Climate Change and Water

Effects of climate change on water resources and aquatic systems

The warming temperatures and changing precipitation regimes associated with global climate change have effects on the quantity and quality of water in rivers, lakes, and aquifers. Indeed, it is likely that aquatic systems are among the most sensitive of all ecosystems to climate change, as water temperatures track air temperatures closely, the majority of aquatic species are cold blooded and easily affected by changes in temperature, and many ecological processes such as productivity, decomposition, and nutrient cycling in waterways are closely linked to temperature (Ormerod 2009). These waterways are essential for the functioning of all of the planet's ecosystems, as well as for the maintenance of human life. They also provide essential habitat for more than125,000 species of freshwater animals, representing 9.5% of all known animal species on the planet, along with associated high levels of plant diversity (Strayer 2010). Despite this richness and vulnerability, aquatic systems are often not well protected by traditional protected areas, and receive less conservation attention than terrestrial systems.

At the global scale, warming temperatures increase humidity and precipitation, and precipitation has increased about 2% in the last century (Huntington 2006). However, this figure disguises regional differences, as precipitation is expected to increase at high latitudes, and decrease at low and mid latitudes (Malmqvist 2002). Global precipitation trends will also be driven by changes in atmospheric circulation patterns, and on alterations of multiannual and decadal climate cycles such as the El Nino Southern Oscillation or the North Atlantic Oscillation (Wise 2010). However, the majority of effects on waterways and aquatic systems occur at regional and local scales. The main pathways for change are warming water temperatures, changes in snowpack and timing of runoff events, loss of ephemeral wetlands, and sea level rise causing flooding and salinization of coastal wetlands.

Increasing water temperatures

Climate change has already affected water temperatures in freshwater ecosystems worldwide (Wilby 2010). Warming temperatures affect both the condition of lakes and rivers, as well as their suitability as habitat. Warming air and water temperatures will increase primary production in lakes and rivers, and lead to faster growth rates for phytoplankton and invertebrates, causing oxygen depletion and eutrophication (Meyer 1999). Increased temperatures may increase levels of bioaccumulation of toxins (Malmqvist 2002). Small streams and shallow lakes are especially vulnerable to increased variability (Heino 2009).

The high level of diversity found in freshwater systems is finely distributed by latitude, as aquatic organisms have very narrow environmental tolerances, and species' distributions are closely linked to temperature (Malmqvist 2002). Many fish species are adapted to cold water conditions, and it is estimated that, in the US, habitat for cool- and cold-water fish will decrease by 50% (Malmqvist 2002). For example, increasing water temperatures are already threatening the habitat of many populations of cutthroat trout, with varying effects on different populations that are already affected by numerous anthropogenic stressors (Williams 2009).

Freshwater species appear to have similar trajectories to terrestrial ones regarding potential range shifts under warming climate scenarios. Studies suggest that a four degree increase in water temperature is equivalent to latitude shift of 680 kilometers (Heino 2009).

Rising water temperatures will result in shifts in species distributions, including the potential loss of cold-water fish from some lower stream reaches and from other streams all together, as well as expansions of the ranges of warm-water fish (Lawler 2009). However, while some aquatic organisms, such as dragonflies and other insects, are able to migrate between waterways, many freshwater species have a very limited ability to do so, as movement requires contiguous waterways (Strayer 2010). This limited migratory ability may result in large scale extinctions of cold-water species.

Changes in snowpack and runoff regimes

Warming temperatures and changes in the timing and intensity of precipitation will affect the extent to which snowpack and glaciers regulate and moderate streamflow and runoff, especially in montane and alpine ecosystems. In mountainous areas, a warming climate causes more precipitation to fall as rain rather than snow. In the mountainous West, up to 70% of annual discharge occurs in spring runoff, and with more rain events this spring runoff will be earlier, as well as larger. Earlier peak streamflows have already been seen in many places (Novotny 2007). This trend also increases rain-on-snow events, leading to flooding (Herbst 2010). These high-intensity events have the potential to increase sedimentation and nutrient leaching into waterways.

Changes in time and magnitude of spring runoff also has effects on spawning of fish and emergence of insects, and may lead to loss of synchrony between fish food requirements and the availability of insect food supplies (Williams 2011). These disruptions may put nonnative and invasive species at a competitive advantage (Hauer 1997).

In addition, decreased snowpack and higher pulses of runoff in the spring mean less water in the summer and fall, especially in dry western ecosystems. Models in the Rocky Mountains predict significant declines in summer stream flow (Shepherd 2010); for example the Colorado river is predicted to decrease in flow by 10-30% (Barnett 2009). Reduced summer flows and more frequent drought conditions have effects on species survival, water temperatures, and loads of sediments, nutrients, and toxins (Saunders 2007). It also leads to lower water availability for surrounding vegetation and associated animal species, compounding the effects of warmer air temperatures in changing community composition and increasing fire frequency and intensity. Changes in stream flow can have effects on diversity and composition of riparian plant and animal communities (Scott 2003). In addition, reduced summer flow from snowpack will have significant effects on water availability for urban and agricultural needs (Shepherd 2010).

Alteration of wetland ecosystems

Wetlands cover 6% of the world's land surface, and are home to diverse, rare, and endemic plant and animal communities, including vulnerable populations of amphibians and migratory birds (Erwin 2009). In a range of climate change scenarios, changes in water availability and regimes, erosion, sedimentation, destructive storm events, and invasive species may drastically alter these landscapes. In many coastal wetlands, rising sea levels will lead to flooding and increased salinity. In the Everglades of southern Florida, hydrologic regimes, temperature, and CO_2 levels are strongly correlated with plant community structure, and coral and fish abundance and diversity (Pearlstine 2010). Sea level rise, changes in precipitation, and damage by intense storms events all have the potential to drastically change the composition and structure of this diverse system.

Ephemeral or vernal pools and streams are another specialized wetland type, in which a brief period of standing water provides a crucial breeding habitat for frogs, salamanders, and other amphibians, as well as many invertebrates. In vernal pools, the primary factor determining community richness, abundance, and productivity is the length of the wet period. Many species require minimum periods of as many as 160 days for hatching and larval development, and under drier summer conditions many pools may cease to support these species (Brooks 2009). Many vernal pool species have limited dispersal capabilities, and so are tied to warming pools where increasing water temperatures may lead to decreased fitness and survival (Brooks 2009). In addition, seasonally intermittent headwater streams can be crucial breeding grounds for Coho salmon and other species, and increased variability in water availability has been seen to decrease species richness.

Surrounding habitat and multiple stressors

Streams, rivers, lakes, and wetlands do not exist in a vacuum, and climate change-driven alterations of the terrestrial environment also affect the aquatic environment, through changes in litter and debris in waterways, habitat for aquatic mammals and bird, shading of water, and oxygen provision. Changes in plant species composition, vegetative cover, or the location of treeline can have far-reaching effects on the structure and function of streams and lakes (Hauer 1997).

In addition, the temperature and precipitation changes associated with climate change occur in the context of numerous other anthropogenic stressors on water quantity and quality, such as acidification, pollution by nitrates, metals, and other toxic substances, land use and land cover change, and the introduction and spread of invasive species. Nearly all watersheds are affected by human use, and this use will increase in the future, therefore effects of climate change cannot be separated from other threats to water resources.

Management for adaptation under climate change

In the absence of management directly designed to address these multiple ways in which climate change affects water resources and aquatic ecosystems, waterways which are crucial for aquatic species, ecosystem services, and human use face serious deterioration. Unlike in terrestrial systems, where climate change may lead to shifts in community composition to new states, the poor ability of aquatic species to either cope with changing temperatures or migrate to new watersheds may leave future rivers and lakes species poor, eutrophic, or toxic. In addition, feedbacks between decreased precipitation, more concentrated spring runoff events, changing terrestrial vegetation, and increasing human water needs may nearly or completely deplete waterways. Due to the fragile and essential nature of aquatic systems, scientists may recommend management actions to protect water resources even in wilderness areas and other landscapes where a non-interventionist approaches are the rule.

Conservation of freshwater species

Aquatic systems have thus far garnered considerably less conservation attention that their terrestrial counterparts. However, the richness and vulnerability of aquatic ecosystems often are not well protected in reserves, parks, or wilderness areas designed for terrestrial conservation. There is a growing number of case studies identifying the sensitivity of freshwater communities to climate change, however the magnitude and directionality of effects are largely species- and site-specific (Hamilton 2010), requiring managers and policy makers to operate with a large margin of variability and uncertainty (Milly 2008).

A number of policy tools are already in place which allow for varying levels of protection of scenic or valuable sections of rivers and focal or endangered populations (Abell 2007). However, effective conservation of freshwater species under climate change requires protected areas and wilderness that encompass entire catchments and watersheds, in addition to connective corridors between watersheds, to allow for migration and adaptation (Heino 2009.) A number of species, including vulnerable populations of amphibians, are not well protected by management plans that focus on specifically terrestrial or aquatic systems. Identification and preservation of vulnerable aquatic species and their associated movement corridors that are found within existing wilderness areas should therefore be a management priority.

Future management must account for upstream and downstream connectivity, and adjacent areas, ideally combining conservation goals for freshwater and terrestrial species and landscapes (Amis 2009). Ideally, protected areas should link the headwaters of multiple catchments, to allow the movement of amphibians and other animals between them. As climate change creates drier summer conditions in many areas, these headwaters may shrink, and usable paths between them may become smaller and fewer, making their conservation still more crucial (Olson 2009). Managers may play a role in identifying these linkages and pathways both within and adjacent to protected areas. In addition, managing entire catchments in a natural state within wilderness or protected areas is often an impossibility, and much of the focus currently is on integrated catchment management coordinating protection and management between various landowners and stakeholders (Abell 2007). In addition, waterways are especially susceptible to threats, such as pollution and sedimentation, originating outside of protected areas, therefore protection requires some amount of management of surrounding landscape as well (Heino 2009). Dams and other physical barriers to waterways downstream of protected areas may prevent the ability of fish and other aquatic species to migrate upstream in the face of warming water temperatures (Strayer 2010). Wilderness managers may play a role in this process through outreach and educational programming, and facilitation of and participation in discussions with local stakeholders and landowners.

Preservation and restoration of watersheds and riparian areas

A key feature of management for waterways under climate change is the protection and restoration of the habitat surrounding lakes and rivers. These landscapes not only provide connectivity for both terrestrial and aquatic systems, but help maintain the character and qualities of the waterways themselves. Shading by trees prevents warming water temperatures, and the filtering and buffering capacity of vegetation prevents the influx of sediments and pollutants in periods of increased runoff and storm intensity (Wilby 2010).

Managing the flows of rivers and streams to maintain historical conditions may allow for the persistence of some species. This may include the creation of pools for cold water refugia, removal of sediment or addition of large debris, as well as restoration of appropriate tree species. A common theme is that restoration of waterways is beneficial even when not directly linked to a proximal threat, as more intact riparian and wetland systems buffer watersheds from numerous effects of climate change as well as other threats (Hamilton 2010).

Changes in water temperature may require species to migrate upstream or to other watersheds, or to adapt quickly to changing conditions (Heino 2009), and some suggest that populations be managed to buffer species from the effects of climate change. Proposed actions include the relocation and stocking of fish populations to new upstream or coldwater locations, or directed breeding programs designed to increase population sizes of vulnerable species, and to maintain genetic diversity, population viability, and the ability to adapt to new conditions (Pearlstine 2010).

Adjusting to changing baselines

A key facet of adaptation strategies for waterways involves adapting the tools used by managers and scientists use to monitor and evaluate aquatic systems. Many watershed-related policy and management decisions are made on the basis of biological or ecological indicators, and many of these will likely become irrelevant or misleading as changing aquatic systems lead to changing baseline conditions (Barbour 2010). Instead, several researchers suggest that threatened or vulnerable systems be characterized based on assessment of their sensitivity to climate and land use change, rather than prior measures of species composition or water quality (Hamilton 2010). This requires close monitoring of changing conditions at local scales of relatively short periods of time, including changes in temperature, sedimentation, flow rate, salinity, or pH. In addition, predictions and models based on these data should include high levels of variability and extreme events, rather than relying on past conditions (Milly 2008)

Minimizing compounding stressors

A common theme of assessments of climate change and freshwater is that climate-induced changes can only be understood and addressed in the context of the massive changes in water quality and quantity already occurring due to human land use and water use, the spread of invasive species, and the release of pollutants, which may exacerbate or even trump climate related changes (Scarlett 2010). Grazing regimes also affect the ability of waterways to adapt to climate change, though interactions are complex and variable. In California alone, a study of vernal pools showed that grazing greatly increased the length of ephemeral water (Pyke 2005b), while a study of montane streams in the Sierra Nevada found that grazing around waterways makes aquatic communities more sensitive to flooding events (Herbst 2010). Therefore managing the effects of surrounding land use regimes on waterways requires site-specific monitoring and assessment, and decisions regarding watershed management cannot be made without consideration of these outside forces.

In addition, downstream water use for development and agriculture may affect upstream water temperature, flow, and seasonality. These effects may be exacerbated by changing temperature and precipitation regimes, and managers should include assessment of these downstream dynamics in monitoring activities and decision-making. A reoccurring theme throughout the literature on climate change and aquatic systems is that appropriate management requires an understanding of the waterways both upstream and downstream from a wilderness area, as well as collaboration with surrounding landowners and stakeholders.

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