

International Journal Research Publication Analysis

Page: 01-09

CLIMATE CHANGE-INDUCED ALTERATIONS IN AQUATIC BIODIVERSITY AND ECOLOGICAL INTERACTIONS IN FRESHWATER ECOSYSTEMS

***Dr. Kishan Pawar**

*Department of Zoology, Sardar Vallabhbhai Patel Government College, Kukshi, Madhya
Pradesh, India.*

Article Received: 23 August 2026

Article Revised: 11 September 2026

Published on: 01 October 2026

***Corresponding Author: Dr. Kishan Pawar**

Department of Zoology, Sardar Vallabhbhai Patel Government College, Kukshi, Madhya
Pradesh, India.

DOI: <https://doi-doi.org/101555/ijrpa.4097>

ABSTRACT

Freshwater ecosystems cover less than one percent of the Earth's surface, yet they hold a disproportionately large share of its known species. They are also among the most exposed to a changing climate. This review draws together published evidence on how rising temperature, altered hydrology, declining dissolved oxygen and shifting water chemistry are reshaping freshwater biodiversity and the interactions that hold aquatic communities together. Warming favours small-bodied, warm-tolerant and often non-native organisms, while cold-water specialists and species with narrow habitat needs are squeezed out. Changes in the timing of seasonal events are pulling apart predators from their prey and grazers from their food, and cyanobacterial blooms, oxygen loss and hydrological extremes are pushing some lakes and rivers towards abrupt, hard-to-reverse state changes. Climate change rarely acts alone; it amplifies eutrophication, flow regulation, invasion and over-exploitation. Evidence from tropical and monsoonal Asia remains thinner than that from temperate regions, which is a real limitation for a country such as India. The paper closes with management priorities: protecting thermal and hydrological refugia, restoring natural flow variability, controlling nutrient inputs, and building long-term monitoring at regional colleges and universities.

KEYWORDS: *Climate Change; Freshwater Biodiversity; Warming; Phenology; Food Webs; Cyanobacterial Blooms; Invasive Species; India.*

1. INTRODUCTION

Lakes, ponds, rivers, streams and wetlands together cover only about 0.8% of the planet's surface, but they support close to 6% of all described species, including about a third of vertebrates (Dudgeon et al., 2006; Reid et al., 2019). Beyond their biological richness, these systems supply drinking water, fish protein, irrigation and flood buffering to billions of people. When a freshwater ecosystem changes, both nature and society feel it.

Freshwater biodiversity was already in trouble before the effects of climate change became obvious. Habitat destruction, pollution, dams, overfishing and invasive species had driven steep declines, and the Living Planet data suggest that monitored freshwater vertebrate populations have fallen faster than those of marine or terrestrial groups (Tickner et al., 2020). Climate change now sits on top of these older pressures. Global mean air temperature has risen by roughly 1.1 °C above pre-industrial levels, and the IPCC has concluded with high confidence that inland water systems are already responding, with further change unavoidable (IPCC, 2022).

Why are freshwater habitats so sensitive? Two features stand out. First, most freshwater organisms are ectotherms, so their metabolism, growth and reproduction follow the temperature of the water around them. Second, freshwater habitats are islands: a pond or a headwater stream is separated from the next one by land, and a fish cannot simply walk uphill when the water warms (Woodward et al., 2010; Heino et al., 2009). Marine species can often shift along a continuous coastline or down into deeper water; many freshwater species have nowhere to go.

The aim of this paper is to synthesise what is known about (i) the main climate-driven changes in freshwater environments, (ii) their effects on the diversity and distribution of aquatic organisms, and (iii) their consequences for ecological interactions such as predation, competition and energy transfer through food webs. Attention is given to tropical and monsoonal regions, where the literature is thinner but the human dependence on freshwater is very high. This is a narrative review based on peer-reviewed literature; it does not present new field data.

2. Climate Drivers in Freshwater Systems

2.1 Warming of water bodies

Lakes are warming, and often faster than the air above them. A global analysis of 235 lakes found that summer surface waters warmed at an average of about 0.34 °C per decade between 1985 and 2009, with strong regional differences (O'Reilly et al., 2015). Warmer surface

water strengthens and lengthens thermal stratification. The result is a more stable, longer-lasting warm layer sitting on a colder one, with less vertical mixing between them. Rivers and streams show a similar pattern, although their response depends heavily on groundwater input, shading by riparian vegetation and the amount of water flowing through the channel.

2.2 Altered hydrology

Aquatic organisms are adapted not just to average flows but to the whole pattern of floods, droughts and seasonal timing, which Poff et al. (1997) called the natural flow regime. Climate change modifies precipitation, snowmelt, evaporation and the intensity of extreme events. In monsoon-dependent regions, a delayed or erratic monsoon, or a short burst of very heavy rain followed by long dry spells, can be more disruptive than a modest change in annual rainfall. Reduced flows shrink habitat, disconnect pools, concentrate pollutants and raise water temperature; extreme floods scour streambeds and wash out invertebrates and fish larvae.

2.3 Oxygen and chemistry

Warm water holds less dissolved oxygen, while warmer conditions simultaneously increase the oxygen demand of respiring organisms and of decomposing organic matter. Analysis of long-term records from hundreds of temperate lakes showed that dissolved oxygen fell by about 5.5% at the surface and 18.6% in deep water between 1980 and 2017, a decline much faster than that seen in the oceans (Jane et al., 2021). Longer stratification also means the bottom water is cut off from atmospheric oxygen for more of the year. In addition, warming can accelerate the release of phosphorus from sediments under low-oxygen conditions, feeding back into eutrophication (Moss et al., 2011).

3. Effects on Aquatic Biodiversity

3.1 Phytoplankton and cyanobacteria

At the base of the food web, warming and stratification shift the composition of phytoplankton. Diatoms, which prefer cooler and more turbulent water, tend to lose ground, while buoyant, heat-tolerant cyanobacteria gain an advantage because they can float to the light at the top of a calm water column and generally grow faster at higher temperatures (Paerl & Huisman, 2008; Winder & Sommer, 2012). Cyanobacterial blooms are not merely a nuisance. Many species produce toxins that harm fish, zooplankton, livestock and people, and dense blooms shade out submerged plants and consume oxygen when they die and decompose. Because bloom risk depends on both temperature and nutrient supply, warming and nutrient enrichment reinforce one another (Moss et al., 2011).

3.2 Zooplankton and invertebrates

Zooplankton and benthic invertebrates respond quickly because their generation times are short. Community studies repeatedly find a shift toward smaller-bodied taxa as temperature rises. Daufresne et al. (2009), synthesising field, experimental and palaeontological evidence, argued that a decrease in body size is a third universal response to warming, alongside range shifts and phenology change. For stream insects, warming tends to remove cold-water specialists such as many stoneflies and mayflies from lower reaches, while more tolerant generalists persist, producing communities that are richer in common species but poorer in specialised ones (Woodward et al., 2010).

3.3 Fishes

Fish have well-defined thermal windows for growth, reproduction and survival, and the physiological basis for these limits is increasingly well understood: when the oxygen supply to tissues can no longer keep up with rising demand, performance falls (Pörtner & Farrell, 2008). Ficke et al. (2007) reviewed how warming can affect fisheries by altering spawning time, growth rates, migration and recruitment. A global assessment of the climatic vulnerability of freshwater and marine fishes found that freshwater species, particularly those with small ranges, face high exposure and limited ability to disperse to more suitable habitat (Comte & Olden, 2017). Cold-water fishes such as trout and salmonids in temperate mountains are the classic examples, but warm-water species are not immune. In tropical rivers, many fishes already live close to their upper thermal limits, and their migrations and breeding are tightly tied to monsoon flood pulses (Dudgeon, 2000).

3.4 Macrophytes and riparian vegetation

Submerged macrophytes stabilise sediments, provide shelter for young fish and invertebrates, and compete with algae for nutrients. Warming, brownification (increasing dissolved organic carbon that darkens the water), and phytoplankton blooms can reduce the light reaching them. Loss of macrophytes removes structure from the system, and it is often one of the early steps in a shift from a clear-water to a turbid state (Scheffer et al., 2001). Along rivers, changes in flooding and drought stress riparian vegetation, with knock-on effects on shading, leaf litter input and bank stability.

3.5 Invasive and range-expanding species

Rahel and Olden (2008) pointed out that climate change can help non-native species in several ways: by removing the cold-temperature barrier that previously kept them out, by stressing native species, and by altering the disturbance regime. Warm-tolerant invaders can therefore expand into waters where they previously could not survive, and native species

already weakened by other stresses are less able to resist. Invasions and climate change thus need to be managed together rather than as separate problems.

4. Alterations in Ecological Interactions

4.1 Phenological mismatch

Species time their growth, emergence and breeding to seasonal cues, but different species read different cues. When they respond at different speeds, formerly synchronised interactions can drift apart. Thackeray et al. (2010) found that the pace of seasonal shifts differed among trophic levels in freshwater, marine and terrestrial environments, and a later analysis of more than 21,000 UK time series confirmed that phenological sensitivity varies across taxa and trophic levels, creating the potential for mismatch between consumers and their resources (Thackeray et al., 2016). In lakes, the classic spring bloom of diatoms followed by the peak of grazing zooplankton depends on the two events staying reasonably in step; if the bloom moves earlier and the zooplankton do not, young fish and invertebrates may hatch into a food supply that has already peaked (Winder & Sommer, 2012).

4.2 Food web structure and energy flow

Temperature affects metabolic rates, and metabolic rates set how much prey a predator needs. Warming also tends to shorten food chains and favour smaller organisms, which changes how efficiently energy passes from algae to fish. If large-bodied grazers such as *Daphnia* are replaced by smaller zooplankton, grazing pressure on phytoplankton usually weakens, making blooms more likely. If large predatory fish decline, the release of smaller fish can further suppress large zooplankton (Woodward et al., 2010). Understanding these cascading effects requires studying communities rather than single species, since the response of one species can be amplified or dampened by what its competitors, predators and prey are doing.

4.3 Competition, predation and regime shifts

Warming can alter the balance between competitors when species differ in their thermal optima. Where a warm-adapted species outgrows a cool-adapted one that shares its resources, the local community may lose the latter even if temperatures never approach lethal levels. Feedbacks can then lock in the new arrangement. The well-known theory of alternative stable states describes how lakes can flip from a clear, plant-dominated condition to a turbid, algae-dominated one, and how returning to the earlier state may require much stronger intervention than the one that triggered the change (Scheffer et al., 2001). Climate warming is expected to make such shifts more likely by favouring cyanobacteria, reducing oxygen and adding nutrients from sediments.

4.4 Multiple stressors

In real landscapes, climate change is never the only pressure acting on a water body. Dams, water abstraction, pollution, nutrient loading, land-use change and overfishing are all present, and they interact (Dudgeon et al., 2006; Vörösmarty et al., 2010). Some combinations are worse than the sum of their parts. A reservoir that already stratifies strongly, receives nutrients from agricultural runoff and has lost its native predators will respond very differently to a warm, dry summer than a well-connected, well-shaded stream. Table 1 summarises the main pathways described above.

Table 1. Main pathways linking climate drivers to biodiversity and interaction changes in freshwater ecosystems (synthesised from sources cited in the text).

Climate driver	Biological response	Ecological consequence
Warming	Smaller body size; loss of cold-water specialists; range shifts	Simplified communities; altered predator–prey balance
Longer stratification	Cyanobacterial dominance; oxygen depletion in deep water	Toxic blooms; fish and invertebrate stress; sediment nutrient release
Altered flow regime	Disrupted migration and spawning cues; habitat loss	Reduced recruitment; disconnected populations
Shifted seasonality	Different speeds of phenological change among taxa	Consumer–resource mismatch; lower juvenile survival
Warm-water conditions	Establishment and spread of non-native species	Competition with and predation on natives

5. The Tropical and Indian Context

Most of the mechanistic studies cited here come from temperate lakes and streams in Europe and North America, and the tropical literature is comparatively sparse (Dudgeon, 2000; Reid et al., 2019). This matters because tropical freshwaters differ in important ways: temperatures vary less through the year, so organisms may have narrower thermal tolerance margins; the annual cycle is governed by monsoon flooding rather than ice and snowmelt; and a large proportion of species remain undescribed. In central India, rivers such as the Narmada and its tributaries, together with numerous village tanks, reservoirs and seasonal wetlands, sustain fisheries and agriculture for large rural populations. Their seasonal pulses of flooding and drying make them particularly sensitive to a change in monsoon timing and intensity. Many of these systems are also already modified by dams, sand mining, abstraction and agricultural runoff, so the multiple-stressor problem discussed above is likely to be acute.

Long-term data are the missing ingredient. Without baseline records of species composition, water temperature and dissolved oxygen, it is very difficult to distinguish climate effects from local pollution or management changes. Government colleges and universities that sit close to lakes, rivers and reservoirs are well placed to contribute simple, repeatable monitoring, for example seasonal sampling of plankton, macroinvertebrates and water quality at fixed stations, and this would help fill an important regional gap.

6. Implications for Conservation and Management

No single action will protect freshwater biodiversity from climate change, but several measures are consistently recommended. Tickner et al. (2020) proposed an emergency recovery plan built on six priorities, including accelerating implementation of environmental flows, improving water quality, protecting and restoring critical habitats, managing exploitation of species and invasive species, and safeguarding connectivity of rivers. Many of these also build resilience to climate change. Specific priorities relevant to the issues in this paper are as follows.

First, protect and restore thermal and hydrological refugia. Groundwater-fed springs, deep pools, shaded reaches and connected floodplains can offer places where species survive heat waves and droughts, and they need to be identified and legally protected. Second, restore flow variability rather than only guaranteeing a minimum flow, following the logic of the natural flow regime (Poff et al., 1997). Third, cut nutrient inputs. Because warming raises the risk of cyanobacterial blooms, catchment measures such as buffer strips, improved wastewater treatment and better fertiliser management are among the most effective climate-adaptation tools available for lakes and reservoirs (Moss et al., 2011). Fourth, prevent the introduction and spread of non-native species, especially in waters likely to become thermally suitable for them (Rahel & Olden, 2008). Fifth, maintain connectivity so that species can move to cooler or wetter habitat when they need to (Strayer & Dudgeon, 2010). Finally, invest in long-term monitoring and in studies that measure interactions, not only species lists.

7. CONCLUSION

The evidence reviewed here points in one direction. Climate change is warming freshwaters, lowering their oxygen, changing when and how water arrives, and thereby reorganising both who lives in them and how they interact. Small-bodied, warm-tolerant and non-native species are gaining ground; cold-water and range-restricted species are losing it; and mismatches in timing weaken the links between producers, consumers and predators. Because these effects

add to older stresses, and because freshwater species have few escape routes, freshwater ecosystems are among the most vulnerable on Earth. Knowledge gaps remain, above all for tropical and monsoonal rivers and lakes. Closing them with locally collected long-term data, and pairing that knowledge with the protection of flows, refugia and water quality, is the most practical route to keeping these ecosystems, and the services they provide, intact.

REFERENCES

1. Comte, L., & Olden, J. D. (2017). Climatic vulnerability of the world's freshwater and marine fishes. *Nature Climate Change*, 7(10), 718–722.
2. Daufresne, M., Lengfellner, K., & Sommer, U. (2009). Global warming benefits the small in aquatic ecosystems. *Proceedings of the National Academy of Sciences*, 106(31), 12788–12793.
3. Dudgeon, D. (2000). The ecology of tropical Asian rivers and streams in relation to biodiversity conservation. *Annual Review of Ecology and Systematics*, 31, 239–263.
4. Dudgeon, D., Arthington, A. H., Gessner, M. O., et al. (2006). Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews*, 81(2), 163–182.
5. Ficke, A. D., Myrick, C. A., & Hansen, L. J. (2007). Potential impacts of global climate change on freshwater fisheries. *Reviews in Fish Biology and Fisheries*, 17(4), 581–613.
6. Heino, J., Virkkala, R., & Toivonen, H. (2009). Climate change and freshwater biodiversity: detected patterns, future trends and adaptations in northern regions. *Biological Reviews*, 84(1), 39–54.
7. IPCC. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.
8. Jane, S. F., Hansen, G. J. A., Kraemer, B. M., et al. (2021). Widespread deoxygenation of temperate lakes. *Nature*, 594, 66–70.
9. Moss, B., Kosten, S., Meerhoff, M., et al. (2011). Allied attack: climate change and eutrophication. *Inland Waters*, 1(2), 101–105.
10. O'Reilly, C. M., Sharma, S., Gray, D. K., et al. (2015). Rapid and highly variable warming of lake surface waters around the globe. *Geophysical Research Letters*, 42(24), 10773–10781.
11. Paerl, H. W., & Huisman, J. (2008). Blooms like it hot. *Science*, 320(5872), 57–58.

12. Poff, N. L., Allan, J. D., Bain, M. B., et al. (1997). The natural flow regime. *BioScience*, 47(11), 769–784.
13. Pörtner, H. O., & Farrell, A. P. (2008). Physiology and climate change. *Science*, 322(5902), 690–692.
14. Rahel, F. J., & Olden, J. D. (2008). Assessing the effects of climate change on aquatic invasive species. *Conservation Biology*, 22(3), 521–533.
15. Reid, A. J., Carlson, A. K., Creed, I. F., et al. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews*, 94(3), 849–873.
16. Scheffer, M., Carpenter, S., Foley, J. A., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, 413, 591–596.
17. Strayer, D. L., & Dudgeon, D. (2010). Freshwater biodiversity conservation: recent progress and future challenges. *Journal of the North American Benthological Society*, 29(1), 344–358.
18. Thackeray, S. J., Sparks, T. H., Frederiksen, M., et al. (2010). Trophic level asynchrony in rates of phenological change for marine, freshwater and terrestrial environments. *Global Change Biology*, 16(12), 3304–3313.
19. Thackeray, S. J., Henrys, P. A., Hemming, D., et al. (2016). Phenological sensitivity to climate across taxa and trophic levels. *Nature*, 535, 241–245.
20. Tickner, D., Opperman, J. J., Abell, R., et al. (2020). Bending the curve of global freshwater biodiversity loss: an emergency recovery plan. *BioScience*, 70(4), 330–342.
21. Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., et al. (2010). Global threats to human water security and river biodiversity. *Nature*, 467, 555–561.
22. Winder, M., & Sommer, U. (2012). Phytoplankton response to a changing climate. *Hydrobiologia*, 698, 5–16.
23. Woodward, G., Perkins, D. M., & Brown, L. E. (2010). Climate change and freshwater ecosystems: impacts across multiple levels of organization. *Philosophical Transactions of the Royal Society B*, 365(1549), 2093–2106.