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Editorial

Effects of Climate Change on Freshwater Biodiversity

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Abstract: This Special Issue intended to collect articles focusing on the assessment of the possible effects of climate changes on aquatic species inhabiting inland waters all over the world, including the possible synergistic effects in combination with other anthropogenic stressors. A total of six original articles were published that report on investigations of different freshwater ecosystems across the world, including the mountain streams of the Western United States and Northwest Italy, river basins of Northwest China and Central Italy, a larger lowland river in north Italy, and a high-elevation temporary pond in Central Italy. In most of these papers, special attention was devoted to the repercussions of the climate change and its effects on three important components of the biotic community: the fish, benthic macroinvertebrates, and zooplankton. According to the aims of this Special Issue, three of the articles offer new insight into the synergistic effects of global warming together with other anthropogenic stressors, including water exploitation and alien species invasions. In light of the studies' aim to highlight the effects of climate change, three papers provided analyses of environmental data collected through long-term monitoring. The scientific findings provided by these studies could help to create sound management strategies for freshwater biodiversity conservation.

Keywords: climate change; freshwater ecosystems; fish assemblages; benthic communities; water exploitation; aquatic invasions; biodiversity conservation; anthropogenic stressors

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1. Introduction

Global warming is expected to accentuate biodiversity loss in inland waters, where climate-induced effects will lead to the worsening of the ecological conditions for aquatic biota [1,2]. In these environments, climate change is often associated with increasing water temperatures and decreasing habitat availability, which strongly affect the survival of many species [3]. Furthermore, in many cases, the negative effects of climate change are supplemented by other anthropogenic stressors, such as alien species invasions, water pollution, and habitat fragmentation [4,5]. All these effects may lead to a marked decrease in biodiversity, since inland waters represent isolated environments, from which the inhabiting species rarely have the opportunity to depart so as to colonize new habitats in cases of adverse environmental conditions. Despite high interests in the conservation of many freshwater species, information on climate-related changes in their distribution, population status, and life history strategies are currently limited. With the aim of filling this gap in research, this purpose of this Special Issue was to collect articles focusing on the assessment of the possible effects of climate change on aquatic species inhabiting inland waters all over the world, including the possible synergistic effects in combination with other anthropogenic stressors. This goal was achieved through the publication of six original articles (Table 1). The investigated areas included different countries: Western United States, Northern and Central Italy, and Northwest China. Most of the ecosystems analysed, such as the high-elevation streams and ephemeral waters, can be considered as sentinels of climate change, given their quick responses to decreasing precipitation levels and increasing air temperatures. The scientific findings provided by these studies, in addition to collectively representing a significant contribution to freshwater science, could help to create sound management strategies for freshwater biodiversity conservation.

Table 1. Summary of the six papers published in this Special Issue "Effects of Climate Change on Freshwater Biodiversity" in the journal *Water* (https://www.mdpi.com/journal/water/special_issues/Climate_Freshwater, accessed on **2 December 2022**).

Keywords	Authors	Title	Study Area
drought; stream intermittency; climate change; northern leatherside chub	Larsen, N.E.; Simkins, R.M.; Wesner, J.S.; Tuckfield, R.C.; Belk, M.C.	Species-Specific Abundance Response of Montane Stream Fishes to Drought-Induced Variation in Streamflow	Western United States—mountain streams
fairy shrimp; steno-endemic species; high-elevation pond; ephemeral waters; climate changes; biodiversity conservation	Carosi, A.; Barelli, M.G.; Ambrosi, A.; Rossetti, A.; Morandi, F.; Lorenzoni, F.; Tagliaferri, G.; Lorenzoni, M.	Population Status and Ecology of the Steno-Endemic Fairy Shrimp *Chirocephalus sibyllae* Cottarelli and Mura, 1975 Inhabiting a Mountain Temporary Pond (Central Italy)	Central Italy—high-elevation temporary pond
leaf bags; global climate change; dry rivers; benthic community; CPOM decomposition	Gruppuso, L.; Doretto, A.; Falasco, E.; Fenoglio, S.; Freppaz, M.; Benbow, M.E.; Bona, F.	Flow Intermittency Affects Leaf Decomposition and Benthic Consumer Communities of Alpine Streams: A Case Study along the Po River.	Northwest Italy—mountain streams
water management; water diversion; benthic communities; hydrological parameters; low flows; global warming; long-term monitoring; lowland river	Salmaso, F.; Crosa, G.; Espa, P.; Quadroni, S.	Climate Change and Water Exploitation as Co-Impact Sources on River Benthic Macroinvertebrates	Northwest Italy—larger lowland river
non-native fish species; global warming; fish range shifts; dispersal ability; river connectivity; biodiversity conservation	Carosi, A.; Ghetti, L.; Lorenzoni, M.	The Role of Climate Changes in the Spread of Freshwater Fishes: Implications for Alien Cool and Warm-Water Species in a Mediterranean Basin	Central Italy—Mediterranean river basin
Qilian Mountains; stable isotope; evaporation loss; lc-excess; Craig–Gordon model	Yong, L.; Zhu, G.; Wan, Q.; Xu, Y.; Zhang, Z.; Sun, Z.; Ma, H.; Sang, L.; Liu, Y.; Guo, H.; Zhang, Y.	The Soil Water Evaporation Process from Mountains Based on the Stable Isotope Composition in a Headwater Basin and Northwest China	Northwest China—Headwater basin

2. Summary of This Special Issue

Each of the papers published in this Special Issue is briefly summarized below.

Larsen et al. [6] examined the abundance response of fish in high-elevation streams to the shift from a perennial to intermittent flow using fish data collected over a five-year period and historical stream flow data (60 years) derived from the mountainous area of the Western United States. Their findings suggest that drought-induced variation in the streamflow can cause a significant declines in the abundance of some species, with special reference to the native northern leatherside chub, *Lepidomeda copei*, which is already threatened by habitat degradation and alien species invasions. The authors concluded their study by remarking that, in the context of declining winter precipitation and snowpack levels, only the fish species exhibiting adaptation mechanisms in terms of high recruitment levels and the ability for recolonization after drought will be able to survive and to face flow variations driven by climate change, while other species, such as *L. copei*, could experience local extinction phenomena in the near future.

Carosi et al. [7] evaluated the conservation status of *Chirocephalus sibyllae*, a fairy shrimp endemic to a temporary pond within a protected area of the Apennine chain (Central Italy), in the context of increasing water scarcity. With the aim of updating and integrating the little information on the *C. sibyllae* population and its habitat, the authors processed environmental and biological data collected over a three-year period and a

series of air temperature data spanning twenty years, provided by a meteorological station. Their results contributed to efforts to increase existing knowledge on the life history traits, ecological preferences, and population abundance of the species and to highlight the vulnerability of ephemeral waters to climate change effects. They concluded that climate change appears to represent the main threat to the biocoenoses inhabiting temporary ponds, considering that the progressive increase in air temperatures and the decrease in winter snowfall will likely lead to increasingly shorter filling phases of these biotopes.

Gruppuso et al. [8] provided new insights into the increasing climate-induced phenomena of riverbed drying in mountain streams and their correlated effects on leaf litter (in terms of decomposition rates and the C:N ratio) and the associated macroinvertebrate communities. Using leaf litter decomposition as a tool to assess river ecosystem quality and functional stream integrity, the authors compared this process in perennial and intermittent mountain stream reaches of the Po river (Northwest Italy) and evaluated the benthic community metrics (taxa richness, feeding group abundances). Their results showed faster rate of a leaf litter decomposition in the perennial reaches, where the associated benthic communities were richer and more stable than the intermittent ones, supporting the hypothesis that many rheophilic macroinvertebrate taxa lack the capacity to adapt to drought periods. They concluded that the variations in the hydrology of mountain streams caused by climate change effects, coupled with local water abstractions, could significantly impact on the functional processes and biodiversity of benthic communities.

Another clear example of climate-related impacts on macrobenthic communities was addressed in the research presented by Salmaso et al. [9], who study focused on the assessment of climate change and water exploitation effects in a large lowland river (Northwest Italy). The study aimed to assess the long-term modifications caused by low flow events, intensified by water diversions, and their relative effects on benthic macroinvertebrates. The authors processed a 77-year dataset on the daily discharge and analyzed data on the macroinvertebrates collected within a 6-year period in three stream reaches located downstream of the water withdrawals, representing different **conditions** of hydrological impairment. They provided evidence for the increasing duration of low flow periods and reduced summer flows over time, highlighting the synergistic effects of climate changes and water withdrawals on the zoobenthic community in terms of its reduced diversity and richness and the predominance of tolerant taxa with short life cycles. They concluded by highlighting the need for more sustainable water resource management.

Keeping within the framework of the synergistic effects of climate change and other anthropogenic stressors, the research published by Carosi et al. [10] provided an analysis of the potential climate change effects on the spread of four invasive alien fishes in the hydrographic network of a Mediterranean river basin (Central Italy). With the aim of testing temporal changes in the fish habitat requirements over time, the authors processed long-term environmental and biological data series collected within a 20-year period. In the context of proven rising temperatures and decreasing precipitation, their results showed that the combined effects of water warming and decreasing flow rates may encourage colonization by invasive cool and warm-water fish species, which are favored by the rising temperatures that provide new, suitable habitats in which to live and reproduce. They concluded that in multi-stressed freshwater ecosystems, effective conservation policy and management measures to be taken to counter the introduction and expansion of alien fish species, which should be accompanied by interventions aimed towards mitigating the climate change effects.

Assuming that soil water represents a link between different water bodies and, thus, is of great significance for understanding hydrological processes on the regional scale, Yong et al. [11] presented an analysis of soil water evaporation from mountains in a headwater basin in Northwest China. They used soil water isotope techniques to evaluate the evaporating fractionation of the soil water. Their results revealed that the change in evaporation loss drives the dynamics of the enrichment of the soil water isotopes in arid and semi-arid alpine regions. Moreover, they found that soil water evaporation is restricted

by the soil salt content and surface vegetation, with important implications for ecological restoration programs and animal husbandry policy planning.

3. Concluding Remarks

Most of the articles included in this Special Issue concern the study of aquatic environments located at high altitudes, confirming the fact that these ecosystems represent sentinel environments with respect to climate change and require special attention from a conservation point of view. In fact, mountain rivers and high-elevation temporary ponds are quickly affected by the effects of global warming in terms of increasing air temperature and decreasing winter snowfall, which influence the stream flow and, therefore, the quantity of habitats available for the biocoenoses.

Another aspect that emerges from the analysis of the published papers concerns the analysis of the synergistic effects of climate change and other anthropogenic stressors, such as water withdrawals and biological invasions. These contributions are of particular interest, considering that the detrimental effects of alien fish invasions, water abstractions, and climate change on freshwater ecosystems have been the subject of several investigations but, often, these aspects are treated independently, and their interactions are overlooked.

Considering the types of datasets used in the various articles, we can observe that, in order to achieve significant results in terms of quantifying the effects of climate change, it is essential to have access to historical data series derived from long-term monitoring. Therefore, it is important to increase environmental monitoring so as to collect useful information that can help us to prepare management strategies and develop predictive models that can be used to understand how the environmental situation may evolve in the future.

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