Commentary

Salinization Increase due to Climate Change Will Have Substantial Negative Effects on Inland Waters: A Call for Multifaceted Research at the Local and Global Scale

Erik Jeppesen,[1,2,3,4,*] Meryem Beklioğlu,[3,4] Korhan Özkan,[4,5] and Zuhal Akyürek[4,6,7]
[1]Department of Bioscience, Aarhus University, 8600 Silkeborg, Denmark
[2]Sino-Danish Centre for Education and Research, 100049 Beijing, China
[3]Limnology Laboratory, Department of Biological Sciences, Middle East Technical University, 06800 Ankara, Turkey
[4]Centre for Ecosystem Research and Implementation (EKOSAM), Middle East Technical University, 06800 Ankara, Turkey
[5]Institute of Marine Sciences, Middle East Technical University, 33731 Erdemli-Mersin, Turkey
[6]Department of Civil Engineering, Middle East Technical University, 06800 Ankara, Turkey
[7]Geodetic and Geographic Information Technologies, Middle East Technical University, 06800 Ankara, Turkey
*Correspondence: ej@bios.au.dk
https://doi.org/10.1016/j.xinn.2020.100030

Globally, temperature and precipitation patterns are predicted to change markedly as a result of climate change. Particularly, the regions with a cold or hot semi-arid climate and the Mediterranean climate zone are expected to be strongly affected.[1,2] A 25%–30% decrease in precipitation and increased evaporation are expected by the end of the 21st century in the Mediterranean region, to be accompanied by an even stronger reduction in runoff of up to 30%–40%,[1,2] and this will lead to increasing salinization of lakes in these areas.[1,2] Moreover, land in drought is expected to double from 2000 to 2100 to about 50% of the land worldwide.[1,2] These projections do not consider the concurrent increases in water abstraction, particularly for irrigation purposes, that will increase markedly[3,4] in the years to come due to (1) a global increase in demand for food in a growing population, (2) a shift from animal farming to crop farming in semi-arid and arid areas, and (3) a decrease in net precipitation. Thus, increasing irrigation will further accelerate salinization of lakes in the dry climate zones.

The magnitude of the future changes poses a major threat to the functioning and biodiversity of inland aquatic ecosystems (IAEs) (Box 1). As salinity increases, many IAEs may even dry out temporarily or permanently.[5,6] Studies performed in lakes in north-west China show drastic reductions in biodiversity, food chain length, and average trophic position in the food chain of the lakes, indicating loss of functioning[7] with increasing salinity. Another study on lakes in Tibet has shown non-linear changes for certain salinity thresholds and suggests that even small changes in salinity after surpassing the critical salinity levels may have drastic effects on the structure and functions of lake ecosystems (Figure 1). How such thresholds change with climate is, however, largely unknown. In addition to the temperature- and evaporation-driven changes, the rise in sea level will also increase the input of saline water to coastal brackish lagoons (CBLs), and some freshwaters may become saline, with similar negative effects on structure and function and their biodiversity.[8–10]

Global warming will further increase the frequency and duration of extreme weather events such as droughts, heatwaves, and seawater intrusions, which will further increase the variations in salinity and risk of passing vital thresholds in the IAEs and CBLs.

Box 1. Effects of Global Change

Global change including warming will:

- increase the proportion of inland aquatic ecosystems (IAEs) that are saline and then markedly reduce the available freshwater resources;
- result in the disappearance of many lakes, some of which are old and host many endemic species;
- enhance the variability in salinity, which, in turn, increases the probability that critical salinity thresholds in IAEs and coastal brackish lagoons (CBLs) are passed;
- make IAEs and CBLs more sensitive to other stressors such as excess nutrients and species invasions
- cause a substantial decrease in species richness and functional diversity of the various biotic communities along with an increasing salinity;
- lead to major reduction in ecosystem functions and services of IAEs and CBLs.

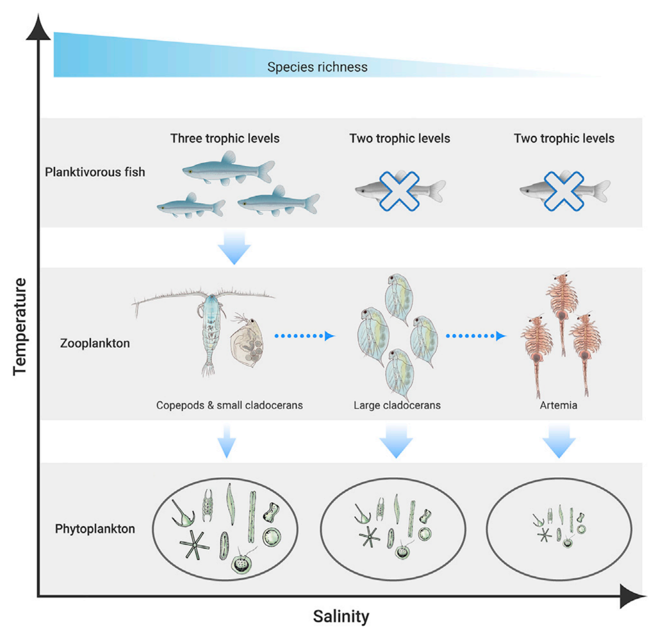

Figure 1. Schematic Diagram of the Shift in the Food Web along a Salinity Gradient in a Study of 45 Lakes in Tibet. The figure and the underlying data show drastic shifts when salinity thresholds are reached: first, loss of fish leading to dominance of the waterflea *Daphnia*; second, loss of *Daphnia* leading to dominance of amphipods (*Artemia*). Such changes have strong cascading effects on the ecological conditions of the lakes (modified from Lin et al.[11]).

Box 2. Research Approaches Suggested

To study the effects of global change on IAEs and CBLs, we need multifaceted and multidisciplinary approaches, including:

- space-for-time substitute approaches using common well-defined protocols across the dry climate zones of the globe for studying nutrient cycling, biodiversity, food webs and functions;
- analyses of existing time series data;
- high frequency data collection to reveal the effects of extreme events;
- remote sensing studies across larger spatial scales;
- controlled parallel running mesocosm experiments on a global scale;
- hydrological and ecosystem modeling on a catchment scale;
- socio-ecological and economic evaluations and research.

While the understanding of the dynamics of freshwater ecosystems and their response to stressors, including climate change, is well advanced, comparatively little is known about saline IAEs and CBLs. This is unfortunate given the ongoing drastic changes in many lakes, including a shift from freshwater to saline conditions and increased salinity of already saline systems.[5] Moreover, the mutual effects of salinity with other stressors (temperature, nutrient loading, and type of salt composition) are virtually unknown.

We call for (1) multifaceted and multidisciplinary approaches to fill the major research gaps outlined (Box 2)—an important area for a new generation of scientists; (2) coordinated research worldwide following common protocols for sampling, experiments, and modeling, allowing strong syntheses across climate and biogeographical gradients with virtual scientific networking and collaboration that would not need direct physical contact (regarding the current pandemic) and with much reduced carbon footprints.

To provide effective mitigation solutions, collaborations between hydrologists, ecologists, modelers, economists, engineers, social scientists are needed, both locally and globally, as well as strong engagement of politicians, NGOs, and local citizens (citizen science).

REFERENCES

1. IPCC (2007). In Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canzian, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, eds. (Cambridge University Press).
2. IPCC (2014). Summary for policymakers. In Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, and R.C. Genova, et al., eds. (Cambridge University Press), pp. 1–32.
3. Yano, T., Aydin, M., and Haraguchi, T. (2007). Impact of climate change on irrigation demand and crop growth in a Mediterranean environment of Turkey. Sensors *7*, 2297–2315.
4. Rodriguez Diaz, J.A., Weatherhead, E.K., Knox, J.W., and Camacho, E. (2007). Climate change impacts on irrigation water requirements in the Guadalquivir river basin in Spain. Reg. Environ. Change *7*, 149–159.
5. Jeppesen, E., Brucet, S., Naselli-Flores, L., Papastergiadou, E., Stefanidis, K., Nõges, T., Nõges, p., Attayde, J.L., Zohary, T., Coppens, J., et al. (2015). Ecological impacts of global warming and water abstraction on lakes and reservoirs due to changes in water level and salinity. Hydrobiologia *570*, 201–227.
6. Cañedo-Argüells, M., Kefford, B., and Schäfer, R. (2019). Salt in freshwaters: causes, effects and prospects – introduction to the theme issue. Philos. Trans. R. Soc. Lond. B Biol. Sci. *374*, 20180002.
7. Vidal, N., Yu, J., Gutierrez, M.F., Teixeira de Mello, F., Tavsanoglu, Ü.N., Çakiroglu, A.I., He, H., Meerhoff, M., Brucet, S., Liu, Z., et al. (2021). Salinity shapes food webs in lakes: implications for increasing aridity with climate change. Inland Waters.
8. Schallenberg, M., Hall, C.J., and Burns, C.W. (2003). Consequences of climate-induced salinity increases on zooplankton abundance and diversity in coastal lakes. Mar. Ecol. Prog. Ser. *251*, 181–189.
9. Flöder, S., and Burns, C.W. (2004). Phytoplankton diversity of shallow tidal lakes: influence of periodic salinity changes on diversity and species number of a natural assemblage. J. Phycol. *40*, 54–61.
10. Jeppesen, E., Søndergaard, M., Pedersen, A.R., Jürgens, K., Strzelczak, A., Lauridsen, T.L., and Johansson, L.S. (2007). Salinity induced regime shift in shallow brackish lagoons. Ecosystems *10*, 47–57.
11. Lin, Q., Xu, L., Liu, Z., Jeppesen, E., and Han, B.-P. (2017). Responses of trophic structure and zooplankton community to salinity and temperature in Tibetan Lakes: implication for the effect of climate. Water. Res. *124*, 618–629.

ACKNOWLEDGMENTS

The authors were supported by the TÜBITAK program, BIDEB 2232 (ID:118C250), Turkey and Erik Jeppesen also by Åge V. Jensen Nature Foundation, project "Østlige Vejler", Denmark.