Climatic Change (2009) 95:469–483
DOI 10.1007/s10584-008-9531-9

Potential impacts of global climate change on the hydrology and ecology of ephemeral freshwater systems of the forests of the northeastern United States

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Received: 7 February 2008 / Accepted: 28 October 2008 / Published online: 6 January 2009

Abstract Global, national, and regional assessments of the potential effects of Global Climate Change (GCC) have been recently released, but not one of these assessments has specifically addressed the critical issue of the potential impacts of GCC on ephemeral freshwater systems (EFS). I suggest that this is a major oversight as EFS occur in various forms across the globe. In the northeastern United States, these systems, whether ephemeral ("vernal") pools or ephemeral or intermittent headwater streams are abundant and provide unique habitats critical to the maintenance of forest biodiversity. Since the hydrology of these waterbodies is strongly affected by weather patterns (in the short-term) or climate (long-term), they are especially sensitive to climate change. In this essay, I review the literature on relationships between climate and hydrology of EFS and on relationships between hydrology and ecology of these systems. I then conclude with my assessment of potential impacts of GCC on the hydrology of EFS and implications for their ecology. The focus of this essay will be on EFS of the forests of the northeastern United States, but will include literature from other regions as they relate to the general relationships between GCC and EFS.

1 Introduction

Ephemeral freshwater systems (EFS) of the northeastern United States (Northeast) include both lentic (flowing water) and lotic (still water) habitats. Ephemeral forest pools, commonly termed "vernal pools", are widely distributed in northeastern forests (Brooks et al. 1998; Burne 2001; Lathrop et al. 2005). These pools typically

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hold standing water for months (temporary, sensu Cowardin et al. 1979) to seasons (seasonal), while the largest pools may remain flooded for longer periods (semi-permanent). However, the pools dry with sufficient regularity as to preclude the development of a permanent fish community. Consequently, ephemeral forest pools are the preferred breeding habitat for wood frogs (*Rana sylvatica*) and mole salamanders (*Ambystoma* spp.) and support a rich and unique invertebrate fauna (Higgins and Merritt 1999; Schneider 1999; Colburn 2004). Headwater streams, as the name implies, occur at the origins of stream and river networks (Vannote et al. 1980). Headwater stream segments are the most common and, cumulatively, most extensive segments of river networks (Gomi et al. 2002; Lowe and Liken 2005). It is commonly cited that headwater streams may comprise more than 70% of stream-channel lengths in the United States (Lowe and Liken 2005). In the highest reaches of these segments, stream flow is generally less than permanent. However, headwater streams contribute significantly to the streamflow, sediment, debris, organic matter, and nutrients of downstream segments (Gomi et al. 2002; MacDonald and Coe 2007; Meyer et al. 2007). As with ephemeral forest pools, the ephemeral flow of many headwater streams precludes the occurrence of permanent fish populations, allowing for the greater abundance of stream-breeding salamanders such as the spring salamander (*Gyrinophilus porphyriticus*) and larval, two-lined salamander (*Eurycea bislineata*) (Barr and Babbitt 2002; Lowe and Bolger 2002). The timing and duration of stream flow of intermittent streams has been shown to be more important than habitat in affecting macroinvertebrate production (Chadwick and Huryn 2007).

Reports on potential impacts of Global Climate Change (GCC) on various resources, including freshwater systems, have been recently issued at global (Kundzewicz 2007; Bates et al. 2008), national (Backlund et al. 2008), and regional scales (e.g., northeastern United States; Frumhoff et al. 2007; Hayhoe et al. 2007). Mention of potential impacts of GCC on EFS is not presented in any of the reports, despite clear relationships between the hydrology of these systems and climate. One exception was the recommendation for improved monitoring of headwater streams as a research priority for the U.S. climate change science program (Lucier et al. 2006). Likewise, journal reviews of potential climate change impacts on freshwater systems of the Northeast rarely mention ephemeral systems (e.g., Magnuson et al. 1997; Moore et al. 1997; Hayhoe et al. 2007). Schindler (1997, 2001), in reviews of potential impacts of GCC on North American freshwater ecosystems, mentions that first-order streams may become ephemeral or may remain dry for longer periods due to increased evapotranspiration.

The goal of this paper is to review the likely impacts of climate change on the hydrology of ephemeral freshwater systems and the consequential impacts on their unique and sensitive faunas. EFS, especially those hydrologically isolated from other freshwater systems, would seem to be especially sensitive to GCC-associated changes in their hydrology. I first review and summarize the literature on the relationships between climate and the hydrology of ephemeral freshwater systems and then between the hydrology of these systems and their ecology. Finally, I review the limited literature on projected impacts of GCC on freshwater systems, which is mainly for streams and suggest possible consequences of these impacts for EFS ecology. The geographic focus is on the Northeast and adjacent Canada, but literature from other locations is included when appropriate.

2 Climate and the hydrology of ephemeral freshwater systems

The hydrology of ephemeral freshwater systems of the Northeast is poorly understood. Generally, both lotic and lentic EFS are sensitive to climate, and exhibit short-term variation in hydrologic features based on changes in seasonal and annual weather patterns.

A small numbers of studies clearly show strong influence of climate on ephemeral pool hydrology. Brooks (2004) showed that hydroperiods of isolated, seasonal forest pools in Massachusetts were largely a function of precipitation and evapotranspiration. Pools would partially fill with late fall rains following leaf fall and then fill to capacity with spring rains and melting of the snow pack. In late spring, as temperatures warmed and forest vegetation was at full foliage, evapotranspiration exceeded precipitation. Evapotranspiration was related to pool drying as pool water likely drained to adjacent uplands to replace soil water or shallow groundwater lost to evapotranspiration.

Boone et al. (2006) and Pyke (2004) validated the critical role of both precipitation and evapotranspiration in vernal pool hydrology in respective modeling of the hydrology of Minnesota and California pools. In Minnesota, vernal pool hydrology was adequately modeled using a classic water budget model, emphasizing precipitation and evapotranspiration, after adjusting for surface runoff and infiltration rates. Knowledge of the importance of precipitation and evapotranspiration in California vernal pool hydrology was used in subsequent assessments of climate change and vernal ecology (Pyke 2005), policy (Pyke and Fischer 2005), and management (Pyke and Marty 2005). Modeling efforts have identified the role of weather factors in the hydrology of other types of ephemeral lentic systems including northern prairie potholes (Poiani et al. 1996), Carolina bays (Sun et al. 2006), karst pans (Hill et al. 2006), and cypress ponds (Mansell et al. 2000). Lentic EFS would be additionally challenged by climatic change as they are often hydrologically isolated from other aquatic systems (Winter and LaBaugh 2003; Zedler 2003; Leibowitz and Brooks 2008). As such, they are not connected to or "subsidized" by other, permanent freshwater systems or regional groundwater resources; their existence is principally an expression of a balance of precipitation inputs and evapotranspiration losses (Winter 2000).

Streamflow, especially of low-order and headwater segments, is closely related to weather patterns and climate. Streamflow across the Northeast has been adequately modeled by temperature, precipitation, and basin-specific geomorphology. Lull and Sopper (1966) identified precipitation and July mean temperature as the most influential climate variables affecting annual and seasonal discharges of 137 watersheds in the Northeast. Precipitation was more influential than any topographic or land-use variable. Vogel et al. (1997, 1999) identified mean annual precipitation and mean annual temperature as significant components of a regression model for mean annual streamflow of 166 northeastern streams, only stream basin area was more influential. In north-central Minnesota, stream flow in three intermittent streams was a linear combination of non-winter precipitation and summer temperatures (Nichols and Verry 2001). Marshall and Randhir (2008) predicted increased winter-season runoff and reduced spring and summer season runoff for the Connecticut River due to climate change. These changes were the result of the change in winter precipitation from snow to rain and a reduced snowpack and from increased summer season evapotranspiration.

Patterns of precipitation and temperature have a clear and significant affect on the hydrology of EFS of the Northeast. Precipitation is generally the principal input to headwater streams and ephemeral pools in northeastern forests. While temperatures of the Northeast are temperate, temperature-driven evapotranspiration nevertheless exceeds precipitation during the summer months. The loss of soil water and shallow groundwater to the atmosphere through forest canopy transpiration has a significant impact on water loss from or reduced inputs to small freshwater systems embedded in forests.

A critical issue is the degree of dependence of a water body on precipitation, and if, or to what extent, flow or hydroperiod is supported by groundwater (Winter 2000, 2007; Winter et al. 2003; Boone et al. 2006; Cook and Hauer 2007). Groundwater inputs are a largely unknown factor, but the dominant glacial-till derived soils of much of the Northeast have low permeability and are often discontinuous due to variable till thickness and bedrock outcrops, so groundwater inputs are likely minor and from shallow and adjacent resources. While groundwater inputs could moderate the impacts of GCC if present, groundwater resources are also directly affected by weather patterns and climate, complicating projections of potential impacts of GCC on EFS (Nichols and Verry 2001; Boone et al. 2006; Hayhoe et al. 2007; Nolan et al. 2007).

3 Hydrology and ecology of ephemeral freshwater systems

Hydrology, especially hydroperiod (the duration of inundation or flow) and hydroregime (the temporal pattern of inundation or flow), is the major if not principal abiotic influence on the ecology of ephemeral freshwater systems (Resh et al. 1988; Power et al. 1988; Brooks 2005). In the Northeast, this is principally observed as affecting the richness, abundance, and productivity of invertebrate and amphibian populations (Pechmann et al. 1989; Schneider 1999; Snodgrass et al. 2000; Colburn 2004; Babbitt 2005). The hydroperiod of ephemeral forest pools influences rates of litter and organic-matter breakdown and carbon storage (Kirkman et al. 2000; Baker et al. 2001; Euliss et al. 2006; Battle and Golladay 2007; Inkley et al. 2008), the physicochemical (geochemical) environment (Magnusson and Williams 2006), the composition and breeding success of pool-breeding amphibians (Semlitsch et al. 1996; Brodman et al. 2003; Jakob et al. 2003; Kolozsvary 2003; Skidds and Golet 2005; Baldwin et al. 2006), and the composition and richness of the invertebrate community (Schneider 1999; Brooks 2000; Colburn et al. 2008).

Reduced hydroperiods or changes in hydroregimes of ephemeral forest pools will affect various ecological processes. Long-term changes in hydrology would result in changes in faunal composition. Pool-breeding amphibians require hydroperiods of some minimal duration for larval development (e.g., 50–135 days for wood frogs [*Rana sylvatica*], 90–160 days for spotted salamanders [*A. maculatum*]; DeGraaf and Yamasaki 2001). If average pool hydroperiods are shortened, fewer pools will provide breeding habitat to support local amphibian populations. The losses of potential breeding pools will increase inter-pool distances and affect larger amphibian metapopulations by negatively impacting inter-pool movements, recolonization, and genetic exchange (Gamble et al. 2007).

The hydroperiod of ephemeral forest pools strongly influences the macroinvertebrate community, with taxa richness and diversity increasing with longer hydroperiods (Brooks 2000; Batzer et al. 2005). Schneider (1999) distinguished the macroinvertebrate community of short-duration forest pools as being structured by abiotic factors and associated adaptations to pool hydroperiod and hydroregime, while that of longer duration pools was increasingly structured by biotic interactions, including competition and predation. This pattern was observed in temporary woodland ponds in Michigan, where insect species, principally predacious species with no adaptations to survive the pool drying, colonized longer hydroperiod ponds in the late spring (Higgins and Merritt 1999).

Flow regimes and flow characteristics of streams, and especially low-order streams, strongly affect stream ecology (Power et al. 1988; Statzner et al. 1988; Chaves et al. 2008). Biotic community structure is especially affected by abiotic (hydrologic) processes in intermittent streams (Poff and Ward 1989). Resh et al. (1988) identified hydrologic regime, quantified as the long-term patterns of monthly maximum and minimum stream flow, as one of two significant features for assessing the effects of disturbance on stream ecology. Temporal variability in habitat diversity, especially volume, was greater in upstream, rainfall-influenced headwater stream segments than in more stable, groundwater-influenced downstream segments (Schlosser 1982). In turn, fish and benthic insect community diversity were positively correlated with habitat diversity.

Poff and Allan (1995) identified and separated assemblages of fish species associated with hydrological variability in 34 stream sites in Wisconsin and Minnesota. Fish assemblages of streams with high hydrological variability (i.e., variation in daily flow, frequency of spates) were often more adaptable, generalist species. The authors conclude that hydrological alteration of streams, including that induced by climate change, could modify stream fish assemblages in the study region. Labbe and Fausch (2000) found that flow variation among seasons and years controlled habitat connectivity at segment scales of intermittent streams, thereby affecting dispersal, reproduction and population characteristics of a threatened fish species. Intermittent streams have been shown to be important habitat for developing coho salmon (*Oncorhynchus kisutch*), and the loss of these streams, by change in precipitation patterns and stream water levels, would have a negative effect on salmon populations (Brown and Hartman 1988; Wiggington et al. 2006).

Feminella (1996) found that benthic macroinvertebrate richness and diversity were subtly, but positively related to flow permanence in six small upland streams in Alabama. While most macroinvertebrate taxa were ubiquitous in distribution across stream permanence, a small number (7% of 171 taxa) were restricted to intermittent streams. Taxa with restricted distributions would be more sensitive to flow regime change. Fritz and Dodds (2005) related measures of hydrological regime (average flow, flow variability, flow duration patterns), expressed as a harshness index, to macroinvertebrate assemblage diversity and abundance in intermittent prairie streams. Steam harshness indices, high in intermittent streams and low in perennial streams, were negatively related to diversity and richness.

Salamanders are the dominant vertebrate in intermittent, headwater forest streams (Lowe and Bolger 2002; Peterman et al. 2008). As with pool-breeding amphibians, breeding in intermittent streams reduces or avoids competition with or predation by fish. However, increased variability in stream flow could increase mortality risks from exposure of developing larvae (Petranka 1983; Lowe and Bolger 2002) or early metamorphosis, resulting in reduced adult size and fitness (Semlitsch et al. 1988; Newman 1992).

Lytle and Poff (2004) identify three types of adaptation (life history, behavior, and morphology) to flow regimes used by stream biota. The same types of possible responses by ephemeral pool fauna are undoubtedly valid. The type of adaptive response and the rate of responsiveness of the adaptation will affect a taxa's ability to respond to change in flow regimes. Change in the hydrology of ephemeral freshwater systems, whether from climate change or any disturbance factor, would have clear and significant impacts on the ecology of these systems. The preceding discussion shows that there is abundant scientific evidence that the composition and diversity of macroinvertebrates and fitness of vertebrates of EFS are closely linked to the hydroperiod and flow regimes of these systems.

4 Potential impacts of global climate change on the hydrology and ecology of ephemeral freshwater systems

Climate change will result changes in seasonal and annual temperatures and in precipitation patterns and possibly amounts. These climatic attributes drive important hydrological processes, including evaporation, water vapor transport, and precipitation (Carpenter et al. 1992; Hayhoe et al. 2007). Trends in recent–past climate measurements indicate that climate change is on-going across the Northeast (Hayhoe et al. 2007, 2008). Recent trends in the hydrology of perennial or permanent waterbodies, in response to current climate change and to projected impacts of future GCC, provide insight to potential impacts of GCC on ephemeral waterbodies. Observed and projected impacts on perennial waterbodies will have much enhanced impacts if they occur in ephemeral waterbodies.

The historic climate of the Northeast is temperate with abundant, reliable precipitation occurring evenly throughout the year (Moore et al. 1997; Brooks 2004). The Fourth Assessment of the Physical Science by the Intergovernmental Panel on Climate Change (IPCC) projected warming across North America in the twenty-first century, with the greatest change occurring in winter minimum temperatures (Christensen et al. 2007). Additionally, annual mean precipitation was projected to increase in winter, with the increase occurring as rain rather than snow and in spring, resulting in reduced snow season length and snow pack depth; precipitation was projected to decrease in summer. The IPCC later projected that freshwater resources will to be affected by these climate changes, but the vulnerabilities and impacts vary from region to region across the continent (Field et al. 2007; Bates et al. 2008). Overall, warming will result in higher evaporation, partially offsetting projected increases in precipitation or enhancing the effects of decreased precipitation. Further, the patterns of precipitation are projected to be more episodic, with less frequent but more intense storms and longer inter-event droughts (Bates et al. 2008). These projected changes are likely to have the greatest impact on endorheic (closed) aquatic systems because of their sensitivity to changes in the balance of inflows and evaporation (evapotranspiration) (Bates et al. 2008). Generally, projected climate change is expected to result in a drying trend in wetland ecosystems.

Climate projections specifically for the Northeast include temperature increases and changes in precipitation patterns (altered rain–snow ratios, more episodic precipitation events) (Hayhoe et al. 2008). Precipitation projections call for reduced duration of snow cover and a decrease in the frequency of convective summer thunderstorms, with longer inter-event droughts, but an increase in their intensity (Moore et al. 1997; Trapp et al. 2007; Hayhoe et al. 2008). These climatic changes would result in earlier and reduced snow melt runoff, greater rates of evaporation and evapotranspiration, increases in seasonal water deficits during the summer and early autumn, and decreases in water surplus in the late autumn and winter seasons (Moore et al. 1997; McCabe and Wolock 2002; Hayhoe et al. 2008).

Global climate change is projected to have major impacts on freshwater systems across the globe (Poff et al. 2002; Kundzewicz 2007; Hulsmans et al. 2008). In the Northeast, impacts are projected to be of lesser magnitude than in other regions, but nevertheless significant. These assessments may be overly optimistic since they failed to consider impacts on EFS. Climate change is projected to affect several hydrological measures across the Northeast, including evaporation, soil moisture, runoff, summer drying or drought, streamflow, and winter snow cover (Hayhoe et al. 2007). However, the impact of climate induced change on the ecology and hydrology of freshwater systems may be difficult to detect in real time due to the inherent spatial and temporal variability in these systems (Pilon and Yue 2002).

The immediate and obvious potential impact of GCC on ephemeral freshwater systems will be on flow patterns of low-order perennial, intermittent, and ephemeral streams and hydroperiods of ephemeral wetlands (Carpenter et al. 1992; Schindler et al. 1996; Schindler 1997, 2001). Climate change impacts are projected to be greater on systems with rainfall-dominated hydrology, rather than those with groundwater or snowmelt-dominated hydrology (Poff et al. 1996). Isolated terrestrial habitat islands (e.g., mountaintop) have been identified as a class uniquely sensitive to GCC (Root and Schneider 2002; Marris 2007; Bates et al. 2008; Backlund et al. 2008). Isolated freshwater systems would seem to be similarly threatened by GCC, especially for biota with limited dispersal abilities (e.g., amphibians, reptiles, microcrustaceans).

Regional-scale evapotranspiration rates tend to decrease with latitude and the ratio of runoff to precipitation tends to increase with latitude across the Northeast, corresponding to decreases in mean annual temperature with latitude (Church et al. 1995; Huntington 2003). Projected increases in temperatures due to climate change can be expected to lower general water levels due to increased evapotranspiration in excess of precipitation (Tung and Haith 1995; Magnuson et al. 1997; Brooks 2004; Huntington 2006, 2008). As a consequence, annual stream flows are projected to decrease with GCC, with greater reductions occurring during the autumn and winter (Moore et al. 1997), and especially during traditionally low flow periods (July–September) (Huntington 2003). Peak flows would occur earlier in the year, with earlier and reduced snow melt, as winter precipitation occurs more often as rain rather than snow (Band et al. 1996; Burn and Hag Elnur 2002; Huntington et al. 2004). Winter rain would be lost as runoff as the soil would be more likely to be frozen due to the reduced snow pack (Hardy et al. 2001). Summer low flows are projected to lengthen due to earlier and increased plant water demands (Band et al. 1996; Hayhoe et al. 2007; Ollinger et al. 2008).

Late spring–summer increases in evapotranspiration, in excess of precipitation would clearly affect water levels of ephemeral forest pools (Brooks 2004). The impact of increased evapotranspiration from ephemeral forest pools is enhanced because of the large perimeter to area ratio of these waterbodies and the resultant increase in transpiration at forest-pool edges (Brooks and Hayashi 2002; Herbst et al. 2007). Earlier and enhanced water deficits due to temperature-induced increases in evapotranspiration, without concomitant increases in precipitation, should result in earlier drying of ephemeral pools and low-order streams.

An intensification of the water cycle, due to increased temperature and a change in precipitation patterns (i.e., fewer, more intense precipitation events, longer inter-event droughts; Huntington 2006; Tebaldi et al. 2006; Mailhot et al. 2007; Trapp et al. 2007; Bates et al. 2008; Groisman and Knight 2008; Hayhoe et al. 2008), would result in a change in hydroregimes of ephemeral freshwater systems. This change in precipitation pattern could result in a cycle of repeated drying and reinundation of forest pools and small, headwater streams (Bauder 2005; Brooks 2005). This change in hydroregime would negatively impact developing larval invertebrates and amphibians, which require a minimum period for development to metamorphosis. An increase in the severity of precipitation events would also increase the erosive power of flood events, the major factor determining stream channel morphology and, in turn, stream ecology (Resh et al. 1988; Madsen and Figdor 2007).

The hydrology of EFS of the Northeast is closely linked to seasonal and annual weather patterns, and, in the long-term, climate, and climatic change will affect these waters (Schindler 2001). Increases in temperature will result in increases in evapotranspiration losses from surface and shallow ground water. These enhanced losses will reduce the hydroperiod of EFS unless offset by increases in precipitation. Changes in precipitation, either patterns and/or amounts, will have a major impact on the hydroregimes of these systems. If precipitation becomes more episodic, with increasing occurrence and duration of droughty periods, EFS will respond with more flashy hydroregimes. Finally, changes in seasonal snow–rain patterns will alter snowpack accumulation and the timing and amount of spring runoff. These will affect the timing, duration, and magnitude of early season stream flow and pool water depths.

Climate-change associated increases in air and water temperatures would result in temperature-related changes in ecological processes and biological communities in EFS (Carpenter et al. 1992; Nelson and Palmer 2007). Increases in headwater stream temperature could remove rare, cold-water taxa and reduce the overall springtime abundance of macroinvertebrates (Durance and Ormerod 2007). Climate-induced increases in stream water temperatures could also reduce thermal habitat for cold- and cool-water fish (Eaton and Scheller 1996) and amphibians (Spotila 1972) across the range of these species. Increases in water temperatures would increase development rates of larval invertebrates and amphibians (Voss 1993), and could result in early metamorphosis and reduced adult fitness (Semlitsch et al. 1988).

While not a function of hydrology, GCC is projected to affect the composition of northeastern forests, with a general northeastward migration of forest types and species (Iverson et al. 2008). The food webs of EFS are detritus based, and changes in the composition of leaf litter input to these systems (e.g., from mixed hardwoods to oak and pine), could affect the entire food web if the decomposition rates and/or nutritional quality of litter resources declines (Baker et al. 2001; Palik et al. 2006; Battle and Golladay 2007). Changes in forest composition would also affect forest evapotranspiration due to interspecies differences in stomatal resistance, with subsequent effects on transpiration rates and streamflow (Federer 1977; Huntington 2003, 2008; Ollinger et al. 2008).

The ecology of EFS is closely linked to their hydrology, especially hydroperiod and hydroregime. Climatic change that affects these abiotic factors will, in turn, affect the ecology of these systems. The likely impacts of climate change on EFS will be to shorten overall hydroperiods (earlier drying in the spring due to increased temperatures/evapotranspiration, later inundation in the fall due to longer growing season/later leaf fall/later period of evapotranspiration), shift the open-water component of the hydrological cycle to earlier in the calendar year, and increase the 'flashiness' of hydroregimes. The consequences of these changes would almost certainly be a change in characteristic fauna, to more generalist species, better able to adapt to these conditions. Furthermore, the loss of short- and intermediate-duration systems will increase the spatial isolation of the remaining long-duration systems and impact the movement of species, individuals, and genetic material among remaining, productive sites (Gibbs 1993; Griffiths 1997; Semlitsch and Bodie 1998; Bonda et al. 2006).

The potential impacts of climate change on EFS are great. The lack of recognition of the threat to EFS from climate change is discouraging, but understandable based on the general lack of attention these systems have received relative to other aquatic systems. If this situation is to change, increased attention must be given to EFS. Long-term monitoring of the hydrology of EFS will be necessary to assess change due to GCC (Conly and van der Kamp 2001). The dispersed distribution of EFS argues for the use of citizen science to monitor EFS hydrology and ecology (e.g., amphibian breeding efforts) such as called for in the U.S. National Phenology Network (http://www.usanpn.org). Improved modeling of EFS hydrology will refine our understanding of possible impacts of GCC (Johnson et al. 2005; Pyke 2004; Boone et al. 2006) and produce information which can be used to guide monitoring efforts. Modeling will require intensive studies of EFS hydrology at multiple locations, especially to address important but unknown issues such as groundwater relations, winter precipitation, delineation of hydrological catchments, and evaporation–transpiration relations. Research needs to be increased to better our understanding of the relationships among EFS hydrology and ecology and short-term weather factors (Sand-Jensen et al. 2007), which will improve our projections for the potential impacts of long-term climate change. An increased research focus on EFS and climate change could result in new conservation priorities and strategies to mediate potential impending impacts.

5 Conclusions

The hydroregimes of EFS of forests of the Northeast, both headwater streams and forest pools, are principally expressions of weather patterns, or climate over the long-term. Climate projections for the Northeast are for increases in average annual temperature and change in precipitation patterns, with more intense events separated by longer drought periods. These projected changes will results in an increase in evapotranspiration rates with enhanced losses of surface water and soil water to evapotranspiration. The impact on EFS should be reduced hydroperiods and changes in hydroregimes, characterized by a more 'flashy' pattern of repeating cycles of inundation and drying. Larger, longer-hydroperiod pools would be increasingly isolated as smaller pools, which serve as 'stepping stones' for species and genetic exchange, became unavailable.

The impact of such change on freshwater fauna would be immense. The breeding success and/or composition of the characteristic fauna of northeastern, ephemeral forest pools (wood frogs, ambystomid salamanders, microcrustaceans) and cool-/cold-water headwater streams (brook trout [*Salvelinus fontinalis*], stream-breeding salamanders) would be severely impacted. A number of these species endemic to EFS are already state listed because of other threats to these habitats (e.g., land development).

Acknowledgements I very much appreciate the constructive reviews of early drafts of this manuscript by K. Nislow, A. Calhoun, and W. Lowe. The initial support for the author's research on climate and vernal pools was provided by the U.S. Forest Service's Northern Global Change Research program.

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