water in the landscape can be studied all over the world – whether during dry spells in Brandenburg or hurricanes in Central America.

Prof. Dr. Dörthe Tetzlaff, d.tetzlaff@igb-berlin.de

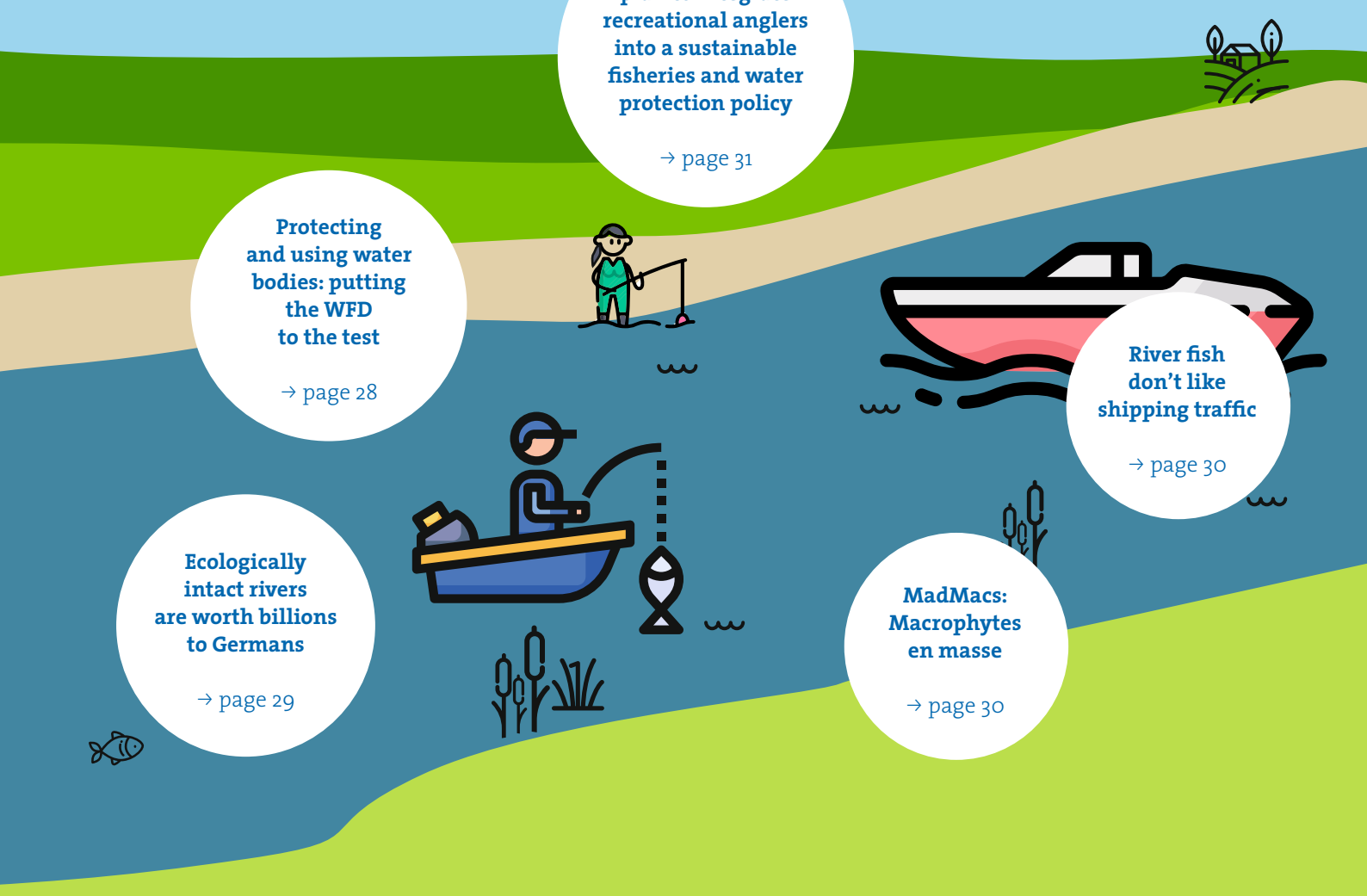
Sanchez-Murillo, R. et al. (2019). Deciphering key processes controlling rainfall isotopic variability during extreme tropical cyclones. **Nature Communications**, 10, art. 4321. doi:10.1038/s41467-019-12062-3

IGB offers excellent scientific infrastructures to its own scientists and external researchers. These include the globally unique LakeLab in Lake Stechlin, an aquaponics system, a 3D telemetry system and the state-of-the-art isotope laboratory.

→ www.igb-berlin.de/en/infrastructure

Protection and use, a conflict of objectives?

We conduct research for the future of our freshwaters: this also involves giving objective and evidence-based information and advice to policymakers, authorities, associations, industry, educational institutions and the public. Our research findings should enable society and decision-makers to face a changing environment and to manage and conserve water-based resources and ecosystems for the welfare of mankind and nature.



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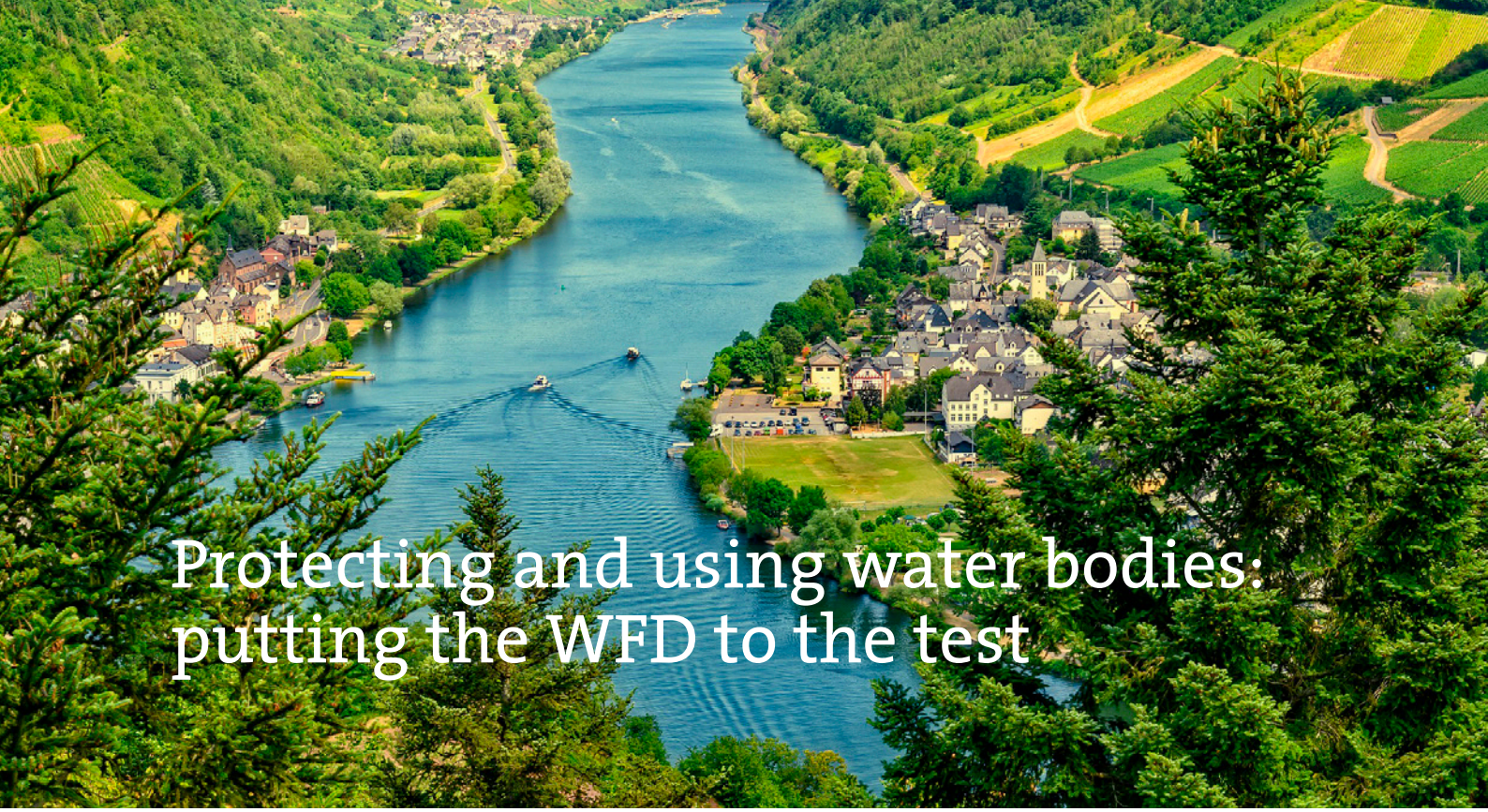


Protecting and using water bodies: putting the WFD to the test

Agriculture and settlement, road, rail and shipping traffic: water bodies and their floodplains, such as the river Moselle, are often heavily used. Water protection and resource use therefore needs to be more balanced. The European Water Framework Directive (WFD) is a technically sound and target-oriented policy document for achieving this.

Since the Water Framework Directive (WFD) came into effect 20 years ago, little improvement of the status of EU water bodies has been observed. 60 per cent of all water bodies in the EU fall short of the target; in Germany, action is required in no less than 93 per cent of flowing waters and in 73 per cent of standing waters. But does this mean that the WFD is not good legislation?

Besides providing valuable habitat, our inland waters, such as rivers and lakes, are also important resources. This repeatedly results in conflicting goals of protecting freshwaters and using them as a resource, which must be countered using the most effective and efficient legislation possible. In European legislation, the Water Framework Directive (WFD) and its daughter directives play an important role in this respect. The WFD requires all water bodies in the EU to achieve at least good chemical and ecological status or good ecological potential by 2027.

The EU periodically reviews its directives by undertaking "fitness checks" to determine whether the original aims are being met. The WFD underwent such an analysis in 2019, flanked by consultation processes involving experts, associations and the interested public. These consultation processes were heavily used by pressure groups seeking to influence legislation as they saw fit. It is therefore all the more important that objective, research-based knowledge is included in such policy processes.

Evidence-based policy consultation stemming from freshwater research

In keeping with our guiding principle "Research for the future of our freshwaters", IGB – Germany's largest freshwater research centre – participated in this consultation process. In an IGB Policy Brief, our researchers identify the key strengths and weaknesses of the WFD, and offer options for action to policymakers and practitioners.

Overall, the researchers come to the conclusion that the WFD provides one of the most advanced regulatory frameworks for water management, and is a technically sound and target-oriented policy document. Reasons for the poor performance are not down to the WFD itself. Instead, its practical implementation needs urgently to be reinforced. Effective protection of water bodies in Germany and the EU would be seriously jeopardised if, in contrast, the principles and objectives of the directive were questioned.

Rooting water protection as a cross-sectional task in other policy areas

Our researchers conclude that new integrative approaches are urgently needed at the policy, administrative and practical implementation level to achieve better water management. Restoration projects must be planned at much larger scale – and the measures taken must be more effective. Administrative processes must be systematically improved, and procedures need to be devised and established for resolving conflicts. To reach this goal, it is essential to root sustainable water management systematically in all relevant policy areas. This is particularly important for the domains of agriculture, energy (including hydropower), transport (shipping), mining and, of course, flood control and nature conservation.

Unless there is a firm commitment to sustainable management and ecological improvement, the multiple functions of freshwaters as habitat and a key resource in Europe cannot be

Photos: Mosel © Tama66/Pixabay; Intact river © Susanne Jutzeler/Pixabay

"Reasons for the poor performance are not down to the WFD itself. In fact, it is a technically sound and expedient policy document. But the very limited ecological improvements that have been observed to date indicate that the directive falls short of striking an appropriate balance between the conflicting goals of protecting freshwaters and using them as a resource – and that significant shortcomings exist in the practical implementation."

MARK GESSNER

preserved or restored. Pressure to use freshwaters as a resource is ever growing, and global climate and environmental change is rapidly advancing, including the widespread loss of biodiversity. IGB therefore urgently recommends strict adherence to the principles and objectives of the WFD beyond 2027 – and, above all, the achievement of significant improvements in its practical implementation.

The European Commission's own report on the fitness check was published in December 2019. The researchers appreciated the fact that several of their opinions are also reflected in this document. Now new negotiations on the WFD are about to take place, also with the relevant EU Member States, which will again lead to controversial debate. IGB will continue to accompany this process so as to advise on European water policy from an evidence-based perspective.

Johannes Graupner, graupner@igb-berlin.de

Read the IGB Policy Brief on the Water Framework Directive
→ bit.ly/IGBPolicyBriefWFD


Synopsis

Strengths and weaknesses of the Water Framework Directive (WFD)

Ecologically intact rivers are worth **billions** to Germans

Freshwaters and the animals and plants that live in them produce benefits to society. However, it is difficult to quantify this importance economically. How does the public from four European countries economically value ecological characteristics of domestic rivers? Projections show that the total willingness to pay for ecologically intact rivers amounts to 27 to 47 billion euros per year in Germany for example.

An economic choice experiment was conducted in the four countries Germany, Sweden, Norway and France. Respondents were asked to select preferred combinations of ecologically relevant attributes for the rivers in their residential environment, with the provision that they would have to make an obligatory financial contribution to a river development fund to achieve the selected river status. From the responses, the researchers were able both to identify the preferences of the population for river characteristics and to estimate the willingness-to-pay for the improvement of rivers.

Respondents from all countries favoured rivers with high bathing water quality and biodiversity, and with characteristic river fish species such as sturgeon, brown trout and salmon. The results can be seen as a signal to policy makers to step up their efforts to improve water quality and the ecological status of rivers.

Prof. Dr. Robert Arlinghaus, arlinghaus@igb-berlin.de

Project: SalmonInvade, **Duration:** 01/2014-12/2016, **Funded by:** Deutsche Forschungsgemeinschaft (DFG), **Lead:** Prof. Dr. Robert Arlinghaus, **Research group:** Integrative recreational fisheries management, Dept. Biology and Ecology of Fishes

Riepe, C. et al. (2019). Managing river fish biodiversity generates substantial economic benefits in four European countries. **Environmental Management**, 63(6), 759-776. doi:10.1007/s00267-019-01160-z

River fish don't like shipping traffic

Germany is one of the most important markets for freight transport by inland navigation. In addition, there is a growing, but barely regulated recreational navigation. IGB researchers have investigated how commercial and recreational navigation affect fish communities in six large European rivers. They analyzed almost 400 fish samplings at 88 different sites – a unique large-scale study.

The researchers applied statistical models to assess whether ship type (cargo vessels, river cruisers or sport boats) or ship frequency, ship size and the amount of empty running vessels affect the fish assemblages. The result: Besides cargo vessels, increasing numbers of particularly sport boats but also passenger ships result in significantly decreased fish densities. Fish species that depend on gravel spawning grounds and shallow shore zones are particularly sensitive.

The results should also be of interest for the federal program "Blue Belt Germany", which aims to ecologically upgrade less frequented shipping lanes, but at the same time to develop more tourism. However, the loss of biodiversity can only be halted by revitalizing river-typical habitats. Therefore, the objectives of future development programs such as the Blue Belt Germany should rather be determined by their ecological development potential.

Dr. Christian Wolter, wolter@igb-berlin.de

Project: Managing Aquatic ecosystems and water Resources under multiple Stress (MARS), **Duration:** 02/2014-01/2018, **Funded by:** EU FP7 (GA 603378), Lead at IGB: Dr. Markus Venohr, m.venohr@igb-berlin.de, **Research groups:** River revitalization, Dept. Biology and Ecology of Fishes, et al.

Zajicek, P., & Wolter, C. (2019). The effects of recreational and commercial navigation on fish assemblages in large rivers. **Science of the Total Environment**, 646, 1304-1314. doi:10.1016/j.scitotenv.2018.07.403

MadMacs: Macrophytes en masse

The MadMacs project deals with the causes and consequences of mass development of aquatic macrophytes. The researchers are developing a guideline to help cope better with mass developments of aquatic macrophytes – without destroying the ecosystem and ecosystem services.

Aquatic plants (macrophytes) are an important part of most aquatic ecosystems. They influence carbon and nutrient cycles and interact with the other groups of aquatic organisms. Increasing anthropogenic nutrient loading often caused the decline of submersed macrophytes, while floating-leaved plants partially benefited from this. The recent reduction in nutrient loading enabled the revival of submersed plants, which now often attain very high densities. Such mass developments may impair ecosystem functions, but also water flow or traffic.

In the project, the researchers want to find out more about the conditions for mass developments of aquatic vegetation, learn more about the importance of plant populations as habitats for algae, benthic invertebrates and fish, and deepen our knowledge of the role of macrophytes in carbon cycling and the emission of greenhouse gases. In addition, the MadMacs team investigates the importance of macrophyte stands for nutrient retention as well as the hydraulic effects of aquatic vegetation and explores management options to reduce the biomass of macrophytes, if a nuisance. This knowledge is also supposed to be put to practical use: the researchers intend to develop a guidance for the management of lakes and rivers with dense aquatic vegetation.

Dr. Jan Köhler, koehler@igb-berlin.de

Project: MadMacs, **Duration:** 02/2019-01/2022, **Funded by:** Federal Ministry of Education and Research (BMBF) within the international Joint Programming Initiative "Water challenges for a changing world", **Lead:** Dr. Jan Köhler, **Research group:** Photosynthesis and growth of phytoplankton and macrophytes, Dept. Ecosystem Research

→ www.igb-berlin.de/en/project/madmacs

Photos: Shipping traffic © Thomas B./Pixabay; Water plants © Sabine Hilt/IGB; Angler © Florian Möllers

Five-point plan to integrate recreational anglers into a sustainable fisheries and water protection policy

In public and political perception, the social, economic and environmental importance of recreational angling is greatly underestimated compared to commercial fishing. In many inland waters, however, recreational anglers are now the main users of wild fish stocks. And also in coastal and marine fishing, the significance of angling is growing continuously. Up to now, however, the management of aquatic ecosystems and their fish stocks has been primarily geared towards the needs of commercial fishing or nature conservation. This leads to conflicts of use and is not conducive to the sustainable management of fish stocks. Fisheries scientists, economists, sociologists and ecologists have therefore drawn up a five-point plan for a reform of international fisheries and water protection policy.

1 Explicitly integrate angling targets into aquatic ecosystem and fisheries management

Sustainable management in the fisheries sector requires taking into account objectives specific to recreational fisheries, which differ considerably to those of commercial fisheries. Management tools applied in commercial fisheries, for instance those under the umbrella of the concept of maximum sustained yield, are inappropriate in recreational contexts.

2 Establish angler organisations and involve them in fisheries management

In central Europe, most anglers belong to a club or an association. In the rest of the world, however, this is rarely the case. The establishment and involvement of angler organisations in practical fisheries management represent key components towards future-oriented fisheries and aquatic ecosystem management.

3 Permit variable management approaches, and implement them at the local level

A single fishery typically cannot satisfy the often conflicting objectives of a heterogeneous group of recreational fishers. As a consequence, standard tools, such as minimum-size measures and other harvest regulations applicable to all waters in a particular region are problematic. However, provisions and rules tailored towards local needs call for a degree of decision-making sovereignty on the part of anglers and other managers. As the examples of local private property fishing rights in central Europe show, it pays to involve anglers in local management measures, and to equip them with a certain level of management competencies for local waters via clubs and associations.

4 Use the right tools

All anglers use a common pool resource, which may also be depleted by their activities. Many stocks are under high harvest pressure due to both professional fishers and anglers. Non-fishing factors such as river engineering and climate change also have a negative impact on fish productivity, which reduces even further some stocks' resilience to fisheries. Under such circumstances, unpopular management strategies such as access restrictions or individually costly harvest tags are more appropriate than continuing to release annual licences permitting a theoretically unlimited number of anglers and individually unlimited landings.

5 Improve monitoring

All these measures are only of any use if the most important stocks and waters are periodically assessed. The provision of high-quality, compelling data is ultimately also the responsibility of anglers. Only then can gradual overfishing be prevented, and management targets and strategies adapted, where needed. New technologies such as smartphone apps enable catches to be monitored and other data from and about anglers to be captured almost in real time. Some anglers and associations consider such technologies to be a form of surveillance, and are therefore against them. However, conflicts cannot be resolved or targeted management established without the use of modern monitoring techniques that enable the cost-efficient collection of data from hundreds of thousands of people. Anglers' trust in the transparent and targeted use and analysis of such data must first be built up and secured long term.

Prof. Dr. Robert Arlinghaus, arlinghaus@igb-berlin.de

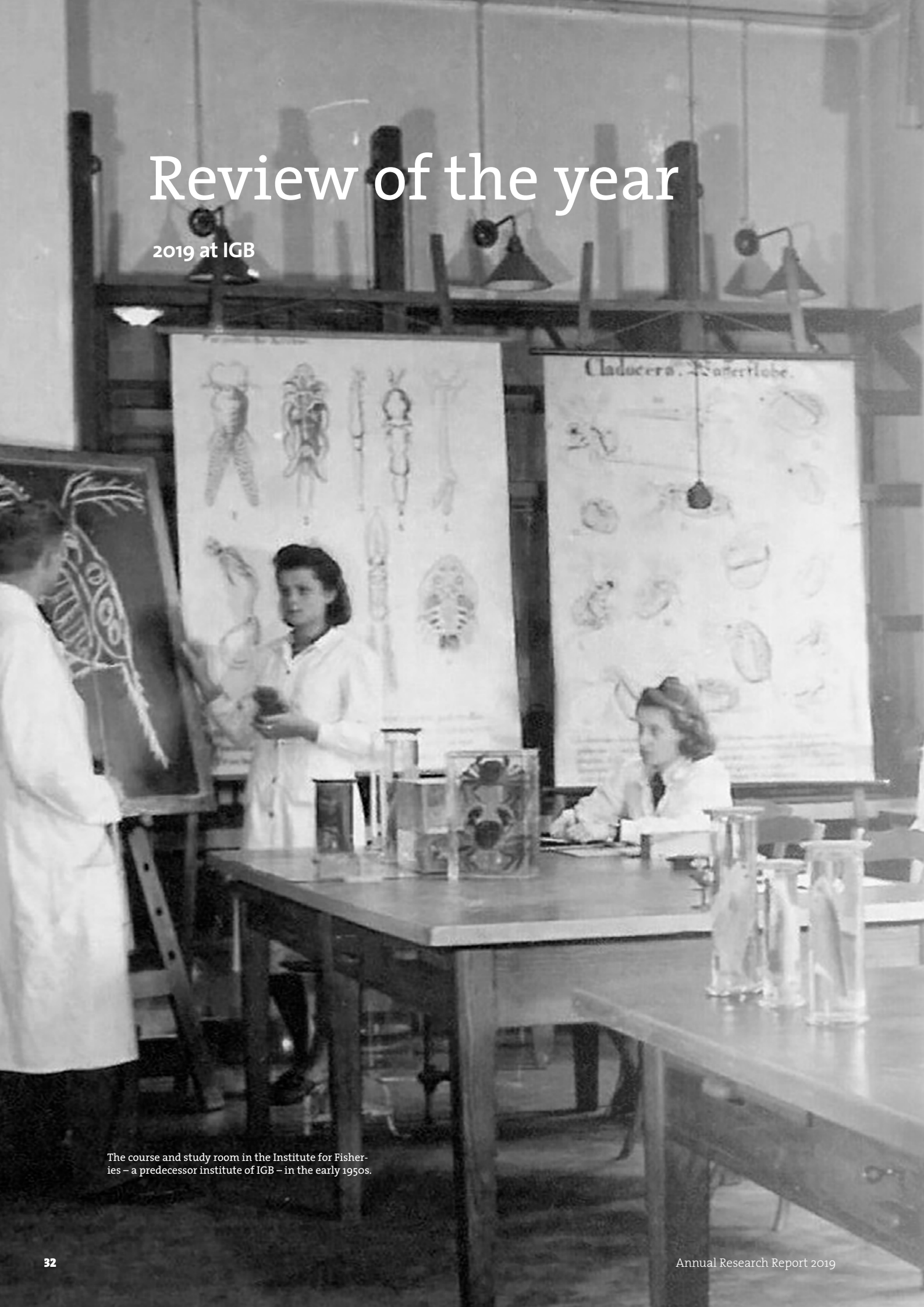
Project: Boddenhecht, **Duration:** 01/2019-06/2023, **Funded by:** EU and Land Mecklenburg-Vorpommern, **Lead:** Prof. Dr. Robert Arlinghaus, **Research group:** Integrative recreational fisheries management, Dept. Biology and Ecology of Fishes

→ www.boddenhecht-forschung.de

Arlinghaus, R. et al. (2019). Governing the recreational dimension of global fisheries. **Proceedings of the National Academy of Sciences of the United States of America**, 116(12), 5209-5213. doi:10.1073/pnas.1902796116

Review of the year

2019 at IGB



The course and study room in the Institute for Fisheries – a predecessor institute of IGB – in the early 1950s.

ACTION for Citizen Science projects

On 2 February, ACTION was launched, a project that supports citizen science projects working on pollution of all kinds, such as water, air or light pollution. IGB coordinates the ACTION Accelerator, which provides support to develop and grow a citizen science project. This includes intensive training in project design, mentoring for project pilots and beyond, and consultancy on a diverse range of common citizen science challenges such as data management.

PD Dr. Franz Hölker, hoelker@igb-berlin.de

ACTION

Along the river Spree: On the trail of sulfate & Co.

The water quality of the Spree has declined dramatically in the recent past. Background to this is the pollution, above all with sulphate and iron from the Lusatian brown coal mining regions. Once a year, two IGB teams sample the river Spree and its tributaries at 78 measuring points. The collected data are included in IGB's long-term monitoring programme and serve to assess water quality but also to document the changes of recent years.

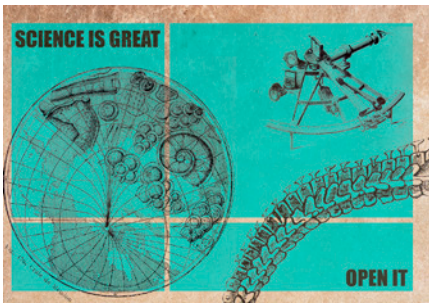
Dr. Tobias Goldhammer, goldhammer@igb-berlin.de

JANUARY FEBRUARY MARCH

Uncharted Waters: Business Basics

How much is my research knowledge worth, how can I protect and use it at the same time? How do I set up a company? And what do I need to consider in R&D projects? In our workshop series Uncharted Waters, IGB researchers learned in entertaining exercises how science and business can be brought together productively.

Johannes Graupner, graupner@igb-berlin.de



IGB Open Science Week

Open Science – just science done right!? The first week of March was dedicated to Open Science. The IGB library, the PR and Knowledge Transfer team and external speakers gave an overview of the current developments in the Open Science movement and the support options at IGB.

Library and PR and Knowledge Transfer, bib@igb-berlin.de and pr@igb-berlin.de

Tomatofish receives the Dahrendorf Prize

For the resource-saving aquaponics breeding method they developed, the three researchers Werner Kloas, Fabian Schäfer and Hendrik Monsees received the Ralf Dahrendorf Prize for the European Research Area. The prize, which is endowed with 50,000 euros, was presented by Federal Minister of Education and Research Anja Karliczek in Berlin on 9 May. The prize shall support making aquaponics better known outside its own discipline.

Prof. Dr. Werner Kloas,
werner.kloas@igb-berlin.de

Long Day of the CityNature

Urban Ecology is an important field of research for IGB. On the Long Day of CityNature on 25 May, more than 300 people came to the nature campus of IGB, the Leibniz Centre for Agricultural Landscape Research (ZALF) and the Eberswalde University of Applied Sciences for Sustainable Development (HNEE), which offered information about aquatic species diversity in Berlin, recreation on the water and aquaculture.

Nadja Neumann,
nadja.neumann@igb-berlin.de

MARCH APRIL MAY

Girls' Day at IGB

15 potential future female freshwater scientists attended the Girls' Day at IGB on 28 March – they were curious to learn about freshwater biodiversity and to get to know how to efficiently protect freshwaters. They were fascinated by the freshwater giants Arapaima and Atlantic sturgeon, and the "tomatofish". But they also enjoyed the chemical analyses of water quality. Every girl printed her own bag with a freshwater motif as a souvenir for this special day.

Nadja Neumann,
nadja.neumann@igb-berlin.de

IGB scientist Thomas Mehner is new president of the International Society of Limnology

On 8 May, Thomas Mehner (on the left) took office as 13th President of the International Society of Limnology (SIL). SIL is an international specialist society whose members are devoted to the processes in inland waters such as lakes, rivers, and wetlands, as well as the changes caused by warming, eutrophication or pollution.

PD Dr. Thomas Mehner, mehner@igb-berlin.de

Photos: Girls' Day © Nadja Neumann; Mehner © Katharina Bunk; Long Day of the CityNature © Nadja Neumann; Soapbox Science © Franziska Sattler; Artists in Residence © Marco Abram/Locarno Festival; FVB Science Day © Ralf Günther/FVB; Students for Rivers © Gabriel Singer

Soapbox Science: Fascinating female scientists at Alexanderplatz

Twelve international female scientists, among them IGB's Selin Kubilay, presented their research on 22 June at Berlin's Alexanderplatz standing on a wooden box – the Soapbox. Since 2011, the Soapbox Science initiative promotes greater gender equality in science. It was brought to Germany in 2017 by scientists from IGB and the Max Planck Institute for Gravitational Physics.

→ twitter.com/berlin_soapbox

FVB Science Day and LabSlam

Naturally, IGB scientists did not miss the Science Day "Water" of the Forschungsverbund Berlin e.V. At the LabSlam – scientists give a brisk lecture – Carolin Doran represented the IGB well and got the audience hooked on her topic "Why do animal groups behave so differently?"..

Dr. Carolina Doran, doran@igb-berlin.de

JUNE

Filmmakers as Artists in Residence at IGB

How can lakes and the live largely hidden within them be made experienceable? A film project by the Bosnian film director Dane Komljen deals with this question. For the shooting, he, the camerawoman Jenny Lou Ziegel and producer Zsuzsanna Kiràly lived as Artists in Residence at IGB in Stechlin in June.

Dr. Martina Bauchrowitz,
martina.bauchrowitz@igb-berlin.de

JULY

Research for free flowing rivers

On 12 July, the first Students for Rivers Camp took place at the Soča in Slovenia. The meeting was organised by the River Intellectuals, a new network that brings together young committed people from science and nature conservation. Their aim is to protect the rivers in the Balkans from the rapid expansion of hydropower there. Among the River Intellectuals are the IGB junior researchers Jessica Droujko, David Farò and Helena Hudek.

Prof. Dr. Gabriel Singer,
gabriel.singer@igb-berlin.de

Science meets soulbottles

Within the workshop series Uncharted Waters, IGB regularly invites interesting representatives from businesses, associations and politics to an open exchange. On 27 August, the team of soulbottles was our guest. The young company from Berlin produces sustainable drinking water bottles without plastic, and financially supports water and sanitation projects in developing countries.

Uncharted Waters: Water Law for Scientists

The waters that surround us and on which we conduct research are subject to different and often complex legal regulations. The crash course familiarised IGB scientists from various disciplines with the EU Water Framework Directive (WFD) – one of the most important laws – and its influence on (inter)national legislation and water management practice in Europe and Germany.

Johannes Graupner,
graupner@igb-berlin.de

Opening of the Futurium with IGB swarm specialist

At the opening of the Futurium in September 2019, Jens Krause, as a representative of the Leibniz Association, presented his research results on collective behaviour and collective intelligence on one of the future islands in the Futurium. The Leibniz Association is one of 15 partners of the Futurium.

Prof. Dr. Jens Krause, j.krause@igb-berlin.de

AUGUST

16th Symposium of Aquatic Microbial Ecology

250 scientists from 30 countries, six days of exchange, one topic in mind: From 1 to 6 September IGB and the University of Potsdam were hosting the 16th Symposium of Aquatic Microbial Ecology (SAME) in Potsdam. The scientists shared their new perspectives on microbial interactions, aquatic interfaces, the role of microorganisms in biogeochemical cycles, and on modelling in marine and freshwater ecosystems.

Prof. Dr. Hans-Peter Grossart,
hgrossart@igb-berlin.de

SEPTEMBER

Workshop on evolution of female and male

From 19 to 22 September, an international workshop about the paradigm shift in the evolution of sex chromosomes with over 50 scientists from evolution biology took place at IGB. The participants came together to formulate fundamental questions, find answers and uncover knowledge gaps on the evolution of sex chromosomes, especially in vertebrates.

PD Dr. Matthias Stöck,
matthias.stoeck@igb-berlin.de

Photos: Soulbottles © Katharina Bunk; SAME © IGB; Futurium © Axel Rückemann; Evolution © B. Evans

8th Dialogue at Lake Stechlin: Fish, fisheries and lakes in transition

This year's Lake Dialogue, which took place on 30 November, focused on fish, fisheries and lakes in transition. Together with guests from science, angling and inland fishing, authorities and associations as well as citizens, we discussed the challenges, opportunities and options for action for the future-oriented development, protection and sustainable use of our lakes from different perspectives.

Dr. Peter Casper, pc@igb-berlin.de

Internal exchange on the IGB Science Day

IGB staff from all areas of work gathered on 17 December for the annual Science Day, which was opened by Alexander Zehnder, former director of Eawag, with an external impulse on "Value and Values of Water". In the morning, current projects and initiatives at IGB were presented and in the afternoon, young scientists presented their work.

Dr. Ina Severin, severin@igb-berlin.de

OCTOBER NOVEMBER DECEMBER

IGB Aquaculture Research at the Aquaculture Europe

A research focus of IGB is the development of scientific foundations for sustainable fishing and resource-efficient aquaculture. Together with users, we can develop efficient concepts for the sustainable use of freshwaters and aquatic resources. At the Aquaculture Europe 2019, the IGB projects Aquakulturinfo, CUBES Circle, InProSol, CityFood – and the minds behind them – presented themselves.

Prof. Dr. Werner Kloas, werner.kloas@igb-berlin.de

60 years of limnological research at Lake Stechlin

With the construction of the GDR's first nuclear power plant at the end of the 1950s between Nehmitzsee and Stechlinsee, a first limnological research centre was established on the banks of Lake Stechlin. It began work on 11 November 1960. Today, the cooling water of the nuclear power plant no longer stresses Lake Stechlin, but environmental changes such as climate change do. Today, the Department of Experimental Limnology is located at the IGB site in Stechlin.

Prof. Dr. Mark Gessner, gessner@igb-berlin.de

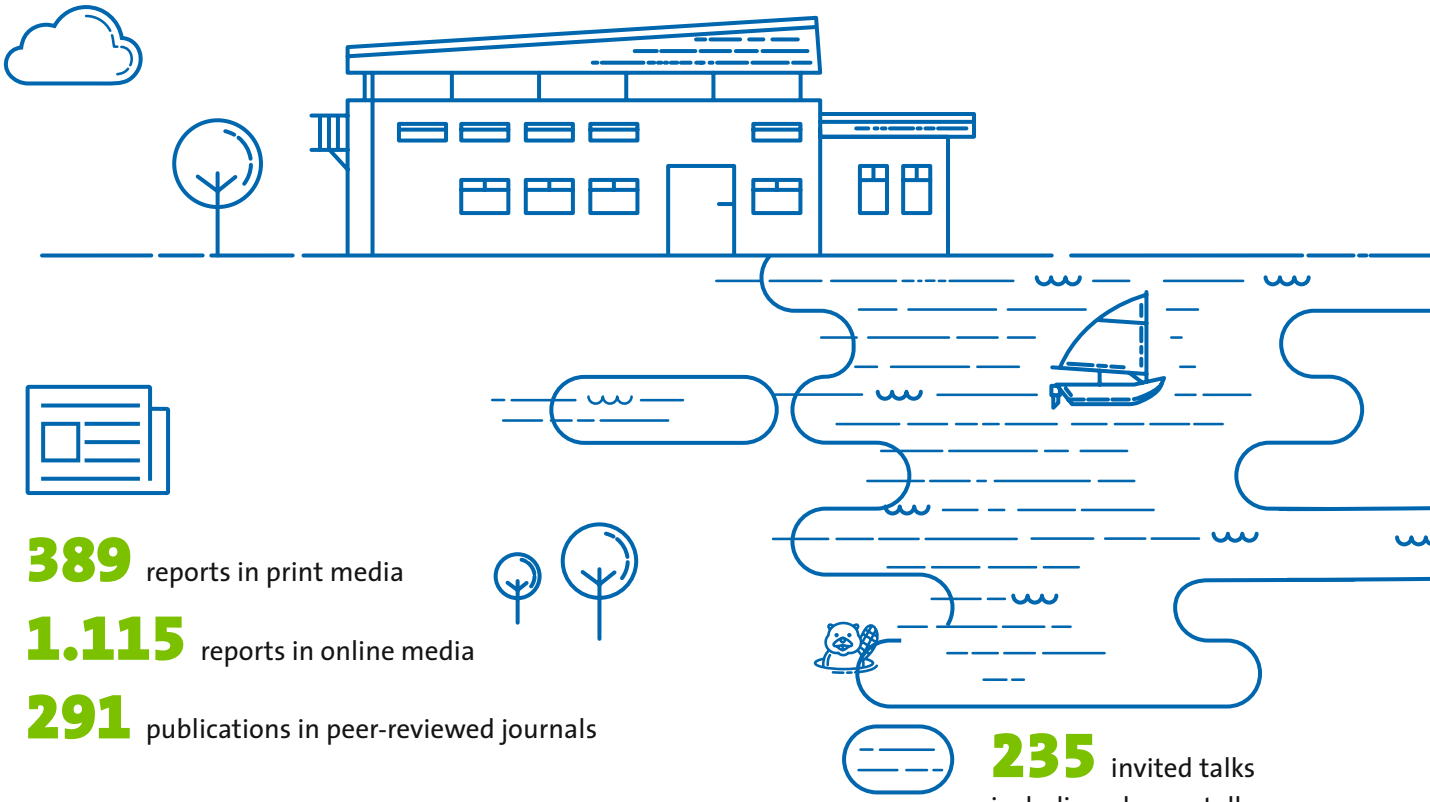
Photos: Dialogue Lake Stechlin © Marc Kupetz; 60th anniversary © Wolfram Scheffler

About us

2019 in numbers

374 employees and guests
including **148** scienctists
and **92** science supporting staff

40 employees active in committees and expert associations



389 reports in print media

1.115 reports in online media

291 publications in peer-reviewed journals

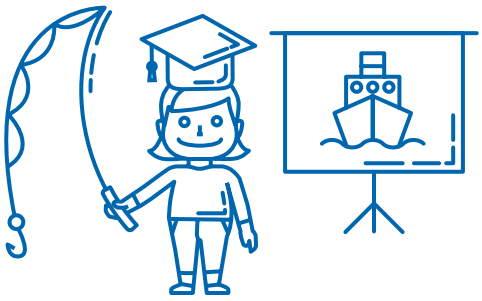
235 invited talks
including plenary talks,
keynote lectures and
other scientific talks

57 scientific events and workshops

including **52** with international participation

and

2.485 participants in total



Status as of 31 December 2019

29 employees active in teaching

53 doctoral students

20 doctoral dissertations

13 diploma, master and bachelor theses

11 joint professorships with universities

35 IGB colloquia (public scientific talks with internal and external speakers)

External grants: **11.518.326 €**

Institutional funding: **17.357.400 €**

Overall budget: **28.875.726 €**

Proportion of external funding: **40 %**

People

Permanent professorship

First Heisenberg professor, now professor for life: In 2014, **Jonathan Jeschke** and his Ecological Novelty group at the IGB and the Freie Universität Berlin embarked on his research into biological invasions. In 2019 he was appointed to a permanent professorship. Jonathan Jeschke and his team work intensively on invasive species and other new organisms and their ecological and socio-economic effects. Jeschke also wants to foster integrative biodiversity research and strengthen such research in Berlin and Brandenburg.will diese in Berlin und Brandenburg stärken.

Prof. Dr. Jonathan Jeschke,
jeschke@igb-berlin.de

Honorary fellowship

The Geological Society of America (GSA) has selected **Dörthe Tetzlaff** as honorary fellow. This fellowship honours international geoscientists who have distinguished themselves in geoscience investigations, promoting environmental awareness, linking science and society, or providing notable service to implementing public policy in natural resource managements.Dörthe Tetzlaff was selected for her seminal contributions to understanding streamflow generation processes. With her work on streamflow generation, isotopic tracing, and the role of plants in water transport through catchments she is regarded as one of the leading landscape hydrologists worldwide.

Prof. Dr. Dörthe Tetzlaff,
d.tetzlaff@igb-berlin.de

Honorary doctorate

The Université Toulouse III Paul Sabatier has awarded **Mark Gessner** an honorary doctorate for his scientific merits in limnology. Mark Gessner and his cooperation partners in Toulouse look back on 30 years of collaborative research. Together with other scientists in Europe, they have undertaken pioneering work on leaf litter breakdown in freshwater ecosystems. Many of his publications on the subject have become seminal papers in the pertinent literature.

Prof. Dr. Mark Gessner,
gessner@igb-berlin.de

Successful in Leibniz Competition

The Leibniz Junior Research Group "Global freshwater biodiversity, biogeography and conservation" aims to gain a more detailed overview of ecological significance and distinctiveness of freshwater biodiversity and to link their analyses with nature conservation planning. With this innovative concept, **Sami Domisch** was able to win the Leibniz Competition 2019: The Leibniz Association enables him and three other postdocs to establish their own junior research group.

Dr. Sami Domisch,
domisch@igb-berlin.de

We also congratulate:

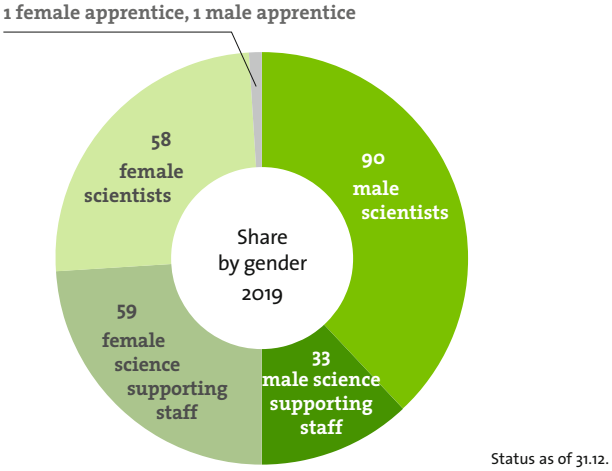
- Werner Kloas, Fabian Schäfer and Hendrik Monsees: Ralf Dahrendorf Prize for the European Research Area from the German Federal Ministry of Education and Research (BMBF) → **page 16**
- Jonas Schaper: 2nd place of the Schwoerbel-Benndorf Young Scientist Award of the German Limnological Society (DGL)
- Oleksandra Shumilova: 3rd place of the Schwoerbel-Benndorf Young Scientist Award of the German Limnological Society (DGL)
- Thomas Wanke: Promotion Prize of the Association of German Fisheries Administrators and Fisheries Scientists (VDFF)

For their life's work they were honoured with retirement:

- Gunnar Nützmann after 28 years at IGB, among other things, as head of the Department of Ecohydrology and as acting director
- Angela Krüger after 28 years at IGB, as scientific staff member in the Department of Chemical Analytics and Biogeochemistry, and for many years as equal opportunities representative
- Christof Engelhart after 28 years at IGB, among other things, as lead of the physical limnology research group, and long-standing chairman of the IGB works council as well as the general works council of the FVB
- Hartmut Gaertner after 28 years in charge of cars and boats at IGB
- Carola Kasprzak after 28 years at IGB as technical assistant in the Department of Experimental Limnology
- Edith Tesch after 28 years at IGB as technical assistant in the Department of Experimental Limnology

Employees at IGB 2019

148	scientists
	incl. 53 postdoctoral scientists
	incl. 37 doctoral students
92	science supporting staff
2	apprentices
2	IGB-funded fellows
30	assistants and temporary staff
100	guests (other persons working at the institute such as guest researchers, third-party fellows, students, interns, FÖJ)
374	**in total**



Status as of 31.12.

Young scientists, dedicated teams, international perspectives

IGB is a diverse and inspiring workplace and research environment. We provide training and promote individual development at every career level. Our teams include students, doctoral candidates and postdoctoral researchers from all over the world. We are linked to four universities in Berlin and Brandenburg through joint professorships, and are actively involved in teaching. We also pass on our knowledge to young researchers through the IGB doctoral programme, in our postgraduate schools and through the international master programme in Fish Biology, Fisheries and Aquaculture at the Humboldt-Universität zu Berlin.

We are especially proud of the diversity and commitment of our early career researchers, more than half of which are from countries outside Germany – from 31 different countries, to be exact. Such diversity makes IGB a special, multicultural and lively place to work. It is a pleasure working with our young scientists, whose enthusiasm is contagious.

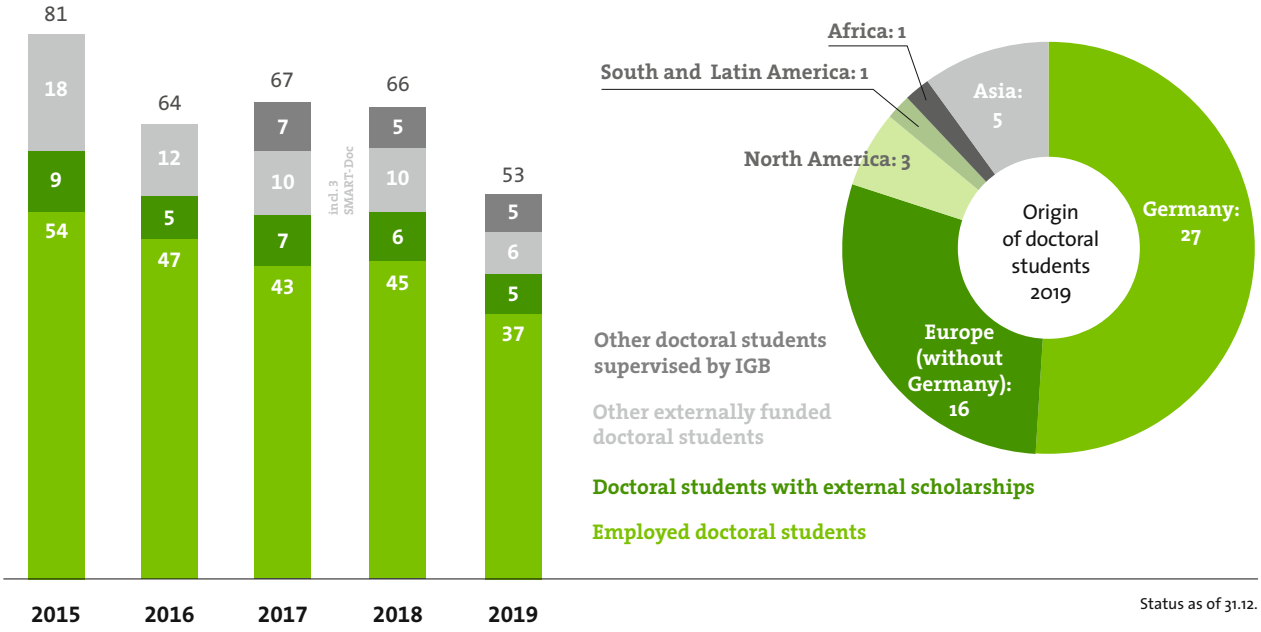
The IGB doctoral programme offers a wide range of courses to give our doctoral students the best possible support and to help prepare them for a career both within and outside academia. All courses combine theoretical knowledge with practical elements. Our basic, intermediate and advanced courses in statistics – tailored to meet our young scientists' needs – are especially popular. IGB postdocs design courses on the complex foundations of mixed linear models and on Bayesian statistics. Our intensive course on writing scientific articles remains a favourite with our doctoral students, who learn the skills required to more or less complete a manuscript for publication within one week. Many doctoral projects are part of postgraduate schools that offer their own training programmes in addition to IGB's own doctoral programme. The training networks and postgraduate schools in which IGB is involved train the students' and doctoral students' understanding of broader contexts.

Our postdocs were – and continue to be – curious, focusing on a new issue each year for their own training opportunities. Most recently, they trained performing peer reviews for scientific publications, and took a look at career opportunities outside the academic field.

Dr. Kirsten Pohlmann, kpohlmann@igb-berlin.de

More information about our philosophy and about working and researching at IGB is available on our website. It also features current job offers.
→ www.igb-berlin.de/en/career

Doctoral education



Status as of 31.12.

Excellent training at IGB

For 13 years now, IGB has been offering apprenticeships in several professions. In 2019, we were awarded the label for Excellent Training Quality by the Chamber of Industry and Commerce of Berlin (IHK) for our commitment to professional qualification.

"I am a chemistry and math freak. I really enjoy working in the laboratory," says Elisabeth Schütte in the third year of her training as a chemical laboratory assistant at IGB. Meanwhile, she is employed in the Department of Chemical Analytics and Biogeochemistry, and in 2019 she has been awarded a three-year BMBF grant for further training to help her start her career. Behind her lies a wide-ranging education: Her entry into theoretical and practical chemistry was provided by the teaching laboratory of Freie Universität Berlin. The young chemical laboratory assistant then came to IGB to learn about the latest analytical methods, e.g. metal analysis at the ICP-OES, quantitative determination of anions at the ion chromatograph, and the determination of antibiotics at the LC-MS (QTOF). In our laboratories we examine, for example, sediments, microorganisms and pathogens from rivers and lakes. Taking, preparing and analysing samples is naturally part of the job.

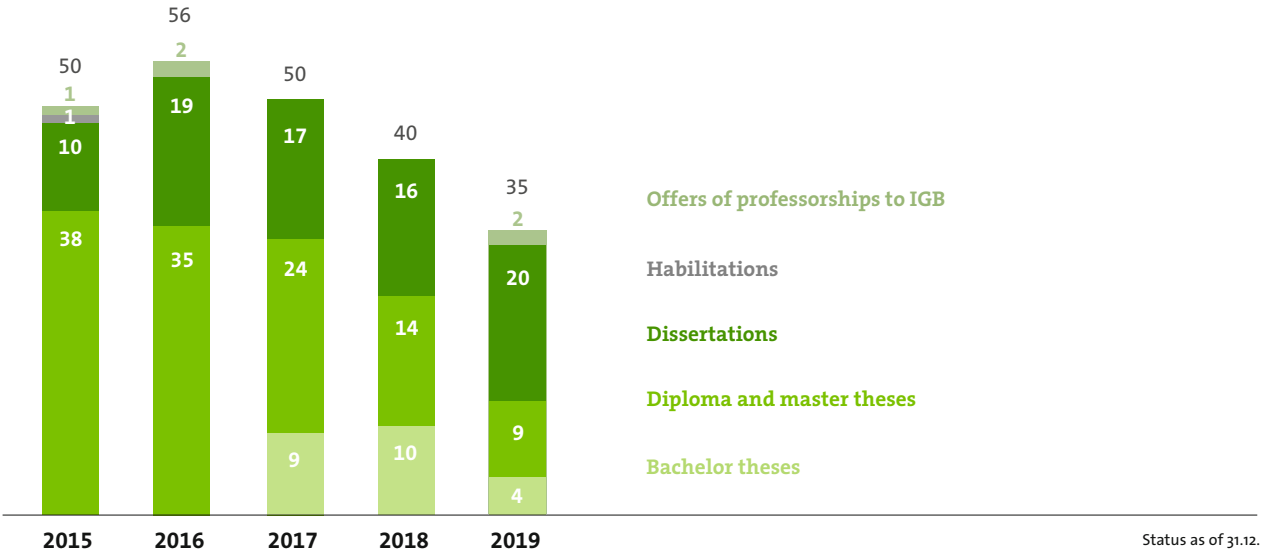
The versatile training Elisabeth Schütte completed at IGB is one of currently four dual training courses offered at IGB. The professions of biology laboratory assistant, IT specialist and office management assistant can also be learned at IGB.

In 2019, the institute applied for the IHK label for Excellent Training Quality and was awarded in May. In addition to the criteria in the two categories Mandatory and Excellence, we have also fulfilled the "on top criteria". For example, it is not only a matter of course that our trainees receive an appropriate training compensation and that we provide them with all necessary work equipment free of charge, but also that our trainees are offered individual examination preparation. In an interview with the trainees and colleagues who are responsible for the training at IGB an IHK training consultant reviewed whether our ideas of good training also meet the needs of our trainees. Result: trainees and trainers confirm the special quality and the compliance with the criteria.

Marlis Lange and Melanie Oertel, personal@igb-berlin.de

More about apprenticeships at IGB
→ www.igb-berlin.de/en/apprenticeships-internships-and-foj
→ bit.ly/azubi-broschuere-fvb

Degrees & Co.



Status as of 31.12.

Publications

In 2019, IGB produced a total of 345 publications, including 291 articles in peer-reviewed journals. All publications are collected centrally in our library. They are indexed in our library catalogue (OPAC) at → www.igb-lib.igb-berlin.de and are available to all interested readers.

IGB supports open access to knowledge and research results. In 2019, 130 publications were immediately accessible in open access – in other words, a share of 45 per cent took the "golden road". In 2018 we introduced a mandate for the self-archiving of all studies which have been carried out at IGB and were published in subscription journals. This way, in 2019 we were able to make an additional number of 28 publications open access via the "green road" in the repository PUBLISSO. These articles are now directly available to the public, free of charge. Thanks to our own Open Access Publishing Fund, that covers the article processing charges (APC), as well as the Leibniz Association's Open Access Publishing Fund, an additional 18 IGB articles could be funded. In December 2019, we agreed on an Open Access Policy for IGB to promote the principles of Open Science and to continuously make more and more research knowledge freely accessible.

As a central services facility, the library primarily serves the institute's employees, and provides IGB with scientific information. External guests are very welcome to use the library after calling to make an appointment.

→ www.igb-berlin.de/en/library

By the way, the article with the highest Altmetric score (506) in 2019 is:

He, F. et al. (2019). The global decline of freshwater megafauna. **Global Change Biology**, 25(11), 3883-3892. doi:10.1111/gcb.14753

The so far most cited article from 2019 is:

Reid, A. J. et al. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. **Biological Reviews**, 94(3), 849-873. doi:10.1111/brv.12480

OPEN ACCESS

Open Access stands for unlimited and free access to quality-controlled academic information in the Internet. Through the removal of technical, financial and legal barriers, Open Access is instrumental in accelerating academic innovation processes and improving the visibility of research results. This supports those working in academia in their research and publication processes, and maximises the benefits of publicly funded research.

A list of all IGB publications from 2019
→ bit.ly/IGB-Publications-2019

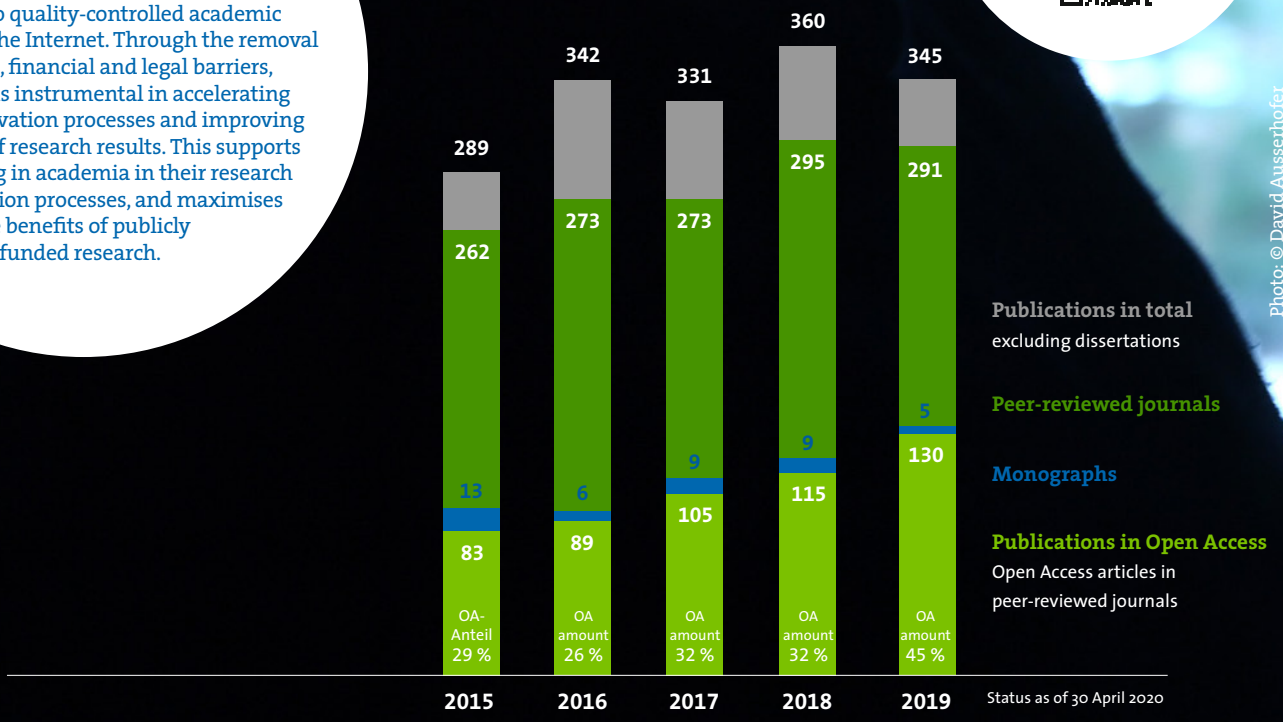
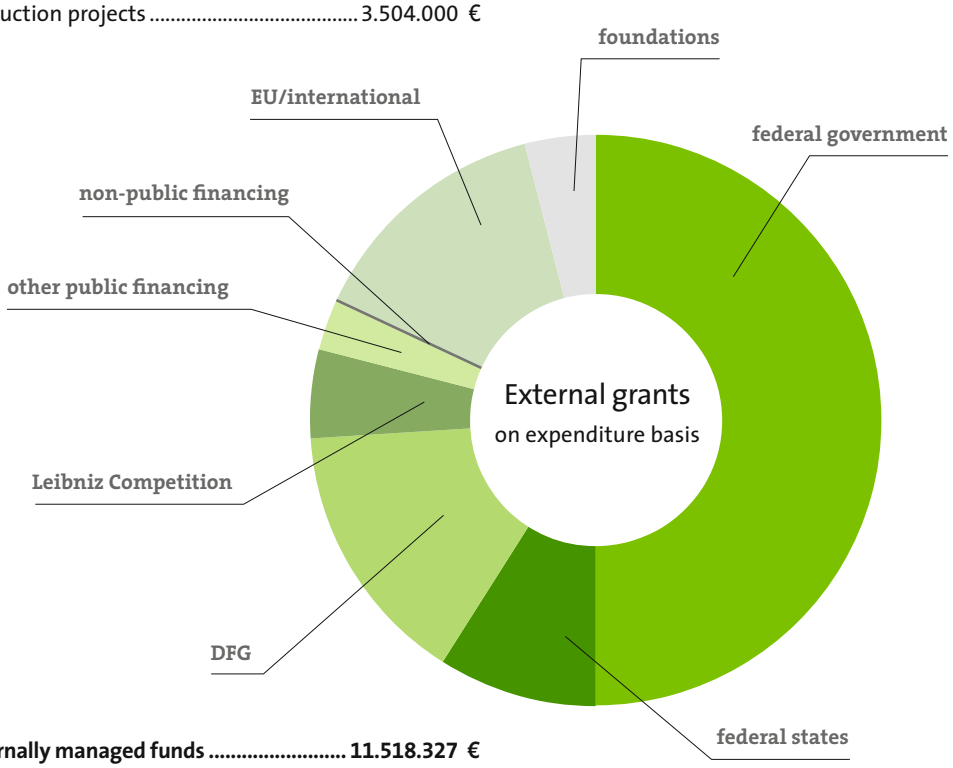


Photo: © David Ausserhofer

Finances 2019

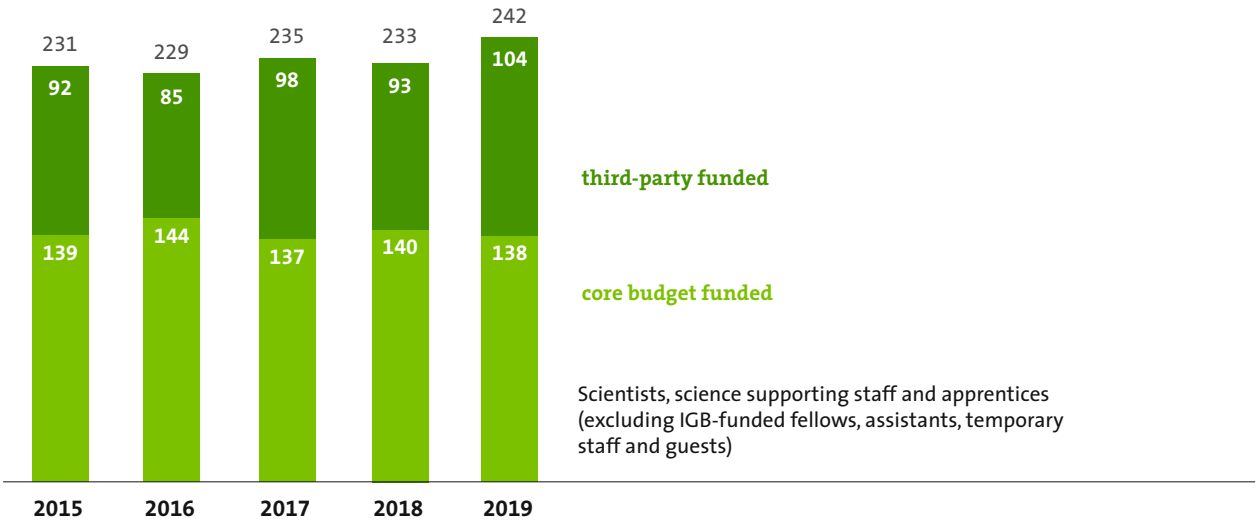
Status as of 31 December 2019

Institutional funding by the federal government and the federal states ..... 17.357.400 €
thereof core budget ..... 13.853.400 €
thereof for major construction projects ..... 3.504.000 €



External grants incl. externally managed funds ..... 11.518.327 €
thereof federal government ..... 5.591.823 €
thereof federal states ..... 873.734 €
thereof DFG ..... 2.046.748 €
thereof Leibniz Competition ..... 517.700 €
thereof other public financing ..... 307.165 €
thereof non-public financing ..... 4.565 €
thereof EU/international ..... 1.725.567 €
thereof foundations ..... 451.024 €

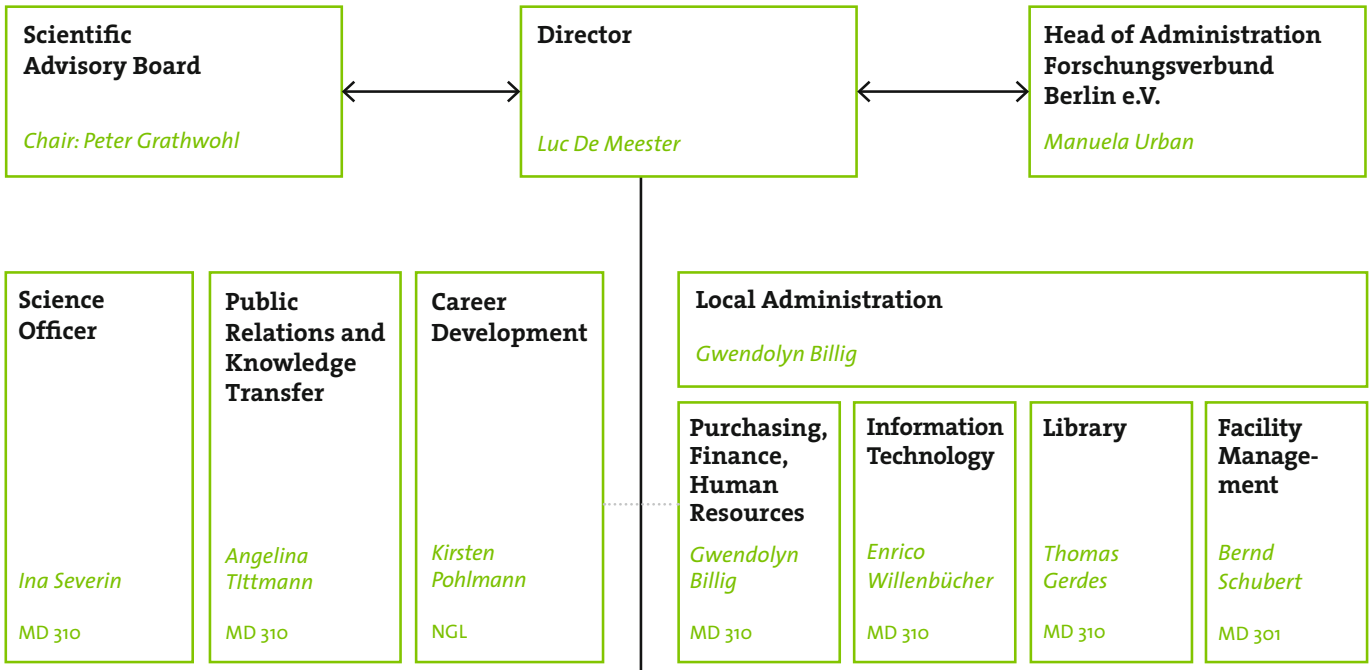
Employees by financing



Structure

Leibniz Institute of Freshwater Ecology and Inland Fisheries

Forschungsverbund Berlin e.V.



Research Departments

Cross-cutting Research Domains

CCRD 1 – Aquatic Biodiversity

Hans-Peter Grossart and Jonathan Jeschke
NGL & FU Berlin

CCRD 2 – Aquatic Boundaries and Linkages

Tobias Goldhammer (a.i.) and Sabine Hilt (a.i.)
MD 301

CCRD 3 – Human-Aquatic Ecosystem Interactions

Christian Wolter
MD 310

MD 310: Müggelseedamm 310, Berlin | MD 301: Müggelseedamm 301, Berlin | NGL: Neuglobsow, Stechlin

Status as of 30 September 2020

Scientific Advisory Board of IGB

Prof. Peter Grathwohl
Chair of the Scientific Advisory Board
Department of Geoscience, Universität Tübingen, Germany

Prof. Wolfgang Cramer
Mediterranean Institute of Marine and Terrestrial Biodiversity and Ecology (IMBE), France

Prof. Joseph Holden
School of Geography, University of Leeds, UK

Prof. Ken Irvine
UNESCO-IHE Institute for Water Education, the Netherlands

Prof. Otomar Linhart
Faculty of Fisheries and Protection of Waters, University of South Bohemia, Czech Republic

Prof. Gunilla Rosenqvist
Uppsala University – Campus Gotland, Sweden

Prof. Christoph Schneider
Geography Department, Humboldt-Universität zu Berlin, Germany

Prof. Bernhard Wehrli
Deputy Chair of the Scientific Advisory Board
Department Surface Waters Research & Management, Eawag, Switzerland

Prof. Karen Wiltshire
Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research & Biological Institute Helgoland & Wadden Sea Station Sylt, Germany

Representatives at IGB

Ombudsperson
Sabine Hilt, Sabine Wollrab (deputy)

Equal opportunities representatives
Kirsten Pohlmann, Justyna Wolinska (deputy)

Disability representative
Georg Staaks

Doctoral student representatives
Benjamin Archer, Laura Jentzsch, Birgit Müller, Hanna Schulz, Kai-Ti Wu

Postdoc representatives
Andreas Jechow (speaker), Gregor Kalinkat, Katrin Kohnert, Simone Podschun, Kingsly Chuo Beng

Works council
Sascha Behrens (chair), Thomas Hintze, Eva Kreuz, Marén Lentz, Kerstin Schäricke, Claudia Schmalsch, Viola Schöning, Georg Staaks, Antje Tillack

Always up to date on our website
→ www.igb-berlin.de/en/structure

Status as of 30 September 2020

The annual research report of IGB gives you an insight into the research work and structure of our institute. For more information, please visit our website or contact us directly at:

Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB)
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Newsletter: www.igb-berlin.de/en/newsletter

Imprint

We would like to thank all colleagues who contributed to this annual research report and supported us!

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“It is important to me that IGB is a community”

The Belgian aquatic ecologist and evolutionary biologist Luc De Meester is the new Director of IGB and Professor of Freshwater Science at Freie Universität Berlin since January 2020. He has been a professor in ecology and evolutionary biology at the University of Leuven (KU Leuven) in Belgium for more than 20 years. Where is he from, and where does he want to go with IGB and its staff? On his first days in office, he told us about what motivates him, and what plans he has.

Luc De Meester, we wish you a warm welcome to IGB! You have already disclosed the fact that you are very direct. This fits in well with the reputation of the capital region. Thus, let us come straight to the point: What made you want to become the director of IGB?

I am indeed in favour of a quite direct style, although perhaps direct Belgian style might still be somewhat different from direct Berlin and Brandenburg style. Above all I think clarity and transparency is important. It strongly reduces the likelihood of misunderstandings. But let me come straight to your question: IGB is one of the most outstanding freshwater research institutes in Europe and worldwide. The institute has achieved a phenomenal development, and so this was an ideal moment in time to take on this position – IGB is highly recognised internationally, while there is still much scope for growth. This potential to further grow in excellence and broaden the research portfolio of the institute is very attractive. The breadth in scope, that we can study all aspects of entire ecosystems, combined with the long-term perspective sets us apart from typical settings in university laboratories, where research activities are often largely driven by the short-term perspectives offered by standard research projects. Here at IGB, we have the opportunity to really think long-term, and to combine the development of innovative research ideas with the translation of research outcomes to practice. I think this breadth and flexibility is wonderful, and extremely important for conducting relevant future-oriented research. The past twenty years at the university in Leuven, I led a quite large research group, conducted research, and contributed a lot to teaching. It was at times challenging to combine all this, but it was very rewarding and I very much enjoyed it. But as IGB’s director, I envisage being able to make a greater contribution to society, promoting a more sustainable management of our freshwater resources.

So IGB’s guiding principle – research for the future of our freshwaters – appeals to you entirely?

Absolutely. It is precisely this guiding principle that has made IGB what it is today. I find IGB’s holistic approach of bringing together the different disciplines and facets of freshwater research and considering ecosystems in their entirety both visionary and essential. One of my key strategic tasks will be to further refine the objective of IGB in close cooperation with the researchers, whilst preserving the productive diversity of the institute’s expertise and topics.

What challenges do you expect to face in your new position?

In my own research, I am fascinated by how communities and populations of organisms respond to environmental change or extreme events. Resilience and the flexibility to respond to and take profit of change are very important. But it is also important that changes are not too drastic or extreme. I think this also holds for an institute such as IGB. Changes are often necessary and can create new momentum. But, similarly to how evolution works, one builds on existing structures. Evolution resulted in a dazzling variety of species and traits, amongst others because it builds on existing structures, which often leads to creative solutions. It will be a balancing act to radiate a strong vision, while building on existing structures and keeping all staff on board. It is important to me that IGB is a community, that we jointly pursue the same goals. Being a Belgian, there is the additional challenge for me to familiarise myself with the German language and the German science landscape and research policy. But challenges...

Photo: © David Ausserhofer

„A research institute is a community of individuals who spend a considerable part of their lives together, achieving goals as a team. I would like to help creating the best possible conditions for this community so that we can continue to be successful in research.“

LUC DE MEESTER

...can also be opportunities?

Yes, sure. In Germany, large investments are being made in sustainability research, which is a terrific opportunity. And I get the impression that German society has a very positive attitude towards science and scientific insights, and that politicians in this country are open to research-based consultancy.

Is there anything that you would like to share with us – the IGB team – right now?

Enthusiasm is a character trait I consider very important. I hope my new colleagues at IGB feel and share my enthusiasm for the institute and the research opportunities ahead. The flexibility to embrace new ideas without losing track of the “grand picture” is, I think, of key importance. Tolerance, gender equality and sustainability are also matters of great importance to me, and should be core to IGB. A research institute is a community of individuals who spend a considerable part of their lives together, achieving goals as a team. I would like to help creating the best possible conditions for this community so that we can continue to be successful in research both to the profit of the institute as a whole as well as for the development of the careers of the individual people. In the case of IGB, being “successful in research” also naturally means: inform society and politicians, co-develop research with societal stakeholders and increase society’s resilience in the face of a rapidly changing global environment. It will be key to strike the right balance between protecting and using freshwater-based resources and ecosystems, considering that sufficient protection is necessary to enable use in the future. Finally, I have a small request: a bit of leniency with regard to my current, still very limited knowledge of German.

The interview was conducted by Nadja Neumann and Katharina Bunk in January 2020.

Luc De Meester takes over as director from Klement Tockner, who headed IGB from 2007 to 2016, before being appointed President of the Austrian Science Fund FWF. In the intervening period, Mark Gessner, head of the Department of Experimental Limnology at IGB, served as the interim director of IGB, and oversaw the institute’s successful evaluation.

Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB)
Forschungsverbund Berlin e.V.

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