Chapter 6
Aquatic Conservation Planning at a Landscape Scale

Keith H. Nislow, Christian O. Marks, and Kimberly A. Lutz

Abstract Inland surface waters provide vital ecosystem services and support a diverse and important biota. An overriding feature of freshwater ecosystems is connectedness, which has been compromised by a wide range of human actions. Strong connections between terrestrial watersheds and receiving waters, and upstream and downstream linkages within river systems, make a large-scale perspective essential in conservation planning. In this chapter, we present the essential elements of large-scale aquatic conservation planning, with emphasis on stream and river ecosystems of the Northern Appalachian/Acadian Ecoregion. We review relevant aspects of the structure and function of freshwater ecosystems, discuss different approaches to aquatic conservation, and provide a case study of large-scale conservation planning and implementation in the Connecticut River basin.

Keywords Anadromous fish • Aquatic conservation • Connecticut River • Floodplain forests • Freshwater ecosystems

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K.H. Nislow (✉)
Research Fisheries Biologist and Team Leader, USDA Forest Service – Northern Research Station, Massachusetts, MA 01003, USA
e-mail: knislow@fs.fed.us

C.O. Marks
The Nature Conservancy, 25 Main Street, Suite 220, Northampton, MA 01060, USA
e-mail: cmarks@tnc.org

K.A. Lutz
Director, Connecticut River Program, The Nature Conservancy, 25 Main Street, Suite 220, Northampton, MA 01060, USA
e-mail: klutz@tnc.org

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6.1 Introduction

Although inland surface waters cover a small fraction of the Earth's surface, they represent critically important environments for landscape-scale conservation. Aquatic habitats vary in many important attributes and range in size from tiny forest pools and headwater streams to great rivers and large lakes. These habitats support a diverse and important biota, provide vital ecosystem services, and possess powerful esthetic, economic, recreational, and spiritual values. At the same time, increasing demands by an expanding human population have put immense pressure on aquatic habitats and resources and emphasize the need to support aquatic conservation and management (Dynesius and Nilsson 1994).

Aquatic resources have long been at the forefront of conservation efforts. A major impetus behind the inception of the U.S. National Forest System was the protection of water resources that had been threatened by destructive forestry practices (Glasser 2005). Initial efforts were largely focused on water quality and quantity related only to drinking water, and an extensive body of legislative and regulatory protections, ranging from the landmark Federal Clean Water Act of 1972 through a wide array of state and municipal regulations and statutes, has formed to protect this essential resource.

In addition to water quality, the extensive loss of freshwater wetlands, along with a belated recognition of their ecological importance, has resulted in significant regulatory protection for these habitats. Most recently, emphasis has increased on more inclusive aspects of aquatic habitats, including loss of aquatic biodiversity, which is both a global (Dudgeon et al. 2005) and regional problem (Saunders et al. 2006). In addition to the protections for freshwater species listed under the Endangered Species Act, specific legal protections in the U.S. for aquatic biota include the Anadromous Fish Restoration Act of 1965, which mandates conservation and management to conserve and protect fish species that migrate between freshwater and marine habitats.

The New England region of the U.S. (including the states of Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont), embedded in large part within the Northern Appalachian/Acadian and the Lower New England/Northern Piedmont ecoregions, provides a prime example of these issues, both in terms of their impacts and efforts to address them on a landscape scale. This is a well-watered area, whose abundance of freshwater habitats has contributed greatly to the health and welfare of the human population resident there. Following European settlement, large-scale land conversion, along with major projects to engineer river flow that fueled early industrialization, seriously compromised the ecological integrity of aquatic ecosystems throughout this region. Since then, major shifts away from heavy industry and agriculture and an increasing understanding of the value of water resources have led to large-scale recovery of forestlands and major improvements in water quality. In addition, a public that increasingly appreciates the ecological values of aquatic habitats provides a strong public base of support for conservation.

However, the legacy of land use (Nislow 2005, 2010), atmospheric pollution (Driscoll et al. 2001), and hydrologic change (Magilligan and Nislow 2001; Nislow et al. 2002), combined with emerging threats from climate change (Sharma et al. 2007; Chap. 15), invasive species (Les and Mehrhoff 1999), urbanization, and residential development (McMahon and Cuffney 2000) remain significant challenges (Chap. 2). As is the case for terrestrial conservation, perhaps the biggest institutional challenge to large-scale aquatic conservation planning is the pattern of land ownership. In contrast to other ecoregions, where large blocks of land are managed under single jurisdiction, the Northeastern U.S. is made up almost entirely of small landholdings, which can greatly complicate landscape-scale planning. While distinct, these regional characteristics and threats are not unique relative to other landscapes. Lessons learned in this region about aquatic conservation planning should be broadly relevant to conservation practitioners elsewhere.

In this chapter, we review the opportunities and challenges of aquatic conservation in the Northeastern U.S., particularly in New England and the Adirondack Mountains in order to provide an ecoregion-appropriate perspective on aquatic conservation planning. We focus this chapter on running water ecosystems (e.g., streams, rivers, and their associated floodplain and riparian corridors), but many of the principles we consider apply to ponds and lakes as well. As an illustration of these concepts, we outline and discuss the approach to aquatic conservation currently being implemented by the Connecticut River Program of The Nature Conservancy (TNC).

6.2 Attributes of Rivers and Streams in the Northeastern U.S.: Implications for Conservation

A number of excellent reviews of the structure and function of stream and river ecosystems is available for a wide range of levels of expertise and background (cf., Allan and Castillo 2007; Karr and Chu 1999). In this section, we review some of the aspects of river and stream ecosystems that are particularly relevant to conservation planning in the Northern Appalachian/Acadian ecoregion. While many of the examples are specific to this ecoregion, the general patterns and processes identified are relevant to aquatic ecosystems everywhere, and thus need to be taken into account in any aquatic conservation program.

6.2.1 Terrestrial-Aquatic Linkages

A major consideration in aquatic conservation planning is the intimate relationship between the stream and its valley (Hynes 1970). The strong influence of the terrestrial environment – the watershed – determines the physiochemical conditions of surface waters (Golley 1996). The transformation of chemical constituents as they move through terrestrial ecosystems determines the chemical and nutrient composition of the surface water. The timing, magnitude, and seasonality of runoff, influenced by the type of parent material and land cover, acts to erode and deposit sediments and other materials and form the physical structure of the stream channel. Terrestrial ecosystems also influence the flow of solar energy into the aquatic ecosystem via interception by forest canopies.

For the most part, the interaction between aquatic ecosystems and their watersheds go in one direction – downhill – as flows of water, sediment, and nutrients follow the direction of gravity. These large, unidirectional influences have an important consequence for aquatic conservation planning, as conservation measures for terrestrial ecosystems can contribute to and, in some cases, accomplish important aquatic conservation goals. Thus, aquatic conservation essentially requires a watershed-based perspective on the landscape, focusing on both aquatic and terrestrial upland habitats within the watershed.

However, while processes and conditions at any place in the watershed can influence aquatic habitats, areas directly adjacent to streams and rivers – riparian areas – have a disproportionate influence. Direct interception of sunlight by riparian trees has a large influence on water temperature (Moore et al. 2005), which in turn determines the types of aquatic organisms a waterbody can support. Trees in the riparian zone also contribute the majority of coarse organic material, in the form of leaves and downed wood. Fallen leaves frequently are the base of the food webs of small streams (Vannote et al. 1980), while large woody debris (LWD) has a major influence on stream ecosystem structure and function (Dolloff and Warren 2003).

While the direction of influence generally flows from terrestrial uplands to aquatic ecosystems, there are some important exceptions. In large rivers flowing through broad lowland valleys, the ‘balance of power’ between terrestrial and aquatic habitats may shift as the flood and sediment regimes of large rivers create distinct soils, landforms, and disturbance regimes that provide habitat for distinct floral and faunal assemblages (Naiman and Decamps 1997).

One fundamental consideration of the importance of terrestrial-aquatic linkages in conservation planning is that conserving terrestrial habitats (such as intact forest blocks) can go a long way toward conserving aquatic ecosystems. In the Northeastern U.S., large-scale reforestation (Foster et al. 2002) and reduction of point-source terrestrially-derived pollution has made a substantial contribution to aquatic conservation via major increases in water quality (Mullaney 2004). Because such conservation goals are likely to be promoted for other reasons, a fundamental decision for prioritization in any landscape-scale aquatic conservation program might well be to target aquatic conservation goals that will not be achieved as a corollary to terrestrial conservation.

In spite of the recovery of terrestrial ecosystems in many locations following the nadir of their ecological condition, current and expected future threats to aquatic habitats in the context of aquatic-terrestrial interactions remain. First, even a century past the historical peak of deforestation in the Northeastern U.S. (Foster 1992), the legacy of these large-scale changes in land-use remains on the landscape because some ecological processes critical to structure and function in aquatic ecosystems may take centuries to recover. In landscapes that have been subject to extensive timber harvest and land-use conversion, recovery of LWD to pre-disturbance levels lags behind forest recovery on the order of centuries (Bragg 2000). As a result, river systems in the Northeastern U.S. have some of the lowest levels of LWD recorded in North America (Magilligan et al. 2008). Given current trajectories for forest recovery, these levels are likely to increase substantially over the next 50 years (Nislow 2010). As another example, in spite of major legislation mandating pollution emission reductions, decades of base cation loss associated with acid rain will continue to make streams in the Northern Appalachian/Acadian ecoregion vulnerable to episodic acidification for decades to come (Driscoll et al. 2001). Finally, hydrologic alteration associated with the large number of dams and impoundments in this ecoregion will continue to affect river morphology and connectivity between rivers and adjacent riparian areas and floodplains (Magilligan and Nislow 2001).

6.2.2 Upstream–Downstream Linkages

Just as water flows from hill slopes to the stream channel, streams continue to flow downstream. In the process, they form predictable networks of channels as small streams meet and form larger streams, which in turn meet and form larger rivers. This characteristic network structure of stream and river ecosystems has important consequences for aquatic conservation planning. Due to the predictable longitudinal changes in physical habitat conditions, aquatic habitats at different points in the network support distinct natural communities (Vannote et al. 1980). Headwaters and large rivers have distinct fish communities, with overall fish species diversity tending to consistently increase in a downstream direction. At the same time, some species use the entire river network at different points in their life cycle. For example, a number of fish species spawn in small streams, putting their vulnerable eggs and fry in habitats with few predators, then move to more productive downstream areas that provide better conditions for growth. This pattern is most evident in anadromous fishes such as the Atlantic salmon (*Salmo salar*), which spawn in streams and rivers and then migrate to productive marine or lake environments. Fish may also use different parts of a river system as refugia from disturbances such as extreme temperatures, floods, or droughts.

The longitudinal connectivity of river systems has been seriously compromised by human activities in the Northern Appalachian/Acadian ecoregion, as it has in most ecoregions throughout the continent south of the boreal forest. Water power was the backbone of early industrialization in most of North America. In the Northeastern U.S., many of the small mill dams of that era still dot the landscape, along with major dams on all of the region’s large rivers. These structures, combined with a more recent bout of flood control dams in the early-to-mid-twentieth century, have resulted in the Northeastern U.S. having the highest number of dams per square kilometer of any region in the U.S. (Graf 1999). While the effects of dams on river ecosystems are a national and global issue, the way that the impacts of dams are manifest in aquatic ecosystems in the Northeastern U.S. has important implications for conservation. In spite of the high density of dams, dams in the Northeastern U.S. impound a lower portion of the total annual runoff than in any other ecoregion (Graf 1999). This is due to a combination of the high annual runoff characteristic of this mesic region, combined with a large number of small dams, which are frequently either run-of-the-river or have only limited storage capacity. At the ecoregional scale, therefore, dams may impact rivers in the Northeastern U.S. more through effects on connectivity than through changes in hydrologic or sediment regimes (Graf 2006).

Further, in addition to dams, agricultural, residential, and urban development have resulted in very high road densities (Riiters and Wickham 2003), which often run along valley floors and cross streams at numerous points. Many of these road crossings are barriers to the passage of fish and other aquatic organisms (Warren and Pardew 1998). The combination of numerous small dams and high road densities underscores the importance of longitudinal connectivity as a conservation issue in this region.

6.2.3 Invasions, Extirpations, and Restorations in Aquatic Ecosystems

While the physico-chemical regime is an important target for aquatic conservation, major changes in aquatic community structure itself can have feedback effects at the species, community, and ecosystem level. These changes include invasions (the purposeful or accidental introduction and establishment of non-native species), range extensions (natural changes in species abundance and distribution), extirpations (elimination of a native species), and restorations (re-establishment of native species that have been extirpated).

As a function of its long post-European settlement history and comparatively early development, all of these factors have had major influences on aquatic and riparian ecosystems in the Northeastern U.S. In a sense, even the ‘native’ flora and fauna are composed of relatively recent colonists following the recession of the most recent glacial ice sheet beginning approximately 19,000 years ago (Curry 2007; Schmidt 1986). As a consequence, native aquatic assemblages in the region are naturally depauperate, with a low number of widely distributed species, in strong contrast to unglaciated rivers such as the Colorado River in the Southwestern U.S., which has a unique and specialized fauna that has evolved over millions of years (Stanford and Ward 1986). This low species diversity in the Northeastern U.S. may in itself contribute to vulnerability to invasion, as some evidence indicates that invasive species are more likely to become established in species-poor communities, particularly in highly human-modified watersheds (Gido and Brown 1999). Apart from obligate aquatic species such as fishes, many exotic plant species have invaded riparian areas, where open canopies and frequent disturbance provide ideal conditions for colonization (Zedler and Kercher 2004).

Invasive species present a special challenge for aquatic habitat conservation. Frequently, eliminating these species is a costly undertaking with high uncertainty that these efforts will work. In some cases, not dealing directly with invasive species may make other conservation efforts (such as habitat conservation) moot (Simberloff et al. 1999). At the same time, in the case of well-established and valuable sport fishes, such as introduced salmonids and black basses, these species have strong constituencies among sport and commercial fishers, and efforts for removal and control frequently meet with public resistance. Further, it is important to distinguish between range extensions and invasions, particularly in the context of species responses to global climate change (Chap. 15). All of these difficulties, however, emphasize the conservation value of sites that are relatively free from invaders and suggest the vital importance of efforts to prevent the establishment of invasive species in these areas whenever possible.

In addition to invasions, European settlement brought with it a wave of extinctions and extirpations of aquatic species. Two driving factors for this stand out in importance. First, barriers to migratory fish resulted in widespread extirpations at the regional and watershed levels (Saunders et al. 2006). For example, in the Connecticut River basin Atlantic salmon were completely extirpated, Atlantic and shortnose sturgeon (*Acipenser oxyrinchus* and *A. brevirostrum*) nearly extirpated, and the abundance of American eel (*Anguilla rostrata*), American shad (*Alosa sapidissima*), and blueback herring (*Alosa aestivalis*) reduced by an order of magnitude (Gephard and McMenemy 2004). Given that anadromous fishes make up as much as 30% of native fish faunas in some coastal rivers, this constitutes a substantial change in aquatic community structure. Second, intensive trapping caused major declines in and widespread extirpation of North American beaver (*Castor canadensis*). Beaver are a keystone species in aquatic and riparian ecosystems throughout the northern hemisphere, profoundly altering aquatic habitats by constructing dams and influencing riparian vegetation by their use of trees for forage and materials (Collen and Gibson 2000).

However, in the last century, coincident with a decline in water-powered industry, an increase in forested land cover, and major changes in public sentiment toward conservation, several extirpated aquatic and riparian species have been re-established in the Northeastern U.S. Beaver have been re-established via initial management reintroductions along with natural recolonization from local refugia following the regulation of trapping and now have reached high population densities in many areas (Foster et al. 2002). Also, for the last 30 years, migratory fish species such as the Atlantic salmon have been the subject of active restoration efforts throughout this region, involving substantial investments at the federal, state, and private levels. In contrast to the natural recovery of beaver, efforts to re-establish native anadromous fishes have met with only mixed results, and the majority of native anadromous fishes are still absent or at substantially reduced population sizes compared to historical levels (Saunders et al. 2006).

6.3 Aquatic Conservation Strategies in the Northeastern U.S.

6.3.1 Species-based Approaches to Aquatic Conservation

Many conservation efforts are explicitly tied to the population status of particular species or groups of species. Others are concerned with the conservation of overall species diversity. Both of these approaches require an understanding of the habitat requirements that support either particular species of concern or the habitat features associated with a high level of species diversity.

A species-based approach confers some important advantages (Chap. 17). Species that are economically important and have large public constituencies provide considerable support to conservation efforts. Conserving habitat and protecting environments for so-called ‘umbrella’ species can help to conserve other non-target species, as well as to protect key ecosystem services such as erosion control and maintenance of water quality. Species-based approaches also can provide specific, measurable targets (e.g., species persistence, increased abundance and distribution) to evaluate the success of the conservation action. Finally, powerful legislation (such as the Endangered Species Act) can provide significant support for species-based conservation programs. Anadromous fishes in the Northeastern U.S. are a major focus of species-based conservation efforts (Gephard and McMenemy 2004). These efforts are backed up by two major pieces of federal legislation. The Anadromous Fish Conservation Act of 1965 applies to all native anadromous species, while two native species, the Atlantic salmon and the shortnose sturgeon are also listed under the Endangered Species Act.

In addition to their strong constituencies and legal support, anadromous fish such as Atlantic salmon, alewife (*Alosa pseudoharengus*), and native populations of sea lamprey (*Petromyzon marinus*), which require a wide range of habitats to complete their complex life cycles, may serve as useful umbrella species for all those species that require only a subset of these habitats. For example, the listing of the last remaining wild Atlantic salmon stocks in Maine under the Endangered Species Act (National Research Council 2004) has resulted in the purchase of conservation easements along hundreds of kilometers of riparian forests (Haberstock et al. 2000; National Research Council 2004) as well as the removal of dams and other barriers in many watersheds (Gephard and McMenemy 2004).

The ecological realities associated with the landscape-scale context of the New England and the Adirondack Mountains, as well the rest of the formerly glaciated portions of North America, present some major challenges to species-based conservation, as well as provide examples of some of the intrinsic limitations of this approach. Compared to other regions on the continent, where high species diversity and high rates of endemism make resident freshwater fishes important conservation targets, the Northern Appalachian/Acadian ecoregion has a generally depauperate stream and river fauna, made up of common, widely-distributed habitat-generalist species. However, even for species whose habitat requirements have been extensively studied, species-based approaches have some important pitfalls. Habitat factors may be limiting to species abundance and persistence under some environmental contexts but not others, and the effect of habitat conservation or restoration may be therefore quite uncertain. For example, re-establishment of riparian forests may increase the population abundance of stream salmonids in warmer streams where riparian shade prevents temperatures from increasing beyond tolerable levels, but may reduce abundance in colder streams (Nislow 2005, 2009). Perhaps most problematic, in many situations, species abundance and persistence may have a strong stochastic component or may be largely determined by factors external to conservation efforts. For example, in spite of major habitat conservation efforts in rivers and streams throughout the Northeastern U.S., anadromous fish populations continue to decline precipitously throughout the region (Saunders et al. 2006). While this may be in large part due to factors influencing marine survival, and despite the fact that improvements in freshwater habitat may have wide-ranging positive effects, conservation efforts undertaken on behalf of species that continue to decline run the risk of being judged as failures.

6.3.2 Process- and Services-based Approaches to Aquatic Conservation

As an alternative to species-based conservation planning, process- and services-based approaches focus on conserving or restoring critical processes and habitat conditions that have been altered by human activity. In this approach, the explicit goal is the process (e.g., sediment balance, flow regime, longitudinal connectivity) with the implicit assumption that these processes, if restored to their natural state, will help conserve species of concern and biological diversity at multiple spatial scales.

This approach acknowledges the large indeterminacy in species response to habitat management and change. In addition, the process-restoration approach may help to avoid the conflicts that can emerge when managing separately for multiple species of interest. Also, because the target of a process-based approach is the process or condition itself, targets may be easier to set, monitor, and achieve. Finally, protecting key processes protects key ecosystem services derived from freshwaters, including protection of water supply and mitigation of catastrophic floods, along with recreational and associated economic opportunities.

Process-based restoration is increasingly used in river management (Beechie and Bolton 1999; Rheinhardt et al. 1999). In particular, the restoration of natural flow regimes has become an important goal in river conservation and restoration, with the expectation that restoring this key process will result in across-the-board improvements in habitat conditions for a wide range of riverine and riparian species (Poff et al. 1997). The process-based approach has also been widely incorporated into floodplain and river channel restoration efforts (Beechie et al. 1996; Berg et al. 2003). More recently, it has been expanded to include an emphasis on restoration of a natural range of variability (Richter et al. 1997) as opposed to targeting specific conditions.

In spite of important advantages compared to species-based approaches, process-based conservation approaches pose significant challenges, particularly in the Northeastern U.S. For example, large tracts of wilderness in the Northwestern U.S. and Canada and eastern Siberia provide useful reference conditions that help guide process-based restoration in those regions (Naiman et al. 2002). In contrast, the majority of rivers in the Northeastern U.S. have a long history of anthropogenic modification. Apart from making it difficult to determine appropriate reference conditions, environmental change may dramatically alter both the magnitude and direction of process restoration impacts. For example, restoration of historical flood regimes with the expectation of restoring native floodplain vegetation may have the opposite effect in the presence of exotic invasive vegetation, which can often take advantage of flood-disturbed soils (Zedler and Kercher 2004). In addition, large-scale impacts, particularly global climate change, may dramatically alter the way in which processes affect target species and communities. Finally, it is unclear whether the corollary effects of either species-based approaches (with process and services conservation as a byproduct) or process-based approaches (with species conservation as a byproduct) are most effective at achieving the goals of aquatic conservation. In an explicit comparison, Chan et al. (2006) found that targeting biological diversity achieved a high percentage of service-based goals, whereas targeting services failed to protect a large percentage of species.

Given these considerations, it seems that incorporating both species-based and process-and services-based approaches would have a number of benefits for achieving aquatic conservation on a landscape scale. To further explore this point, in the following section we discuss in detail an example of a major aquatic conservation program in the Northeastern U.S. that uses both these approaches.

6.4 Case Study: The Nature Conservancy's Connecticut River Program

6.4.1 The Geographical and Cultural Context for Conservation of the Connecticut River

The 660 km-long Connecticut River is New England's longest river. Its headwaters are in the Fourth Connecticut Lake at the Canadian border in Québec, and it empties into Long Island Sound at Old Saybrook, Connecticut. The watershed encompasses an area of over 28,000 km^2 and has 44 major tributaries each with drainage areas greater than 75 km^2. All told, there are over 32,000 km of streams in the watershed. The Connecticut River drops 730 m from its source to the sea, and has a daily average flow of nearly 450 m^3/s. The flow has ranged as high as 8,000 m^3/s and as low as 27 m^3/s. The lower 100 km of the river are tidal, with the boundary between salt and freshwater about 27 km from its mouth under normal conditions. It has a major influence on the coastal marine ecosystems near its mouth, as its waters represent 70% of the freshwater inflow to Long Island Sound.

Because it runs predominantly north-south, the Connecticut River valley encompasses almost the entire range of environmental and socio-economic conditions in the Northeastern U.S. and provides an example of nearly all of the threats and issues found in the region (Chap. 2). During the colonial period up through the early part of the twentieth century, most of the basin was heavily deforested with associated erosion of soils, followed by a dramatic recovery of forest cover starting in the mid-1800s in Southern New England (Foster et al. 2005). The watershed is now 80% forested, 12% agricultural, 3% developed, and 5% wetlands and water.

The southern half of the Connecticut River valley was among the first parts of the country to industrialize, which brought with it increasing levels of water pollution. The mills from that era left a legacy of altered fluvial geomorphology (Walter and Merritts 2008) and numerous dams that continue to obstruct fish passage (Fig. 6.1) and alter the hydrologic regime of the river and its tributaries (Magilligan and Nislow 2001). Since the widespread initiation of wastewater treatment following the 1972 Federal Clean Water Act, along with the loss of heavy industry throughout the watershed, water quality has improved in the Connecticut River, with downward trends in total phosphorus, total nitrogen, and indicator bacteria, and upward trends in pH and dissolved oxygen (Mullaney 2004). At the same time, major efforts to restore key anadromous fishes that had been extirpated or greatly reduced in abundance are active in the basin (Gephard and McMenemy 2004), including extensive efforts by the U.S. Fish and Wildlife Service to restore Atlantic salmon to the watershed and improve passage for other species.

The conservation opportunity in this recovery of natural forest cover and water quality in the Connecticut River is challenged by most of the major threats to ecosystems in the region. Urbanization and residential development, particularly in the southern part of the Connecticut River watershed, is a significant emerging threat. The watershed has 390 towns, villages, and cities, which are home to 2.3 million people. Urbanization and residential development are challenges for river conservation in many ways including polluted runoff, increased sediment, and greater runoff from impervious surfaces that increase flash flooding. Specifically, much of the urbanization and residential development, both historic and contemporary, is located in the river's floodplains. Consequently, protecting urban centers from flood damage has led to the construction of a system of 14 flood control dams on major Connecticut River tributaries.

The Connecticut River floodplains contain some of the richest farmland in the Northeastern U.S. Its deep, well-drained soils are a product of glacial Lake Hitchcock, which flooded much of the valley as the last ice sheet receded northward at the end of the most recent period of glaciation, in combination with more recent river floods (Klyza and Trombulak 1999). In a region with generally steep topography, these large flat sites are also, quite understandably, coveted for development. The construction of roads and other infrastructure associated with urbanization and residential development increasingly fragment both streams and riparian habitats (Fig. 6.1). This proliferation of edges and disturbance and cultivation of fertile soils often create ideal conditions for the spread of invasive plant species that further degrade remnant natural riparian forests.

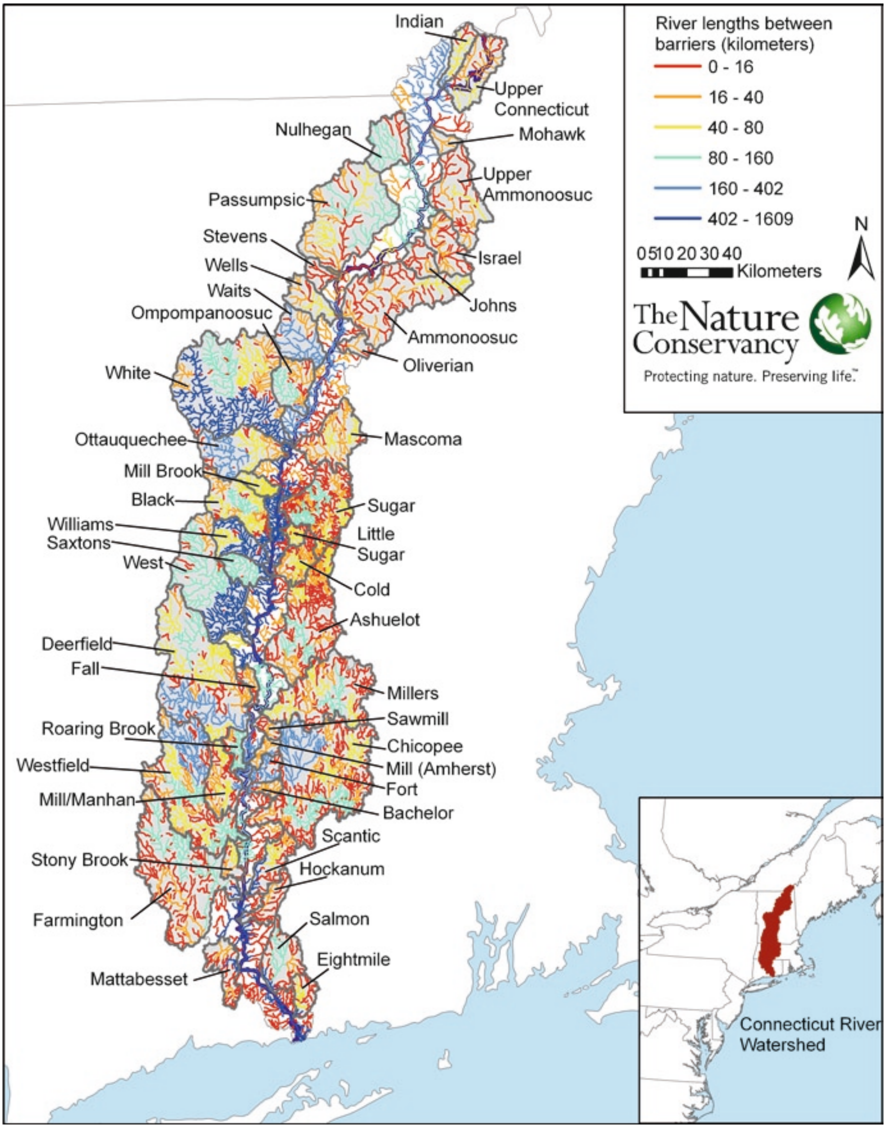

Fig. 6.1 Map of the Connecticut River watershed categorizing streams by the length without stream barriers (Datasources: Watersheds from TNC's size 2 and 3 watersheds, 2001; Connected lengths from USGS NHD-plus, 2006) (Copyright: The Nature Conservancy, Connecticut River Program)

The relatively recent origin of New England forests after agricultural abandonment and periodic logging have resulted in a forest structure with on average much smaller trees than in the pre-settlement forest. Consequently, fewer logs of sufficient size fall into streams to form important pool habitat (Magilligan et al. 2008; Nislow 2010). Streams flowing through agricultural fields also often lack the requisite riparian buffers with large trees. While much of the Connecticut River basin has higher buffering capacity than other major basins in the region due to a preponderance of calcium-rich bedrock, headwater streams, particularly in the upper watershed north of the Massachusetts border are in areas with acidic forest soils overlaying granitic parent materials, and are consequently vulnerable to acidification. Both trees (Driscoll et al. 2001) and fish have been severely affected (McCormick et al. 2009).

These current and emerging threats require regulation to keep pace, a considerable challenge give that the Connecticut River basin includes parts of four states (Connecticut, Massachusetts, New Hampshire, Vermont), and numerous municipal jurisdictions, which in New England play a strong role in manifesting specific conservation practices (Chap. 4). For example, the combination of increased precipitation and runoff due to projected climate change (Marshall and Randhir 2008) and development spreading further onto floodplains could have dire consequences for both people and nature. Regulatory foresight by municipalities and proper management of floodplains could reduce these potential impacts.

Non-governmental organizations and land trusts can also do much to meet these conservation challenges as they have done in the past. The Nature Conservancy has been working in the Connecticut River landscape for more than 40 years. The Conservancy's first land acquisition in the watershed was 18.6 ha at Burnham Brook in East Haddam, Connecticut in 1960. Acquisition of ecologically significant properties accelerated during the late 1990s and early 2000s as land-use patterns began to change and large forested tracts in the northern portion of the basin became available for purchase. These largest tracts include the protection of the 8,900 ha in the Nulhegan River watershed of Vermont, protecting a complex of northern hardwood forests, ponds, and lowland spruce-fir forests, and the acquisition with several key partners of three large tracts (totaling over 73,000 hectares) in New Hampshire that conserve mountain peaks, ponds, wetlands, and lowland forests and swamps in the New Hampshire headwaters region. In addition to significant land protection in the northern portion of the basin, several thousand hectares of tidal wetlands were purchased, following the Ramsar Designation, recognizing international significance of the wetlands of the Connecticut River. In total, The Nature Conservancy and its partners have protected over 100,000 ha in the watershed.

6.4.2 *Project History*

In the late 1990s, as regional (in contrast to site-based) planning efforts began in earnest throughout The Nature Conservancy, the Connecticut River emerged as an area of regional significance. The Nature Conservancy chapters located in the four states through which the Connecticut River flows initiated a coordinated Conservation Action Planning (CAP) effort designed to identify the most important sites within the basin. It was during this first CAP process that the vision of a watershed-scale project, as opposed to separate site-scale projects, was adopted.

From April through November 2004, the Connecticut River Program hosted three more basin-wide CAP workshops, but with a fundamentally different goal than the previous workshops. The goal of the second round was to explicitly address freshwater conservation at the basin scale. Close to 50 attendees from all four basin states, including federal and state natural resource staff, academics, non-profit organizations, and staff from The Nature Conservancy, participated in one or more workshops (Chap. 11). In addition, expertise in a wide variety of disciplines was represented: fisheries biologists, mussel experts, floodplain specialists, hydrologists, geomorphologists, botanists, and ecologists. During the CAP planning process, attendees focused on three tasks:

1. Identify the biological diversity of greatest interest, referred to in this process as conservation targets, and its current and desired status.
2. Identify the most critical threats currently or likely to degrade this biological diversity.
3. Develop strategies to abate the threats and maintain or restore biological diversity given existing constraints and opportunities.

The outcomes of these three tasks were as follows:

Connecticut River Conservation Targets The biological diversity of the Connecticut River basin is comprised of numerous species and communities, making it impractical to evaluate each for conservation planning. Conservation targets, therefore, represent a subset of species, communities, and ecological systems, which were selected to comprehensively represent the biological diversity of the basin. The CAP participants identified six conservation targets for the Connecticut River basin:

1. The Connecticut River's main stem
2. Its tributary ecosystems, which include 38 major tributaries encompassing over 38,000 km of river
3. Its tidal wetlands and estuaries, which include an extensive system of high-quality freshwater and brackish tidal marshes
4. Its floodplain ecosystems and riparian zones
5. Migratory fish, which include ten diadromous fish known to inhabit the river
6. Mussel assemblages, including 12 species tracked by state heritage programs, the rarest of which are the dwarf wedgemussel (*Alasmidonta heterodon*), brook floater (*A. varicosa*), and yellow lampmussel (*Lampsilis cariosa*)

Key Conservation Strategies During the workshop, more than 45 strategies were identified, many of which were already being implemented in whole or in part by the numerous organizations and agencies that have a stake in the health of the Connecticut River. Therefore, TNC decided to critically examine where its skills and expertise could best be used to take a leadership role in advancing a strategy that had yet to be fully implemented, or to be a catalyst for a strategy that had been implemented but hadn't gathered sufficient momentum to achieve its desired conservation outcomes.

The five strategies selected were as follows:

1. Restore the natural flow, form, and other dynamics of the river to improve aquatic diversity along the waterway.

2. Promote river connectivity – unbroken access to the river throughout the length of the river and its floodplain – which is essential for healthy floodplain forests and the movement of fish and other species.
3. Reduce the spread of invasive plant and animal species, which displace native species and their habitats, and safeguard uninvaded areas.
4. Restore floodplain forests along floodplain rivers.
5. Protect and preserve lands critical to the river's health.

This plan was adopted by the four state chapters of The Nature Conservancy, and the Connecticut River team was assembled. The original team consisted of Conservancy staff in all four basin states as well as a regional freshwater team leader. While the core team has remained much the same, numerous working groups have developed since 2004, and these working groups include key agency partners such as U.S. Army Corp of Engineers, U.S. Fish and Wildlife Service, U.S. Forest Service and U.S. Geological Survey. Although the objectives and action steps presented in November 2004 at the end of the project's planning phase have been refined over time, the same themes continue to form the basis of the work today. We believe that involvement of a wide diversity of stakeholders in the planning process was critical in creating a robust conservation plan. First, the participants' expertise in a variety of disciplines and in geographies allowed for a robust discussion of the important elements of biological diversity and of ecosystem process across the entire basin. The variety of perspectives on the development of strategies also required the diversity of perspectives from watershed-based NGO's to large federal agencies. Finally, the process itself was designed to bring groups to consensus decisions, which in turn empowered TNC to implement strategies that were selected by the group.

6.4.3 Current Program and Future Challenges

The vision for the Connecticut River Program resulting from the CAP is to improve the health of New England's largest river system by restoring both natural flow patterns and connectivity. Specifically, the program envisions the restoration of flow patterns that (1) display natural variations in magnitude, frequency, duration, timing, and rate of change, (2) transport appropriate loads of sediment and nutrients, and (3) maintain productive and diverse habitats supporting numerous species. Further, the program seeks to restore unfragmented, connected river and stream networks that permit the natural movement of nutrients, materials, and individual organisms and sustain populations and ecosystems.

The Connecticut River Program is further envisioned as a center of scientific excellence, actively exporting knowledge in environmental flow management, solutions to stream fragmentation, and floodplain restoration. Five years after the initial planning, substantial progress has been made on all fronts. Progress on each of these goals is described below.

Current Research The relatively large involvement of scientific research from the beginning of this project was needed in part because the CAP identified critical gaps in knowledge about how this aquatic system functions. Specifically, streams in the watershed have far more barriers on them than can be dealt with individually (Fig. 6.1). To prioritize stream barriers for removal, it is important to know the minimum distance of connected stream length that can support a viable fish population. Even for well-studied, widespread species such as Eastern brook trout (*Salvelinus fontinalis*), clear answers for this question are not known. To address this knowledge gap, a partnership was established with the U.S. Geological Survey and the U.S. Forest Service. By capitalizing on a long-term study site, TNC has a unique opportunity to learn from its partners to test the effects of increasing stream connectivity via culvert replacement on a wild brook trout population. Long-term monitoring of survival, growth, and movement will enable determination of the effects of increasing connectivity on a stream system that is highly representative of impacted streams throughout the Northeastern U.S. on a species that is a widespread sentinel of ecosystem change and is of strong management and public interest.

Similarly, floodplain forest ecology has been little studied in the Northeastern U.S., unlike in the southern and western regions of the country. The physical processes of a river not only determine its geomorphology but also act as environmental filters that determine potential species distribution and floodplain forest composition. Threshold values in physical processes that result in changes in species composition can be quantified and combined in a predictive model. For example, species differ in the maximum flood duration that they can survive. The purpose of the floodplain forest research is to quantify these ecological thresholds for floodplain forests and incorporate them into a model that makes spatially explicit predictions about the past, present, and future of Connecticut River habitats as a function of key drivers of environmental change like climate and dam operation. Determining how much flooding different types of floodplain forests in the New England require will be vital to guiding hydrologic restoration prescriptions.

In addition to these knowledge gaps, working at the scale of a whole watershed requires new scientific tools. With 70 major dams on the tributaries and 13 on the mainstem, most sub-watersheds have suffered considerable hydrologic alteration (Fig. 6.2). Major dams are defined as those with a storage capacity exceeding 10% of annual runoff for that sub-watershed. Modifying the operation at all these dams for ecological benefit will require knowing how changes to them interact with changes in other parts of the watershed, because it is crucial to maintain flood protection for downstream sites. To simulate different dam operation and climate scenarios, a model is needed that includes all 44 major tributaries and 70 major dams. Such a model is being developed in collaboration with the U.S. Army Corps of Engineers and the University of Massachusetts. Since watersheds in the Northeastern U.S. tend to have multiple dams rather than the simpler case of a single dominant dam, as is more typical in the Western and the Southern U.S., this modeling approach opens new possibilities for hydrologic restoration throughout much of the region.

With each of the goals above, every attempt has been made to disseminate lessons learned throughout the scientific community. This has been done this through

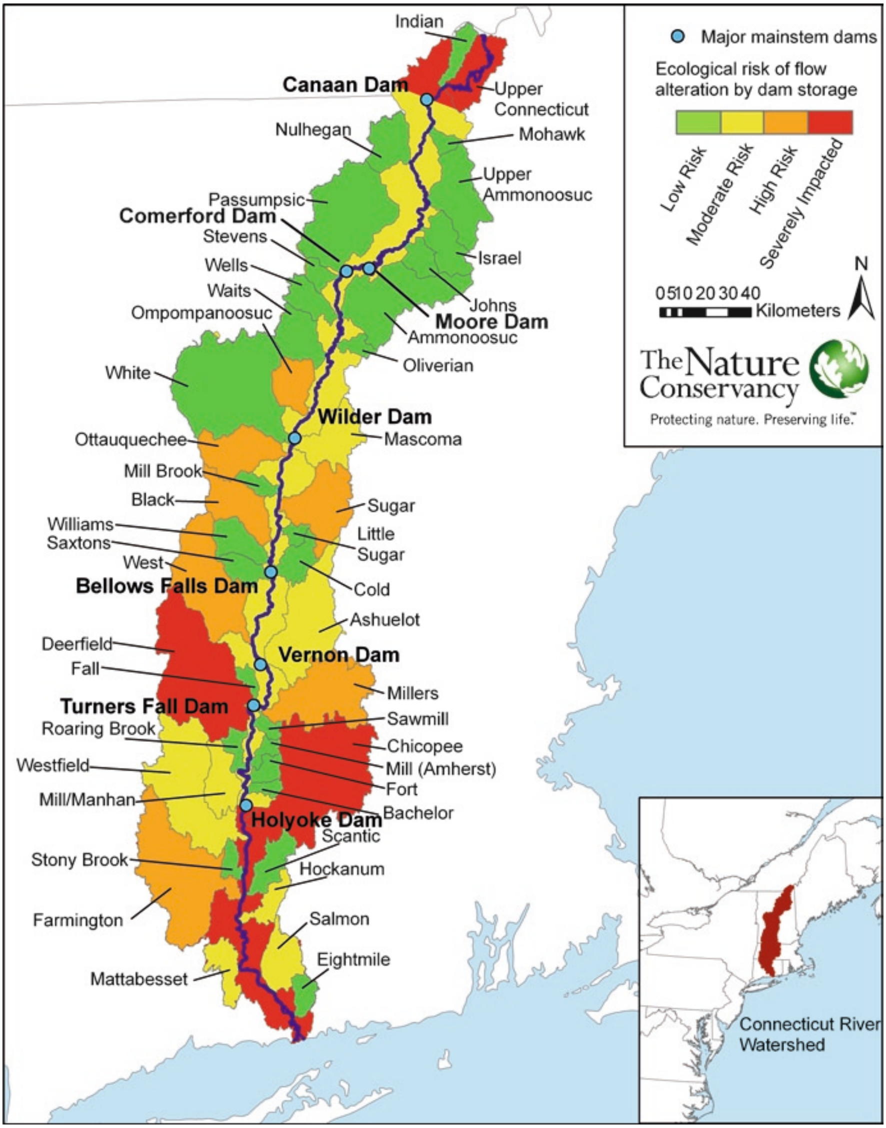

Fig. 6.2 Flow ratings in Connecticut River sub-watersheds, based on the combined storage capacity of large dams within each sub-watershed relative to its annual runoff (see also Zimmerman and Lester 2006) (Datasources: Watersheds from TNC's size 2 and 3 watersheds, 2001; Streams are NHD-plus from USEPA and USGS 2008; Flow rating data from Julie Zimmerman) (Copyright: The Nature Conservancy, Connecticut River Program)

peer-reviewed articles (Letcher et al. 2007; Zimmerman et al. 2010), presentations at national and international meetings (Ecological Society of America, Conservation Biology, Instream Flow Council), and extensive internal communications.

6.5 Lessons Learned

From our experience with the Connecticut River Program, we believe that planning for aquatic conservation at the regional or large-watershed scale brings with it considerable benefits. First, it yields a better understanding of the spatial distribution of threats and the system-wide consequences of management actions. For example, when the project was initiated, the focus was on dam modification at two priority tributaries in the central portion of the basin. However, it was quickly realized that flow alteration was pervasive (a large portion of the basin was altered) and connected (flow modifications at one point could have important impacts well downstream, and dams in many cases are operated in concert). Therefore, the analysis was expanded to all 70 large dams, which will allow the program to deal with altered flow regimes by working at different sites and with different dam operators to achieve basin-wide as well as tributary-specific conservation objectives. In addition, it will help to ensure that flow prescriptions accomplished at one site will not cause deleterious effects downstream.

Second, it allows incorporation of both target-based and process-based approaches. Planning at a larger scale naturally leads to thinking about critical river processes such as flow, sediment transport, and channel migration that are difficult to consider at a limited geographic scale. At the same time, it permits consideration of the relationships between these processes and targets (both species and communities) at scales that are relevant to the maintenance of viable populations.

Third, it gives more opportunities to engage with research early and often. Engagement with the research community is an essential part of the Connecticut River Program. We feel that working at large scales makes it more likely that the interests and expertise of researchers and conservation practitioners will overlap. Further, working at a large scale allows for the level of replication that is essential for generating results that both researchers and conservation practitioners can use.

Finally, it prevents an exclusive emphasis on ‘showcase’ sites. Yet another benefit of regional-scale planning is that it encourages conservation planning to move away from an exclusive emphasis on the ‘best’ sites. Given the uncertainty in determining which sites add most conservation value, particularly in the context of climate and other sources of large-scale environmental change, implementing a range of strategies from protection of the best habitats to restoration of degraded habitats will undoubtedly lead to a healthier watershed.

While offering many advantages, large-scale planning presents challenges. An example is the involvement of partners who, for reasons of organization limitations, cannot work outside of a specific geography. This has been a challenge for The Nature Conservancy, but one that as a multi-state organization, it can manage by deploying chapters to work closely with state agency staff on state-specific aquatic policies or with local watershed groups on tributary-specific issues. While planning should be done at a large scale, implementation usually comes down to site-specific actions. Demonstrating concrete accomplishments at the local scale is, therefore, somewhat paradoxically an essential element in successful landscape-scale aquatic conservation.

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