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Abstract

This report is a literature review focusing on 'adaptive management' and 'restoration efforts' in relation to climate change in rivers. The last ten years of publications in ISI web of science have been accessed and papers including the keywords (stream* or river*) and (climate change* or global change*) and (temperature*) and (adaptive management* or restored or restoration*) has been evaluated for possible inclusion in the review report. In total 41 scientific publications were found using this search strategy, and 20 of these were deemed most suited and included in the review. The review summarises which adaptive management and restoration efforts are currently being used according to the scientific literature and what effects climate change have and will have in the future on the management and restoration of stream and river ecosystems.

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Introduction

This report is a literature review focusing on "adaptive management" and "restoration efforts" in relation to climate change in rivers. The last ten years of publications in ISI web of science have been accessed and papers including the keywords (stream* or river*) and (climate change* or global change*) and (temperature*) and (adaptive management* or restored or restoration*) has been evaluated for possible inclusion in the review report. In total 41 scientific publications were found using this search strategy, and 20 of these were deemed most suited and included in the review. The review summarises which adaptive management and restoration efforts that are currently being used according to the scientific literature and what effects climate change have and will have in the future on the management and restoration on stream and river ecosystems.

On a global scale, biodiversity is decreasing much faster than the natural background rate (Heywood 1995, Jenkins 2003), and freshwater habitats and organisms are among the most threatened ecosystems (Ricciardi and Rasmussen 1999, Revenga, Campbell et al. 2005, Strayer and Dudgeon 2010). Freshwater habitats cover less than 1% of the Earth's surface area but contain about 10% of all known species (Strayer and Dudgeon 2010). There has been substantial global losses of freshwater biodiversity and it is estimated that between 10,000 and 20,000 freshwater species have either become extinct or are seriously threatened, being much higher than in all other ecosystems (Sala, Chapin et al. 2000). Humans are now the dominant drivers of environmental change in the global water cycle and in freshwater aquatic ecosystems, reflecting the fact that we have now reached the Anthropocene (Meybeck 2003, Steffen, Crutzen et al. 2007, Dudgeon 2010). Global climate change is also predicted to severely affect streams, rivers and lakes, especially in combination with environmental stressors such as land use changes (e.g., Meyer, Sale et al. 1999, Sala, Chapin et al. 2000, Moss, Hering et al. 2009).

Global climate change will have a number of effects on freshwater ecosystems through increases in CO_2 levels, increases in air and water temperatures as well as changes in precipitation and runoff regimes (Poff, Brinson et al. 2002). Globally, surface temperature averages have increased by 0.78°C when comparing the average of 1850-1900 with the 2003-2012 period, and according to IPCC (2013) “it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century”. All future scenarios for year 2100 (IPCC 2013) predict that the global average temperature will be 5 to 12 standard deviations above the mean Holocene temperature (Marcott, Shakun et al. 2013). At high northern latitudes (north of 45° N), both summer extreme temperatures and decadal averages measured in the last ten years were warmer than those reported since 1400 (Tingley and Huybers 2013). This is in agreement with the notion that glacial systems at high latitudes are likely to be disproportionally affected by the global climate change (Perkins, Reiss et al. 2010).

Freshwater ecosystems are already undergoing changes in temperature and hydrological regime with effects on biotic communities in lakes (e.g., Smol, Wolfe et al. 2005, Ruhland, Paterson et al. 2008, Williamson, Saros et al. 2009), streams and rivers (e.g., Brown, Hannah et al. 2007, Finn, Rasanen et al. 2010, Muhlfeld, Giersch et al. 2011). Many studies have predicted future changes in community composition in lakes and streams in response to climate change, including for fish (Buisson, Thuiller et al. 2008, Britton, Cucherousset et al. 2010), phytoplankton (Elliott, Thackeray et al. 2005, Jeppesen, Kronvang et al. 2009) and benthic macroinvertebrates (Bonada, Doledec et al. 2007, Rosset and Oertli 2011). Benthic macroinvertebrates such as aquatic insects are affected by alterations in temperature and hydrological regime during their entire life cycle (e.g., Vannote and Sweeney 1980, Durance and Ormerod 2007, Haidekker and Hering 2008) in that temperature affects growth, metabolism, reproduction, emergence and distribution.

Methods

The review is based on an ISI Web of Science (SCI expanded) search using the key words; stream* or river*, climate change* or global change*, temperature*, adaptive management, or restored* or restoration*. This was done for the period 2000 to 2013 in the two publication types "articles" and "reviews" (Table 1). When adding all search terms together a final list of 118 publications were found. The abstract of these publications were scanned and a final list of 41 publications deemed to be relevant to evaluate processes and effects of temperature regimes in rivers and threats due to climate change on current adaptive management and restoration efforts. In the final report 20 of these paper were deemed as the best suited to be included in this review.

Table 1. Results of search query used in the report.

Query	# Hits
Stream* or river*	243595
Climate change* or global change*	148048
Temperature*	1417210
Adaptive management* or restored* or restoration*	118830
All Search terms	**118**
Final relevant papers	41

Interestingly it was clear that studies including climate change and adaptive management and restoration is a research area that has only become relevant in the last years, as there was only one publication published prior to 2006 (Middelkoop, Daamen et al. 2001), and only eight other papers published pre 2010 (Tung, Lee et al. 2006, Whitledge, Rabeni et al. 2006, Battin, Wiley et al. 2007, Viney, Bates et al. 2007, Mainstone, Dils et al. 2008, Acuna and Tockner 2009, Honea, Jorgensen et al. 2009, Palmer, Lettenmaier et al. 2009). While 32 papers (78%) were published between 2010 and 2013 (Figure 1), with 12 papers published in 2013.

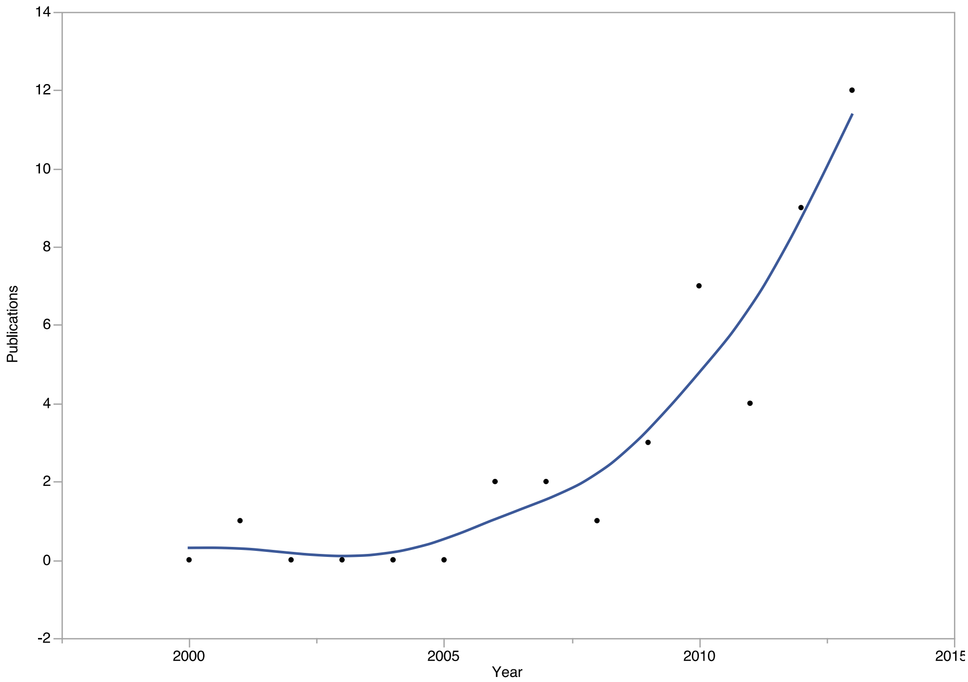

Figure 1. Number of publications each year that included all the search terms used in this study and were deemed to be relevant to study temperature effects on adaptive management and restoration on stream and river ecosystems.

When analysing in what types of journals these 41 papers were published it was quite even between journal with a general focus (24 papers) versus journals with a specific freshwater or water focus (17) papers. Thirteen of the papers were published in journals with an environmental management and/or restoration focus, whereas eight papers were published in journals with a climate change focus, where most papers were published in the journal Climate Change.

Environmental and biological change caused by changing climate

Changes in water temperature

The Formosan land locked salmon (*Oncorhynchus masou formosanus*) only exists in the upper reaches of the TaChia River in Taiwan (Tung, Lee et al. 2006). The habitats of the salmon have been subjected to a large number of restoration efforts, but current projected climate change and thus water temperature increases in the catchment is expected to seriously threaten the habitats of this species. The species has a 12°C upper threshold for spawning and it has been found that the 12°C isotherm in the river has moved c. 1.5 km upstream in the river system. At the same time the Formosan salmon is very sensitive to the diurnal maximum water temperature, where the stream temperature should not exceed 17°C. Similarly in the western US it is predicted that the Pacific salmon (*Oncorhynchus spp*.) will be negatively affected by the combination of increased summertime water temperatures and altered (decreased) stream flows (Mantua, Tohver et al. 2010). In contrast to these cold-water salmon species (Whitledge, Rabeni et al. 2006, Lawrence, Olden et al. 2012) studied the effects of increased temperatures on the warm water smallmouth bass (*Micropterus dolomieu*) in Ozark streams in the US. With increases in stream temperatures, the endemic smallmouth bass has been replaced by the largemouth bass *M. salmoides* and the introduced spotted bass *M. punctulatus* in some streams. Alterations of riparian vegetation which has caused degradation in thermal and physical habitat quality has been pointed out as the likely causes for the displacement of smallmouth bass by largemouth bass in this area. At the same time small mouth bas has also been introduced across the western US and upstream range expansions of predatory bass, especially into sub yearling salmon-rearing grounds, are of increasing conservation concern (Lawrence, Olden et al. 2012). One way to limit the spread of an invading warm water species into the habitats of a weaker competitor i.e. a cold water species) with climate change would be to concentrate on restoration activities that mitigate climate- or land-use-related stream warming (Lawrence, Olden et al. 2012). This is especially important as with a projected future climate change cold-water habitats will either shift to higher elevations or be reduced (Null, Viers et al. 2013) and at the same time we will see a creation of novel aquatic organism assemblages due to the replacement of temperature-sensitive taxa by more tolerant taxa (Stewart, Close et al. 2013).

Changes in flow

Several studies have assessed changes in hydrological regime with climate change as the hydrological regime is affected by precipitation and temperature (Dai, Trettin et al. 2010). Middelkoop, Daamen et al. (2001) and Hamlet (2011) assessed the impact of climate change on the river flow conditions in the Rhine basin. These authors found that changes in climate will cause higher winter discharge as a result of intensified snowmelt and increased winter precipitation, and lower summer discharge due to the reduced winter snow storage and an increase of evapotranspiration. These changes will have potential large effects on e.g. increased flood risk during winter, whilst the low flows during summer will adversely affect inland navigation, and reduce water availability for agriculture and industry. At the same time we will experience larger climate variability on water resources (Hamlet 2011). With the rise of the 0°C -line in the European Alps and the resulting degradation of the alpine permafrost, mass movements and rockslides may occur over larger areas. These may block the courses of mountain rivers, and thus form an additional cause of floods in the rivers in the Rhine catchment. In the Alpine area peak flows may increase by over 10%. Such elevated winter peak flows will also have direct effects on stream biota e.g. in streams in the Pacific northwest of the US, where flow peaks could scour the stream bed and destroy eggs e.g. of salmon (*Oncorhynchus spp.)* (Mantua, Tohver et al. 2010). The decrease in build up of snow packs will also result in lower flows in summer and fall, reducing the amount of available spawning habitat for the salmon and further increase water temperatures in streams and rivers. But successful management of e.g. salmonid fish species requires consideration of all life stage-specific influences (e.g. adult migration, spawning, incubation and rearing (Wade, Beechie et al. 2013) of e.g. water temperature and flow and integration of these effects over the entire life history to predict ultimate impacts of a changing climate on abundance and population viability (Nislow and Armstrong 2012). By understanding where in the stream network changes in temperature and flow will be largest and how different parts of the stream ecosystem will be affected by such changes caused by climate change we will enhance our understanding of where in the stream network we should focus our mitigation and restoration efforts (Ruesch, Torgersen et al. 2012).

Restoration and management efforts and effects of a changing climate

The basis for an integrated management of water within the EU will be provided by the Water Framework Directive as predictions of climate change indicate the need for an integrated catchment management approach to increase the resilience, of catchments, wildlife, and people in relation to an increase in extreme weather conditions and temperature (Mainstone, Dils et al. 2008). At the same time it is clear that increases in water temperature and changes in flow will also be affected in a multiple stressor scenario, where land use changes promote longer dry season flows, concentration of contaminants, allowing the accumulation of detritus, algae, and plants, and fostering higher temperatures and lower dissolved oxygen levels, all of which may extirpate sensitive native species (Cooper, Lake et al. 2013). The adaptation options available to counteract the effects of climate change could be divided into reactive and proactive options (Palmer, Lettenmaier et al. 2009). Proactive measures include e.g. restoration, purchase of land for protection, and measures that can be taken now in order to maintain or increase the resilience of stream and river ecosystems, whereas reactive measures involve responding to problems as they arise by mitigating on-going impacts or repairing damage (Palmer, Lettenmaier et al. 2009).

Changes in water temperature

With increases in water temperatures with climate change it will be necessary to take water temperature changes into account when planning restoration and management measures in stream and river ecosystems. In the study of water temperature modelling of the TaChia River in Taiwan Tung, Lee et al. (2006) found that the suitable habitats available for the Formosan salmon will decrease as the species is very sensitive to increased water temperatures. (Tung, Lee et al. 2006) conclude that local restoration and management measures is not enough to save the salmon as global climate change will cause the increase in water temperatures and therefore mitigation strategies for climate change impacts also has to be taken. The most important measure according to the authors might be to find new suitable stream habitats, which are less sensitive to climate change for the salmon species. In the study of the smallmouth bass in the Ozark river system in the US, Whitledge, Rabeni et al. (2006) conclude that riparian buffer strips can reduce stream warming and thus increase the potential available habitats for positive growth and spawning of fish species and at the same time buffer strips with maximum riparian shade will also experience daily temperature fluctuations <2°C compared to 8-9°C in unshaded or lightly shaded streams in this river system. Another important factor is the groundwater inflow of cooler water, as groundwater plays an important role in preventing summer maximum temperatures to exceed the thermal maxima for e.g. cool water freshwater fish species. Combinations of stream areas with large groundwater inflows (e.g. directly downstream from springs) and maximum riparian vegetation in small (< 5m wide) streams will have the largest effect of keeping stream water temperatures with ranges suitable for species sensitive to warm water situations (Whitledge, Rabeni et al. 2006, Battin, Wiley et al. 2007). But whether or not upwelling hyporheic water is going to be cool or warm depends on the residence time of the water in the hyporheic zone, where water with a long residence time is generally cooler than water with a short residence time, where long residence times also dampen temperature extremes and creating thermal refugia for cold-water aquatic organisms (Acuna and Tockner 2009). On a larger scale potential management options for the mitigation of stream temperature increases in response to climate change including reducing water removal during periods with low flows and high water temperatures (Mantua, Tohver et al. 2010).

In larger streams the stream azimuth will have a strong effect on how much shading the riparian vegetation will be able to provide as per cent stream shading is considerably different between north-south and east-west flowing streams (Whitledge, Rabeni et al. 2006). Such changes in stream temperatures and flows with climate change will make recovery targets e.g. for salmon (Battin, Wiley et al. 2007, Mantua, Tohver et al. 2010) more difficult to achieve. At the same time it is uncertain if and in that case how the fish itself could mitigate climate change effects e.g. through migration to higher elevations, or through behavioural changes such as changes in timing of migration, egg laying or spawning.

Changes in flow

According to Middelkoop, Daamen et al. (2001) increased winter water levels in the Rhine catchment will raise the need of additional flood defence measures along the river, which includes retention of water in the upstream parts of the basin, increasing the discharge capacity of the river channel, establishing an improved flood warning system, and raising the public awareness to floods. Higher winter water levels will also have positive effects for wetland ecosystems as these will move back to a more natural state with winter floods, increased inundations and sedimentations. At the same time periods of intensified water deficit and low river water levels are unfavourable for wetland ecosystems within the floodplain. Increased floodplain inundation may accelerate sedimentation rates, which over a time span of decennia may reduce the discharge capacity of the flood plain. With low water levels in the summer, the water demand will increase e.g., for industry, drinking water production, and water available for agriculture and water temperatures will increase (Hauer, Unfer et al. 2013). Also, the use of river water for cooling purposes may be limited, not only because of a reduced river flow, but also because of higher water temperatures. A policy of 'no-regret and flexibility' in water management planning and design is recommended in the Rhine catchment (Middelkoop, Daamen et al. 2001), where anticipatory adaptive measures in response to climate change impacts are undertaken in combination with on-going activities. These authors suggests that anticipatory measures that serve different goals should be undertaken, such as the spatial ‘reservation’ of sufficiently large floodplain areas alongside the rivers in combination with ecological wetland and river rehabilitation. Also Battin, Wiley et al. (2007) suggest that allowing streams and side channels to flow across a greater proportion of their historical floodplain and reconnect with freshwater and estuarine wetland habitats can improve low flows and lessen the negative impacts of peak flows on fish habitats.

There is also another important reason to carry out restoration activities aiming at making streams and side channels flow across a greater proportion of their historical floodplain and the constructing gravel bars, by side-arm reconnections or by re-meandering stream reaches as this will increase the infiltration and exfiltration capacity of river channels which in turn increase thermal refugia as this will enhance hyporheic water residence time (Acuna and Tockner 2009). It has also been shown that deciduous river bank revetments could contribute to the improvement of ecological conditions in upland watercourses as there are clear ecological benefits from the creation of ”messy” rivers as these authors found that a 300 m woody bank revetment of an upland UK river increased macroinvertebrate diversity significantly (Everall, Farmer et al. 2012). These bank revetments also has the potential to mitigate the risk of rising water temperatures by increasing riparian shade and/or contact time with cooler structures and the creation of ”messy” rivers through a mosaic of river habitats which could then make the ecosystem more resilient to climate change (Everall, Farmer et al. 2012). Further Mantua, Tohver et al. (2010) suggests that restoration could be successfully done by increased riparian planting at the catchment scale, where according to these authors a 10% increase in riparian cover could reduce stream water temperature by 1°C. The effect of riparian shading is, however, dependent on the stream size where mainstream channels will be experience less cooling by shade compared to smaller headwater streams (Cristea and Burges 2010). A very different adaptive management strategy was evaluated using modelling in the Murrumbidgee River, Australia, where climate change effects are predicted to increase riverine *Anabaena* algal blooms. The adaptive management strategy that seems to be most efficient in the study by (Viney, Bates et al. 2007), where pulsed discharges of water from the upstream areas or pools within the rivers in order to ameliorate bloom persistence by removing river water stratification.

Conclusions

There are three main conclusions coming out of this review on “processes and effects of temperature regimes in rivers and threaths due to climatec change on current adaptive management and restoration efforts:

(1) With climate change it is not enough to only plan management and restoration based on the local conditions of the systems under threat. On the other hand local or small-scale regional information is still vital in order to implement adaptive management strategies and restoration in a successful manner in stream and river ecosystems.

(2) Organisms, in small, cold upland stream ecosystems or other systems that are geographically restricted (as e.g. south-western Australia (Mantua, Tohver et al. 2010)) are extra vulnerable to climate change as there is no further areas to migrate to when these systems becomes warmer.

(3) Management approaches that emphasize flexibility and adaptation (in management systems, landscapes, and the fish themselves) may have the greatest potential to meet the challenges posed by climate change" (Battin, Wiley et al. 2007).

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