

Climate Change Effects Upon Trophic Structure and Disease in River Fishes

Chandra Bhushan Tiwary

Received 27 October 2025, Accepted 29 March 2026, Published on 20 April 2026

ABSTRACT

Climate change significantly impacts the structure and dynamics of riverine fish populations, resulting in niche shifts that disrupt species distribution and alter spawning behaviors due to changes in water temperature and flow patterns. These alterations lead to reduced fitness and increased mortality rates as fish experience thermal stress at temperatures exceeding their tolerance thresholds. Additionally, compromised immune systems increase fish susceptibility to infections, while changes in disease transmission modes and water chemistry facilitate the proliferation and spread of parasites, ultimately threatening fish populations. Climate-induced modifications in river ecosystems endanger fish species diversity and ecosystem resilience. A major uncertainty in predicting the effects of climate change on ecosystems lies in

understanding how it alters intra-species interactions. The unforeseen consequences of climate change may arise from the varied responses of different species to environmental temperature changes. Climate change-induced thermal stratification has altered the feeding relationships between phytoplankton and zooplankton in riverine environments. An increasing temporal mismatch in rivers, characterized by a prolonged decline in phytoplankton and small herbivores, could significantly impact resource transfer to higher trophic levels. Changes in fish populations and fisheries can have substantial economic and social repercussions for local fishermen who depend on them. Conservation efforts must prioritize habitat restoration and align with climate change projections to ensure the long-term sustainability of fish populations.

Keywords Food web, Match-mismatch hypothesis, Plankton, Thermal stratification.

INTRODUCTION

Climate change is projected to significantly influence aquatic biogeochemical processes, including carbon dynamics, the structure and dynamics of aquatic food webs, biodiversity, and both primary and secondary production. The range, distribution, quality, and quantity of aquatic fauna will be affected. The production and utilization of carbon-based trace gases will be altered, and nutrient cycling and productivity will be enhanced through nutrient and carbon enrichment. Consequently, it is highly probable that the role of

Chandra Bhushan Tiwary

Assistant Professor, Department of Zoology, MS College Motihari
Bihar, India

Email: tiwary_cb@rediffmail.com

aquatic ecosystems as carbon sinks or sources will change. The magnitude, scope, and duration of these effects and responses will depend on the system and location. The biota, as well as the structure and function of tropical freshwater ecosystems, are likely to be substantially affected by climate change, both directly and indirectly. The alterations in essential physical and chemical parameters at the landscape scale are likely to affect aquatic community and ecosystem characteristics, including species richness, biodiversity, range, and distribution. These modifications will consequently transform associated food web structures and levels of primary and secondary production (Panikkar *et al.* 2022). They emphasized that climate change influence river flow regimes, aquatic ecology and fish diversity, thereby affecting fish catch and the sustainability of riverine fisheries.

Masoumi *et al.* (2024) investigated how climate change may alter the spatial distribution of endemic freshwater fishes in the semi-arid Arabian Peninsula using species distribution modeling. The study showed that rising temperature and changing precipitation patterns could significantly shift or reduce suitable habitats for several endemic species. The findings highlighted the vulnerability of narrowly distributed freshwater fishes and emphasize the need for climate-informed conservation strategies.

Allison *et al.* (2007) examined the vulnerability of inland fisheries and aquaculture systems to climate change and highlighted the importance of adaptive management strategies to sustain fish production and livelihoods. The authors emphasized that resilience can be strengthened through improved water resource management, diversification of aquaculture practices, and integration of climate considerations into fisheries governance. Their work provides a framework for enhancing the adaptive capacity of fisheries-dependent communities facing increasing climate variability.

The ecological impacts of climate change on freshwater ecosystems will be profoundly affected by the rate and extent of alterations in three key environmental factors: the timing, magnitude, and duration of the runoff regime; temperature; and modifications in water chemistry, encompassing nutrient concentrations, dissolved organic carbon, and particulate

organic matter loadings (Barange and Perry 2009). The recent study emphasized modified hydrological flow regimes and thermal stratification leading to changes in oxygen levels, nutrient availability, and overall water quality (Benateau *et al.* 2019, Dahal *et al.* 2025). These hydrological changes affect nutrient transport and the ecological functioning of freshwater systems. Richardson *et al.* (2025) proposed changes in precipitation and discharge patterns affect nutrient loading in rivers and groundwater. These alterations modify nitrogen and phosphorus concentrations, influencing primary productivity and water chemistry in freshwater ecosystems. The previous research also reported that increased atmospheric carbon dioxide and warming cause changes in water chemistry, metabolic stress, and altered growth and reproduction in aquatic organisms (Nimma *et al.* 2025). These changes cascade through freshwater food webs and ecological processes.

Climate change may induce significant disruptions to food webs if interacting species react differently to changing environmental conditions (Reid *et al.* 2024). They emphasize that climate change alters key environmental drivers in freshwater systems, including temperature regimes and hydrological system. Such changes influence water chemistry and habitat suitability, ultimately affecting aquatic biodiversity and ecosystem functioning. These disturbances may be particularly pronounced in seasonal environments characterized by brief intervals within the annual cycle conducive to growth and reproduction, especially in small river and stream ecosystems where trophic interactions are generally robust.

Climate change has caused a shift in synchrony among different fish species, resulting in an increasing discrepancy between phenology in overwintering regions and summer breeding grounds (Yvon-Durocher *et al.* 2010, Tunney *et al.* 2014, O’Gorman *et al.* 2012), leading to their arrival at a suboptimal time for peak food availability. These studies emphasized disturbances through shifting of predator-prey dynamics and energy traffics because climate changes cascade through trophic levels, affecting herbivores and predators and finally altering food-web structure. Miller-Rushing *et al.* (2010) highlighted that species dependent on environmental signals may experience

difficulties adjusting their life cycles to changing climatic conditions. This can lead to impairment between resource availability and organismal demand, influencing population dynamics and ecosystem processes. In aquatic ecosystems, a predator's fitness is contingent upon its temporal and spatial alignment with prey production, as posited by the match-mismatch hypothesis (Cushing 1974). Durant *et al.* (2007) discuss the hypothesis and stated that climate-driven shifts in environmental conditions can disrupt synchronization between predators and their prey, which may impair population growth and ecosystem productivity. In these ecosystems, seasonal variations in temperature and radiation result in a predictable sequence of physical processes, along with the growth of phytoplankton and zooplankton in pelagic ecosystems. Kisku *et al.* (2024) highlighted rich biodiversity in Indian freshwater ecosystem, however increasingly threatened by climate change and anthropogenic pressures. The climate changes affecting habitat quality, species distribution, and ecological processes in rivers and wetlands. The authors emphasize the urgent need for improved monitoring and conservation strategies to safeguard freshwater biodiversity under changing climatic conditions. The proliferation of phytoplankton in spring is predominantly influenced by temperature, turbulence and the intensity of thermal stratification within the water column.

Zooplankton often delays the physical dynamics of diatoms, which serve as the primary source of high-quality nutrition for herbivores during the spring season. Allan and Castillo (2007) describe that zooplankton and other drifting planktonic organisms form an important component of the food base in river ecosystems, particularly during productive seasons such as spring, where increased primary production supports higher zooplankton abundance serve as a major nutritional source for herbivorous and planktivorous aquatic organisms, including fish larvae and invertebrates. Factors such as nutrient limitation, cell sinking, and grazing contribute to the decline of the spring phytoplankton bloom, frequently resulting in a shift from small, single-celled diatoms to larger algae that provide lower nutritional quality for zooplankton. Researchers propose that the synchronization of reproductive timing with optimal food

availability significantly affects predator population growth (Fournier *et al.* 2024, Ratnarajah *et al.* 2023, Renaud *et al.* 2024). Climate change has disrupted the balance between primary herbivore and fish populations, potentially leading to trophic mismatches that reduce predator growth and survival rates, ultimately impacting population dynamics and ecosystem stability. Moreover, altered food web interactions may cascade through higher trophic levels, affecting fishery yields and biodiversity. Understanding these complex responses is essential for predicting and managing the impacts of climate change on freshwater ecosystems.

The primary threats to natural resources, including fisheries and aquatic resources, are pollution, invasive species, overexploitation, and habitat modification (Loh 2008). Freshwater ecosystems and organisms are believed to be vulnerable to climate change. Variations in precipitation serve as reliable indicators of rainfall, flooding, and drought. While flood events can enhance productivity by introducing nutrients into aquatic systems, they can also exacerbate siltation, displace communities, and damage infrastructure. Climate change is anticipated to have a significant impact on the biodiversity of freshwater ecosystems in tropical regions, potentially leading to a range of adaptive responses.

Factors influencing biodiversity (Kumar and Barua 2024) include the adaptability of reproductive and life-history strategies in some aquatic organisms, as well as the availability and variability of local resources, disturbance regimes, local species, and their dispersal opportunities or barriers. There is increasing evidence that climate change will accelerate species loss on both global and regional scales (Heins *et al.* 2023). Furthermore, the impact of biodiversity shifts on ecosystem structure and function is likely more dependent on specific levels of functional diversity than on the total number of species. Additionally, the number and diversity of functional units within a community significantly affect an ecosystem's resilience and susceptibility to change (Harwell *et al.* 2021). Another significant effect of climate change is expected to be changes in species' geographic distribution, impacting biodiversity locally and regionally. As the effects of climate change become more apparent, such as shifts in mean temperature

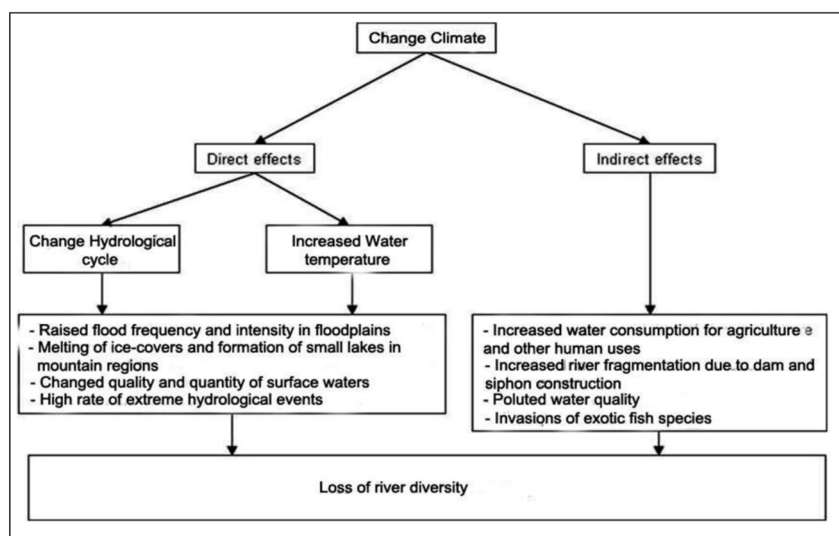


Fig. 1. Climate change impacts on loss of river diversity.

isotherms or degree-day boundaries towards the north, it is anticipated that more ecologically mobile species will expand their geographic distributions (Hecky 2006 a,b). The magnitude, scope, and duration of the impact will depend on the system and location, and it will be challenging to distinguish from other environmental stressors (Fig. 1).

Impacts on aquatic productivity processes

The anticipated effects of climate warming on riverine processes encompass alterations in nutrient dynam-

ics and mobilization, which involve modifications in fish community structure due to environmental constraints. These changes predominantly result in a shift towards smaller-bodied individuals (Jeppesen *et al.* 2009, Ndebele-Murisa *et al.* 2011). Alterations in phytoplankton composition, primary production, invertebrate diversity, and food web dynamics collectively influence aquatic productivity processes (Fig. 2).

Climate factors play a critical role in shaping the life history and productivity of fish, particularly

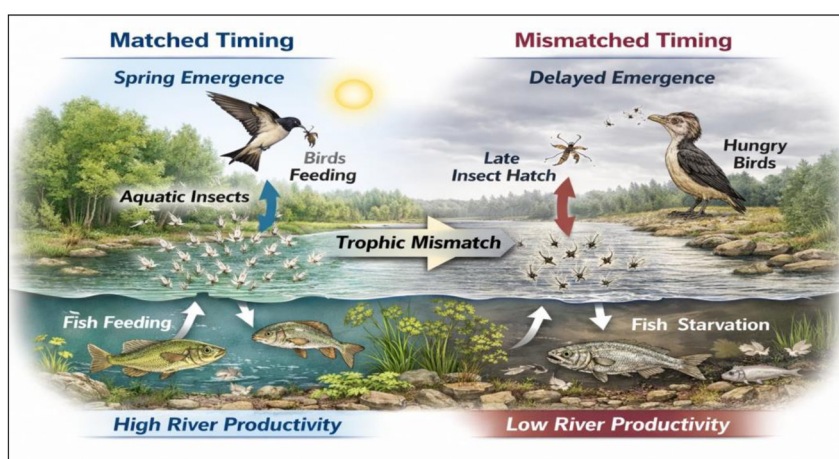


Fig. 2. Trophic interactions and river productivity (Designed @Bio Render) Impacts on the life history and fish yield .

those species that have evolved to thrive under specific hydrological conditions, such as those present in riverine ecosystems. These factors, with a particular emphasis on seasonal variations, are essential to the biological cycles of these fish. As climate change progresses, it is anticipated that there will be shifts in the distribution of plankton, invertebrates, and fish, as well as modifications in the habitats of freshwater species. The migratory patterns of river fish species, along with their spawning activities and the transport of reproductive materials, are likely to be influenced by changes in the timing, intensity, and duration of flood events.

Climate change is anticipated to alter flood timing, potentially leading to the premature emergence of plankton, invertebrates, and fish. A significant response to global warming involves modifications in fish species phenology, which may include the advancement of spring and the delay of cyclical life events (Durant *et al.* 2007). These changes often disrupt the phenology of organisms and their food sources, with impacts that are frequently uneven across populations within trophic levels. Temperature significantly influences parasitic infection in fishes, as it is a major driving force in numerous ecological processes affecting parasitic life cycles. Global average temperatures are anticipated to rise, thereby reducing the productivity of capture fisheries and

aquaculture systems by increasing fish susceptibility to parasite attacks and diseases (Jeyachandran *et al.* 2025). Fish immune systems are compromised by stressors such as high temperatures and crowding, rendering them more vulnerable to disease induced by climate change (Fig. 3).

Climate change may alter the dominance of specific species and has the potential to trigger unexpected and abrupt responses as ecosystems transition between states. The relationship between temperature and life history parameters is significant, with regime shifts in fish stocks being influenced by overfishing, pollution, and climate change. Parmesan (2006) observed that cool-water fish are more susceptible to slight temperature variations compared to warm-water species. Roff (2002) demonstrated that fish species at lower latitudes are generally small in size, mature earlier, exhibit faster growth rates, have shorter life spans, and allocate less energy to reproduction compared to populations at higher latitudes. They explained that environmental temperature strongly influences life-history traits in fishes. Species in tropical or lower-latitude waters are generally reflecting evolutionary adaptations to warmer environments and higher metabolic demands.

Elevated temperatures and reduced oxygen levels are anticipated to facilitate the proliferation of gill



Fig. 3. Climatic change affected Fish disease (Designed @Bio Render).

parasites, leading to respiratory complications and potentially resulting in mortality among infected fish (LyMBERY *et al.* 2020). Furthermore, climate change is projected to exert an indirect influence on aquatic parasites and their hosts through alterations in water levels, pollution, and ultraviolet radiation (MARCOTGLIESE 2025).

Conclusions and recommendations

Climate variability and change progressively impact natural resources, including fisheries and livelihoods, posing significant environmental and socio-economic challenges that are increasingly acknowledged by international, national, and local policymakers and institutions. The effective mitigation of climate change impacts on livelihoods in relation to existing capacity, knowledge, policies, regulations and awareness which remains insufficient and necessitates further implementation to bridge the gap for sustainable resource management. There is need for the formulation of policies to address climate change at all levels and several legal instructions are available to confront these challenges. Nonetheless, the implementation of these policies continues to present a substantial challenge.

REFERENCES

- Allan, J. D., & Castillo, M. M. (2007). Stream ecology: Structure and function of running waters (2nd ed.). Dordrecht: Springer.
- Allison, E. H., Andrews, N. L., & Oliver, J. (2007). Enhancing the resilience of inland fisheries and aquaculture systems to climate change. *Journal of Semi-Arid Tropical Agricultural Research*, 4(1), 1-23.
- Barange, M., & Perry, R. I. (2009). Physical and ecological impacts of climate change relevant to marine and inland capture fisheries and aquaculture (In: K. Cochrane, C De Young, D. Suto, & T. Bahri, Edited Climate change implications for fisheries and aquaculture: Overview of current scientific knowledge). FAO Fisheries and Aquaculture Technical Paper No. 30, Rome FAO, page 7-106.
- Benateau, S., Gaudard, A., Stamm, C., & Altermatt, F. (2019). Climate change and freshwater ecosystems: impacts on water quality and ecological status. Federal Office for the Environment (FOEN) & Eawag. <https://www.altermattlab.ch>
- Cushing D. H. (1974). The natural regulation of fish populations. In F. R. Harden Jones (Ed.), Sea fisheries research (pp. 399-412). London: Elek Science.
- Dahal, D., Bhattarai, N., Silwal, A., Shreshtha, S., Shreshtha, B., Poudel, B., & Kalra, A. (2025). A review on climate change impacts on freshwater systems and ecosystem resilience. *Water*, 18(21),3052. <http://doi.org/10.3390/w17213052>
- Durant, J. M., Hjermand, D. Ø., Ottersen, G., & Stenseth, N. C. (2007). Climate and the match or mismatch between predator requirements and resource availability. *Climate Research*, 33, 271-283. <https://doi.org/10.3354/cr033271>
- Fournier, R. J., Marino, T. C., Carlson, S. M., & Ruhí, A. (2024). Long-term data reveal widespread phenological change across trophic levels in aquatic ecosystems. *Ecology Letters*. <http://doi.org/10.1011.ele.14441>
- Harwell, M. C., Gentile, J. H., & Myers, V. (2021). Climate change impacts on coastal and freshwater ecosystems: Ecological responses and management implications. *Ecological Indicators*, 121, 107102. <http://doi.org/10.1016/colind.2020.107102>
- Hecky, R. E., Mugidde, R., Ramlal, P. S., Talbot, M. R., & Kling, G.W. (2006a). Freshwater ecosystems and climate change: Nutrient dynamics and ecosystem responses. *Limnology and Oceanography*, 51(1), 1-13. <http://doi.org/10.4319/lo.2006.51.1.0001>
- Hecky, R. E., Bootsma, H. A., & Odada, E. (2006b). African lake management initiatives: the global connection. Lakes and reservoirs: *Research and management*, 11, 203-213.
- Heins, D. C, Baker, J. A., & Birge, W. J. (2023). Climate variability and adaptive responses in freshwater fish populations. *Freshwater Biology*, 68 (9), 1625-1638.
- Jeppesen, E., Kronvang, B., Meerhoff, M., Søndergaard, M., Hansen, K. M., Andersen, H. E., Lauridsen, T. L., Liboriusen, L., Beklioglu, M., Özen, A. & Olesen, J. E. (2009). Climate Change Effects on Runoff, Catchment Phosphorus Loading and Lake Ecological State, and Potential Adaptations. *Journal of Environmental Quality*, 38: 1930-1941. <https://doi.org/10.2134/jeq2008.0113>
- Jeyachandran, S., Kumar, P., Singh, R., & Sharma, A. (2025). Climate change impacts on freshwater biodiversity and fisheries resources. Aquatic Conservation: Marine and Freshwater Ecosystems. <http://doi.org/10.1002/aqc.xxxx>
- Kiskuu, S., Kumar, A., & Singh, R. (2024). Freshwater biodiversity and climate-driven threats in India: Status, challenges and conservation priorities. *Environmental Conservation Journal*, 25 (2): 45-58.
- Kumar, A., & Barua, P. (2024). Climate variability, hydrological change and implications for freshwater ecosystems in the Ganga Basin. *Environmental Monitoring and Assessment*, 196, 245
- Loh, J. (2008). 2010 and Beyond: Rising to the Biodiversity Challenge. World Wide Fund for Nature, Switzerland.
- LyMBERY, A. J., Morine, M., Kanani, H. G., Beatty, S. J., & Morgan, D. L (2020). Co-invasive parasites: Emerging threats to aquatic ecosystems under climate change. *International Journal for Parasitology: Parasites and Wildlife*, 12, 1-10. <https://doi.org/10.1016/ijppaw.2020.02.002>
- Marcotgliese, D. J. (2025). Climate change and parasitism in aquatic ecosystems. In: N. J. Smit & B. Sures (eds.), Aquatic parasitology: Ecological and environmental concepts and implications of marine and freshwater parasites (pp 547-593). Springer, Cham. <https://doi.org/10.1007/978-3-031-83903-022>
- Masoumi, A. H., Esmaili, H. R., Khosravi, R., Gholamhosseini,

- A., Korkmaz, M., & Jeppesen, E. (2024). Species on the move: Impacts of climate change on the spatial range of endemic fishes of the eco-sensitive semi-arid area of the Arabian Peninsula. *Science of the Total Environment*, 947, 174095. <https://doi.org/10.1016/j.scitotenv.2024.174095>
- Miller-Rushing, A. J., Høye, T. T., Inouye, D. W., & Post, E. (2010). The effects of phenological mismatches on demography. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365, 3177–3186. <https://doi.org/10.1098/rstb.2010.0148>
- Ndebele-Murisa, M. R., Mashonjowa, E., & Hill, T. (2011). The implications of a changing climate on the Kapenta fish stocks of Lake Kariba, Zimbabwe. *Transactions of the Royal Society of South Africa* 66(2), 105–119. <https://doi.org/10.1080/0035919x.2011.600352>
- Nimma, D., Devi, O. R., Laishram, B., Ramesh, J. V. N., Boddupalli, S., Ayyasamy, R., Tirth, V., & Arabil, A. (2025). Implications of climate change on freshwater ecosystems and their biodiversity. *Desalination and Water Treatment*, 321, 100889. <https://doi.org/10.1016/j.dwt.2024.100889>
- O’Gorman, E. J., Benstead, J. P., Cross, W. F., Friberg, N., Hood, J. M., Johnson, P. W., Sigurdsson, B. D., & Woodward, G. (2012). Climate change and geothermal ecosystems: Natural laboratories for studying ecological responses to warming. *Global Change Biology*, 18(12), 364–372. <https://doi.org/10.1111/j.1365-2486.2012.02786.x>
- Panikkar, P., Sarkar, U. K., & Das, B. K. (2022). Exploring climate change trends in major river basins and its impact on the riverine ecology, fish catch and fisheries of the Peninsular region of India: Issues and a brief overview. *Journal of Water and Climate Change*, 13(7), 2690–2699. <https://doi.org/10.2166/wcc.2022.054>
- Parmesan, C. (2006). Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology, Evolution, and Systematics*, 37, 637–669. <https://doi.org/10.1146/annurev.ecolsys.37.091305.110100>
- Ratnarajah, L., Abu-Alhaja, R., Atkinson, A., Batten, S., Bax, N. J., Bernard, K. S., Canonico, G., Cornils, A., Everett, J. D., Grigoratou, M., Ahmad Ishak, N. H., Johns, D., Lombard, F., Muxagata, E., Ostle, C., Pitois, S., Richardson, A. J., Schmidt, K., Stemmann, L., & Yebra, L. (2023). Monitoring and modelling marine zooplankton in a changing climate. *Nature Communications*, 14, 564. <https://doi.org/10.1038/s41467-023-36241-5>
- Reid, A. J., Carlson, A. K., Creed, I. F., Eliason, E. J., Gell, P. A., Johnson, P. T. J., Kidd, K. A., MacCormack, T. J., Olden, J. D., Ormerod, S. J., Smol, J. P., Taylor, W. W., Tockner, K., Vermaire, J. C., Dudgeon, D., & Cooke, S. J. (2019). Emerging threats and persistent conservation challenges for fresh water biodiversity. *Biological Reviews*, 94(3), 849–873. <https://doi.org/10.1111/brv.12480>
- Renaud, P. E., Daase, M., Leu, E., Geoffroy, M., Basedow, S., Inall, M., Campbell, K., Trudnowska, E., Sandbank, E., Cnossen, F., Dunn, M., Camus, L., Porter, M., Aune, M., & Gradinger, R. (2024). Extreme mismatch between phytoplankton and grazers during Arctic spring blooms and consequences for the pelagic food-web. *Progress in Oceanography*, 229, 103365. <https://doi.org/10.1016/j.pocean.2024.103365>
- Richardson, C. M., Peucker-Ehrenbrink, B., Wyatt, S., Bourbonnais, A., Hatje, V., Frey, C., Sanders, T., Varela, D. E., & Paytan, A. (2025). Effects of climate change on river and groundwater nutrient inputs to the coastal ocean. *Communications Earth & Environment*, 6(1). <https://doi.org/10.1038/s43247-025-02594-6>
- Roff, D. A. I. a. (2002). Life history evolution. Sunderland, Massachusetts Sinauer Associates.
- Tunney, T. D., McCann, K. S., Lester, N. P., & Shuter, B. J. (2014). Effects of differential habitat warming on complex communities: Proceedings of the National Academy of Sciences, (PNAS), 111(22), 8077–8082. <https://doi.org/10.1073/pnas.1319618111>
- Yvon-Durocher, G., Jones, J. I., Trimmer, M., Woodward, G., & Montoya, J. M. (2010). Warming alters the metabolic balance of ecosystems. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365(1549), 2117–2126. <https://doi.org/10.1098/rstb.2010.0038>