State of the inland waters according to an author in the IPCC Sixth Assessment Report

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Professor Rita Adrian is lead author of the current IPCC report. Credit: David Ausserhofer

Rita Adrian is lead author in Working Group II (Impacts, Adaptation, Vulnerability) on the IPCC Sixth Assessment Report, released today. She contributed to the chapter on "Terrestrial and Freshwater Ecosystems and their Services." She is a professor of limnology at Freie Universität Berlin and headed the Department of Ecosystem Research at the Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB) until the end of 2021. She investigates the long-term development of lakes and studies the influence of environmental change on water bodies. Her motto for this interview: Let the numbers speak! So, on the occasion of the Sixth IPCC Report, six numbers that exemplify the current and projected impacts of climate change on freshwater ecosystems. We'll take on the 3, the 4, the 18, the 10, the 20, and the 60.

Ms. Adrian, now it's done, your contribution to the IPCC report. What is going through your mind?

This IPCC report was compiled by 270 authors from 67 different countries and represents the "gold standard" of scientific knowledge on the impacts of climate change on ecosystems and societies. The IPCC reports are a unique collaboration between researchers who write the report and governments who commission the report and use it as the basis for policy decisions. Our report will be the basis for discussions at the COP27 negotiations this November in Egypt. Despite the enormous effort, it is very satisfying as a scientist. We have very good evidence on the impacts of climate change on inland waters. The data base from long-term research, from experimental studies, remote sensing and modeling is improving. So, we can see quite well into the future. Researchers are increasingly active in international networks to explore the effects of climate change locally and, more importantly, globally.

In my role as a citizen, of course, I would now like to see the setting of clear targets on how we are going to reduce emissions and make ecosystems more resilient to climate change.

We agreed to talk about numbers today. You gave me six different ones that are exemplary for freshwaters under climate change. Let's start with the 3.

The 3 stands for the inland waters themselves, which are ecosystems that often slip under the radar in politics as a third habitat alongside the land and the sea. The Intergovernmental Panel on Climate Change's Sixth Assessment Report gives great importance to inland waters and their ecology, and to freshwater as a resource. This is necessary! Climate change is affecting lakes and rivers, as well as the people and animals that depend on them. Inland waters have already warmed considerably, they are losing oxygen, and ice cover is disappearing. Higher water temperatures are enhancing algal blooms with negative impacts for drinking water supplies and recreational value. More and more rivers and small bodies of water are temporarily drying out with negative consequences for biodiversity. The global warming trend is also accompanied by extreme droughts and floods. Many regions are affected by water shortages and declining groundwater levels.

When we think of climate change, the first thing that comes to mind is warming—let's start there. What if we look into the future of climate change—and that's what researchers do by using mathematical model scenarios. What will the warming of freshwaters look like?

If we take the highest climate scenario as a basis, water temperatures such as those observed during the last hot summers in Europe will become increasingly "normal." According to model scenarios, lakes are estimated to warm by 0.9 °C for every 1 °C increase in air temperature. A research team including IGB published a study on this last year. They also projected future trends under different scenarios. Under a low-emissions scenario, average lake warming in the future is expected to stabilize at +1.5 °C above pre-industrial levels. In a high-emissions world, these changes could lead to an increase of +4.0 °C.

4 °C, that sounds dramatic compared to rising air temperatures. What are the consequences?

Water temperature is the main driver for almost all processes in water bodies. It affects thermal structure, mixing of the water column of lakes, nutrient dynamics, growth rates of organisms, and ice cover. With warming, lakes mix less frequently, which negatively affect the renewal of oxygen in the deeper water layers.

So, the oxygen content in the water is decreasing?

Yes, the global average loss in the upper warm water layers was 4 percent, which is due to the reduced solubility of oxygen at higher temperatures. In the deep water, the loss has already reached 18 percent in the last 4 decades. The loss of oxygen in deep waters follows a physical principle and is related to rising water temperatures at the surface and a longer warm period during the year: If the surface water warms when deep water temperatures are stable, the difference in density between these layers, known as thermal stratification, increases. The stronger and longer this stratification is, the less likely mixing is. Thus, less oxygen reaches the deeper water layers.

What are the effects of the reduced oxygen content?

This is especially problematic for the cold-loving fish species that reside in cold deep water. These species can only move upwards to a limited extent—as it is too warm for them there. They are subject to a double stress: from heat and the lack of oxygen. With higher temperatures, metabolic costs increase—negatively affecting growth and reproduction—with losses to biodiversity and fisheries.

This is a major concern for countries where fish is an essential food source for people—as in parts of Africa. Here, large losses are projected under future climate scenarios. In addition to the losses to fisheries, we are also losing a large proportion of endemic fish species- species found only in these lakes. In our latitudes, the southern range limit of cold-loving fish species is shifting northward. This affects, for example, coregonus, salmonids, smelt.

The availability of oxygen also influences water quality: under oxygen-free conditions, eutrophic nutrient-rich lakes fertilize internally from the sediment. This promotes the development of algal blooms, with negative impacts on drinking water supplies and recreational value for the public. This is a classic example of a positive feedback loop initiated by warming and increases in the length of lake stratification. Sustainable agriculture with reduced nutrient inputs to water bodies is one option for adaptation.

You alluded to thermal stratification behavior. To what extent does that play a role in algae development and water quality?

Yes, as always, it is more complex than it appears at first glance. On average, algal biomass in lakes globally has increased in recent decades—due to the positive direct effect of higher temperatures on algal growth and the indirect effect of internal fertilization as a result of the lengthening in thermal stratification in summer, as mentioned earlier. However, in deep nutrient-poor lakes, algal biomass tends to decrease.

The change in temperature stratification affects nutrient availability within the column?

Exactly. And the effect of this can be put in one statement: Green becomes greener and blue becomes bluer. The phenomenon of "green lakes becoming greener" reflects the causal chain of effects mentioned earlier for nutrient-rich lakes: higher temperatures—longer thermal stratification—loss of oxygen at depth—internal fertilization from sediment—increase in algal biomass, which makes the water appear green. This is different in deep nutrient-poor "blue lakes." The deep water is often the only source of nutrients when the nutrients in the upper water layers are depleted. Meanwhile, the upper water layers, which are flooded with light, are separated from this nutrient depot for longer periods of time by extension of thermal stratification. On average, algal biomass is decreasing—lakes are becoming "bluer." This may be accompanied by losses to inland fisheries.

We have now talked primarily about summer; what happens in winter?

Lakes today freeze two to three weeks later on global average and thaw one to three weeks earlier. According to model scenarios, for every 1 °C increase in air temperature, lakes are estimated to warm by 0.9 °C and lose 10 days of ice cover. In addition, lakes increasingly no longer have continuous ice cover, but freeze and thaw several times in a winter. This intermittent ice cover is an observation we have also made at Lake Müggelsee in Berlin. The geographical zone in which lakes now form an intermittent ice cover is shifting further north. This means, for example, that ice conditions prevail in southern Sweden today as we had here in the Berlin area a few decades ago.

Why is the ice cover important? Isn't it said that the lake rests still and rigid?

Although winter is commonly thought of as a time of relative stillness, ecosystem functions are dynamic during this season. Moreover, there is growing evidence that conditions in winter set the stage for conditions in summer and, for example, temperature changes in deep lakes propagate over several years in deep lakes. Ice cover fundamentally changes a lake by isolating it from the surrounding landscape and atmosphere. The thickness and optical properties of ice and snow regulate the amount of solar radiation entering the lake while shielding it from wind. Consequently, ice cover is an important factor regulating the mixing of water in lakes and structuring vertical thermal and chemical gradients.

How are the living conditions for aquatic organisms changing in general?

Yes, it is not only the poorer water quality and declining oxygen conditions that affect the living organisms in the water body. It is also the change in thermal habitat. Think of it this way: Most living creatures in the water are alternately warm (poikilothermal) - that is, they adjust their temperature to the ambient temperature of the water. Each species has its own temperature range to which its bodily functions, such as metabolism and reproduction, are adapted. This temperature range largely determines at what depth and at what time of the year species occur in lakes. Thus, within the large body of water, there are different—warm and cold—thermal habitats. In a recent study we quantified that thermal habitats were reduced by nearly 20 percent globally between the 1978–1995 and 1996–2013 periods in 139 lakes for less adaptable species, e.g., species restricted to one depth and one season, with a warming trend of about 1 °C. For warm-loving species, this may mean an increase in thermal habitat of the same magnitude. We will lose cold-loving species—such as red trout and lake cisco. Heat tolerant species such as bream, roach or walleye could benefit.

Changed habitats in water bodies, but will habitats disappear altogether?

Yes, unfortunately! In the new IPCC report, we document that heat extremes superimposed on warming trends is increasing the tremendous fragmentation of rivers already caused by dam formation or water withdrawal. About 60 percent of global stream reaches temporarily dry up. When sections of water bodies temporarily go dry, this poses an insurmountable hurdle, especially for migratory fish species. In addition, bank sediments are exposed and supplied with atmospheric oxygen. This leads to an increase in microbial degradation of organic material with the release of greenhouse gases. This is just one of the mechanisms that turn lakes and drying rivers into sources of greenhouse gas emissions into the atmosphere—and thus amplify global warming in a positive feedback loop.

The IPCC reports are a success story. Scientific rigor and accuracy are the hallmarks for the IPCC approval—previously evaluated by hundreds of researchers, experts and government officials. Here, we scientists can put our findings and risk assessments into a form that can be used as a basis for policy implementation.

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