

FEATURE

Conservation of Aquatic Biodiversity in the Context of Multiple-Use Management on National Forest System Lands

Photo credit: USFS, Pacific Northwest Region

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The U.S. Department of Agriculture Forest Service (USFS) manages 193 million acres of public lands across 43 states and Puerto Rico. The original intent behind reserving lands managed by the USFS was to improve and protect forests, secure favorable conditions for water flows, and furnish a continuous supply of timber for the nation. Through time national forests have evolved, so they are managed for a broad array of uses. Differing expectations have led to conflicts between aquatic conservation and other aspects of the USFS' mandate. In the 1990s, these conflicting goals came to a head with the listing of the northern spotted owl *Strix occidentalis caurina* and the need to better protect streams that fostered populations of anadromous salmonids. To better balance these conflicting uses, the agency placed additional emphasis on conserving and restoring aquatic systems by integrating conservation concepts into the forest planning process. If the USFS is to succeed in protecting and restoring aquatic biodiversity, it must continue to address traditional challenges such as minimizing the effects of timber harvest, roads, grazing, and mining on aquatic systems while improving policies and practices regarding contemporary challenges such as climate change and invasive species.

People have modified over a third of the global landmass and currently use more than half of the available surface freshwater (Vitousek et al. 1997). This intense modification and use of terrestrial and aquatic ecosystems has imperiled many species (Stein et al. 2000). Of the species at risk, a disproportionate number of these are aquatic such as fishes, crayfishes, mollusks, and amphibians (Ricciardi and Rasmussen 1999; Williams et al. 2011). One of the best ways to minimize threats to these at-risk aquatic species is by protecting their habitat.

For the last 150 years, federal agencies have overseen an expansive federal estate managed for multiple public needs that has played a pivotal role in maintaining biodiversity (Groves et al. 2000). The bulk of these federal lands are administered by the Bureau of Land Management (248 million acres), U.S. Forest Service (USFS; 193 million acres), U.S. Fish and Wildlife Service (89 million acres), National Park Service (80 million acres), and Department of Defense (11 million acres; Vincent et al. 2017). Although many people view national parks and wildlife refuges as the areas with the primary role of protecting the United States' biodiversity, lands managed by the USFS and Department of Defense host the largest number of taxa listed under the Endangered Species Act (ESA, 16 U.S.C. ch. 35 § 1531 et seq.; Stein et al. 2008). These public lands will play an increasingly important role in maintaining aquatic biodiversity given the accelerating development of privately owned rural lands (Martinuzzi et al. 2014), mounting political pressures to limit protection of species on private lands (Epstein 2014), and the projected effects of climate change (Lynch et al. 2016). This article provides an overview of the roles and contributions of the USFS in conserving aquatic biodiversity and the history, laws, and policies influencing the agency's activities in that regard. Moreover, it discusses current efforts as well as ongoing and anticipated challenges to manage for aquatic biodiversity in the context of the agency's multiple-use mandate.

The majority of lands administered by the USFS are in the western United States. This pattern reflects the availability of public lands when the Forest Reserve Act (16 U.S.C. ch. 2, subch. I § 471 et seq.) was in effect (1891–1907) and allowed presidents to set aside lands from the public domain that would eventually become the National Forest System (NFS). In 1911, the passage of the Weeks Act (36 Stat. 961) added 20 million acres of national forest lands to the eastern United States. This bill authorized the purchase of forestlands in headwaters of navigable streams to protect water quality from the effects of timber harvest. The last large expansion of national forest acreage came when damaged agricultural lands purchased under the National Industrial Recovery Act of 1933 and the Emergency Relief Appropriations Act of 1935 were designated as national grasslands and put under the

agency's management in 1960. Currently, the USFS manages land in 43 states and Puerto Rico, comprising 193 million acres across the 154 national forests and 20 national grasslands that collectively make up the NFS.

This breadth of land ownership results in the USFS having substantial influence on aquatic ecosystems across the nation with over 220,000 mi of fishable streams and more than 10 million acres of fishable lakes and reservoirs on these lands (Shively et al. 2018, this issue). Although these numbers are impressive, they do not fully illustrate the value of the agency's protection of watersheds. Protecting the integrity of watersheds on NFS lands is particularly valuable because they constitute the domestic water source for many cities. Nearly one-fifth of streamflow in the United States starts on NFS lands; in the western United States, two-thirds of the precipitation falls on NFS lands and this accounts for more than half of total streamflow (Brown et al. 2008). Furthermore, many of the nation's longest remaining free-flowing sections of rivers traverse land managed by the USFS (Benke 1990).

Because the national forests were originally established to protect forested lands in the western United States and headwater streams in the eastern United States, most of these holdings are at higher elevations, where aquatic systems tend to be relatively unproductive. This pattern of ownership may not be ideal for protecting aquatic biodiversity hotspots (Flather et al. 1998; Burnett et al. 2007; Jenkins et al. 2015) since biodiversity, like aquatic productivity, generally decreases with increasing elevation (Scarnecchia and Roper 2001; Muneeppeerakul et al. 2008). National forests in the southeastern United States and southern California contain the highest aquatic biodiversity in the United States, although NFS lands constitute a relatively small footprint in these areas (Lydeard and Mayden 1995; Moyle 1995; Flather et al. 1998).

National forest lands host at least 355 ESA-listed taxa or species (Stein et al. 2008). If all taxa (save vascular plants) are considered, 157 of 227 (69%) of the taxa protected by the ESA on NFS lands are aquatic. Several of the listed aquatic taxa are migratory and require large, connected riverine networks usually extending beyond NFS lands to ensure their persistence. These include cold-water salmonids such as trout, salmon, and char in the genera *Oncorhynchus* and *Salvelinus*. These species are highly prized for their cultural, commercial, and recreational value (Trout Unlimited 2015). The scope of aquatic habitats on NFS lands has resulted in a wide range of aquatic species being present on these lands (Figure 1). The assessment of the value of NFS lands to aquatic biodiversity has been described at the broad scale (Muneeppeerakul et al. 2008; Stein et al. 2008), but conservation efforts will also benefit from a finer-scale assessment (Shively et al. 2018, this issue).

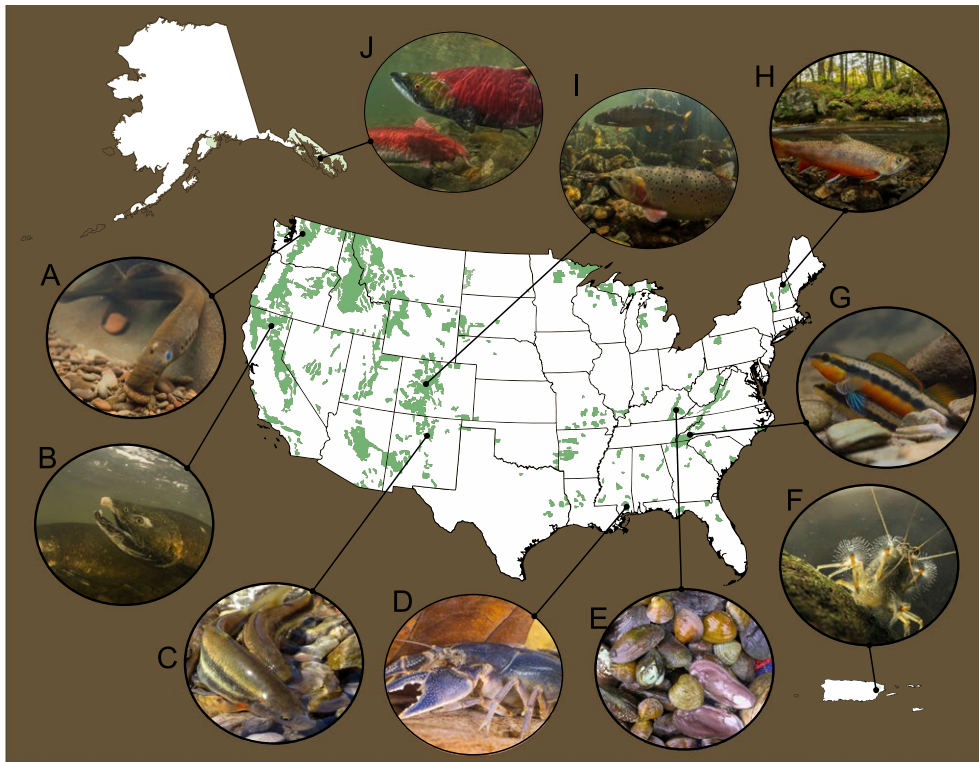


Figure 1. Examples of the diversity of aquatic species on U.S. Forest Service lands (shown in green on the map). Pictures include (A) Pacific Lamprey *Entosphenus tridentatus* (photo credit: Freshwaters Illustrated), (B) Chinook Salmon *Oncorhynchus tshawytscha* (photo credit: Freshwaters Illustrated), (C) Rio Grande Chub *Gila Pandora* (photo credit: Mary Katherine Ray), (D) flatwoods digger *Fallicambarus oryctes* (photo credit: Guenter Schuster), (E) A diverse assemblage of freshwater mussels (photo credit: Monte McGregor), (F) an amphidromous shrimp *Atya lanipes* (photo credit: Freshwaters Illustrated), (G) Tangerine Dater *Percina aurantiaca* (photo credit: Freshwaters Illustrated), (H) Brook Trout *Salvelinus fontinalis* (photo credit: Freshwaters Illustrated), (I) Cutthroat Trout *O. clarkia* (photo credit: Freshwaters Illustrated), and (J) Sockeye Salmon *O. nerka* (photo credit: Freshwaters Illustrated).

Law and Policy Directing Species Biodiversity on National Forest System Lands

The responsibility of the USFS for maintaining and restoring aquatic biodiversity has evolved over time. Even though the national forests were not specifically established to protect fish and wildlife populations or their habitat, they serve as a foundation for the conservation of many species, although this role was not always actively pursued or realized. The Organic Administration Act of 1897 (16 U.S.C. 475) served as the genesis for the USFS and established forest reserves as a means to secure favorable conditions of water flows and furnish a continuous supply of timber. During the first 50 years of the USFS, the agency largely played a passive role in protecting aquatic biodiversity because anthropogenic disturbances such as timber harvest or road building were rare on these lands.

The effects of management actions by the USFS on aquatic biodiversity became more pronounced in the decades following World War II, as the agency focused on developing timber resources for the nation (Langston 1995). Timber harvest on NFS lands increased from less than 3 billion board feet annually prior to World War II to a high of over 12 billion board feet by the end of the 1980s (Farnham and Mohai 1995). This increase in timber harvest was accompanied by a massive increase in the USFS road network from under 3,000 mi in 1916 (Havlick 2002) to over 380,000 mi by 2000 (Federal Register Vol. 65 11676). Increased management activity on these lands put at risk many components of aquatic ecosystems (Meehan 1991).

The shift by the USFS and other federal land management agencies during the late 1950s through the 1980s towards greater resource extraction which negatively affected natural resources such as water, fish, wildlife, and biodiversity aroused public concern. In response to these concerns, Congress passed laws broadening the range of uses to be considered by public land managers, allowed the public a greater voice in federal land management decisions, and provided stricter guidance on how management on these lands should occur (Adams 1993; Vig and Kraft 2003). A general overview of the changes that have helped protect aquatic resources are presented below.

The 1960 Multiple Use and Sustained Yield Act (MUSYA; Public Law 86-517) was landmark legislation establishing the USFS as a multiple-use agency. This law stated “it is the policy of the Congress that the National Forests are established and shall be administered for outdoor recreation, range, timber, watershed, and wildlife and fish purposes” (16 U.S.C. 475). The National Forest Management Act (NFMA, 1976; Public Law 94-588, 16 U.S.C. 1600) provided additional direction on managing for multiple uses by requiring every national forest or grassland to develop an effective Land Management Plan (Forest Plan). This act stated

“the Secretary [of Agriculture] must specify guidelines for developing management plans that ensure consideration of both economic and environmental factors; provide for wildlife and fish; provide for the diversity of plant and animal communities; ensure timber

harvesting will occur only where water quality and fish habitat are adequately protected from serious detriment; ensure clearcutting and other harvesting will occur only where it may be done in a manner consistent with the protection of soil, watersheds, fish, wildlife, recreation, aesthetic resources and regeneration of the timber resource.”

In an attempt to “provide for diversity of plant and animal communities” (16 U.S.C. sect. 1604[g][3][B]), the USFS implemented regulations that stated, “Fish and wildlife habitat shall be managed to maintain viable populations of existing native and desired nonnative vertebrate species.” Furthermore, NFMA led to the identification of sensitive species that were native to NFS lands for which population viability was to be evaluated. These mandates stipulated management of NFS lands “must not result in a loss of species viability or create significant trends toward federal listing” (USFS 2005). Taken as a whole, these laws and policies obligate the USFS to protect habitats for at-risk species. The 2012 Planning Rule (36 CFR Part 219) updated the process for the agency to develop and revise land management plans on NFS lands. It affirmed the intent of the NFMA by stating that the USFS is to

“provide for the diversity of plant and animal communities, and keep common native species common, contribute to the recovery of threatened and endangered species, conserve proposed and candidate species, and maintain species of conservation concern within the plan area” (USFS 2012).

In addition to the species and habitat protections provided in land management plans, many NFS lands have additional land designations that protect biodiversity. Foremost among these are the over 440 designated wilderness areas within national forests, covering more than 36 million acres. Commercial resource extraction from these lands is largely prohibited (Glicksman 2014). The concept of protecting areas in their natural state arose in 1924 when, at the insistence of a young forest ranger named Aldo Leopold, the USFS established the first designated wilderness area in the world, located near the Gila River in New Mexico. This designation marked the beginning of a national system of wilderness areas. The wilderness designation process was formalized with the passage of the Wilderness Act in 1964 (Public Law 88-577:16; U.S. C. 1131-1136).

Across NFS lands, there remained a large number of other undeveloped areas that had been considered for wilderness designation, but were not formally recognized for protection under the Wilderness Act. In 2001, the USFS took administrative action to limit road building on 58.5 million acres of lands that were roadless (Roadless Rule, 36 CFR Part 294; USFS 2001). Due to the Wilderness Act and administrative actions taken under the Roadless Rule, a large portion of the undeveloped NFS land will remain undeveloped into the future, serving as reserves for aquatic biodiversity.

In 1968, the Wild and Scenic Rivers Act (Public Law 90-542; 16 U.S.C. 1271 et seq.) was passed to protect free-flowing rivers that had outstanding natural, cultural, and recreational values. Currently, nearly 9,000 mi of streams have been designated as wild and scenic rivers with the largest length of streams being under USFS jurisdiction (Rothlisberger et al. 2017). Many of these streams were designated because of the exceptional value of their fisheries.

The ecological conditions and processes within landscapes protected by the Wilderness Act, Roadless Rule, and Wild and Scenic Rivers Act provide insight into the natural processes that shape aquatic habitat conditions and this understanding can be used when managing other NFS lands (Kershner et al. 2004a; Stoddard et al. 2006). The Wilderness Act and Wild and Scenic Rivers Act restricts construction of new dams, resulting in the USFS managing some of the longest stretches of connected aquatic habitats in the United States (Benke 1990). Streams given protection under the Wilderness Act and Wild and Scenic River Act serve as an important network protecting of aquatic organisms (Frissell and Carnefix 2007; Rothlisberger et al. 2017) and as refugia for rare species (Bader 2000).

Beyond the specific acts and rules, USFS management is affected by the National Environmental Policy Act (NEPA; 42 U.S.C. §4321 et seq. [1969]), the ESA and Clean Water Act (33 U.S.C. §1251 et seq.). These foundational laws influence how the agency protects and restores aquatic biodiversity. Although NEPA does not require protections of species, it widens the scope of analysis, increases transparency, requires interdisciplinary analysis and allows the public an opportunity to provide input and comment on agency decisions. Each USFS decision for management actions in areas with ESA-listed species must determine if the project will jeopardize the species population or adversely modify their critical habitat. For projects that may affect ESA species, consultation with the Fish and Wildlife Service or the National Oceanic and Atmospheric Administration Fisheries is required. The Clean Water Act limits the degradation of water so as to not affect beneficial uses, including aquatic species and their habitat.

Although these laws clearly required the USFS to protect terrestrial and aquatic biodiversity in its land management decisions, historically the agency struggled to balance biodiversity protection with other multiple-use mandates involving timber harvest, mining, and livestock grazing (Davis 2001; Vig and Kraft 2003). At a time when the USFS was struggling to find this balance (Grumbine 1994), the northern spotted owl *Strix occidentalis caurina* received protection under the ESA within the Pacific Northwest. Although people are aware of the central role the northern spotted owl played in changing public land management practices in the Pacific Northwest, many are unaware of the significant changes in management practices driven by aquatic species.

Modification of land management practices were necessary because Pacific salmon and steelhead populations were declining across the Pacific Northwest (Nehlsen et al. 1991). The decline of these populations was in part due to the magnitude of timber harvest on public and private lands, which were conducted in a manner that seldom protected areas near streams, lakes, and riparian areas (Bisson et al. 1992). Timber harvest and associated road building reduced stream shade and large wood input to streams, increased water temperature, reduced water quality, and fragmented formerly connected habitat (Meehan 1991). Sediment delivery from roads and harvested areas to stream channels increased stream width, decreased stream depth, simplified habitat, and covered spawning gravels used by many cold-water species (Hicks et al. 1991; Dose and Roper 1994; Kershner et al. 2004b).

Due to the environmental impacts of the extensive timber harvest and associated activities on terrestrial and aquatic species, lawsuits were filed that led to a reduction in timber production from the Pacific Northwest. This resulted in financial hardship for rural communities dependent on

timber from federal lands. To address the economic impacts, President William J. Clinton directed the USFS and Bureau of Land Management to devise a strategy addressing these management issues. The result was the Northwest Forest Plan (USDA/USDI 1994), which amended land management plans in western Oregon and Washington and northern California. The goal of this plan was to protect habitats used by terrestrial and aquatic species while allowing some resource production to provide for local economies (Thomas et al. 2006).

An important aspect of the Northwest Forest Plan was the Aquatic Conservation Strategy (ACS) that required land managers to provide for greater protection of streams, lakes, wetlands, and landslide-prone areas to benefit aquatic and riparian-dependent species. This plan also required identification of key watersheds to serve as a network of stream systems that would provide added protections for at-risk fish species such as salmon and trout. The ACS established standards and guidelines further protecting NFS aquatic habitat and riparian areas while requiring any management action in riparian areas to benefit aquatic and riparian-dependent species. Soon after the land management plans within the range of the northern spotted owl were amended by the Northwest Forest Plan, two similar strategies commonly referred to as PACFISH and INFISH (USDA 1995) were implemented to improve the protection of aquatic systems and riparian habitat within the Columbia and Klamath river basins.

Active and passive aquatic and riparian restoration undertaken by the USFS and partners associated with these plans and strategies and other forest plans are now instrumental in the improvement of aquatic biodiversity on NFS lands. Since the late 1980s, the agency has conducted numerous large-scale aquatic restoration projects that sought to restore upslope and instream processes and conditions. Nationally, the Watershed Condition Framework (USFS 2011) was adopted to assess the condition of NFS watersheds and to prioritize them for protection and restoration. This framework rates watershed function based on 12 indicators directly or indirectly related to the conservation of aquatic biodiversity, among them water quality, water quantity, aquatic habitats, distribution of native and nonnative aquatic species, riparian conditions, and the placement of roads and trails. Funding for aquatic restoration efforts is focused on priority watersheds identified by a national forest through this process. With this approach, restoration efforts can focus on a few watersheds until the work identified in watershed restoration action plans are completed and watershed conditions are likely improved. Implementation of the Watershed Condition Framework, however, has not always targeted watersheds that are the highest priority for aquatic species. To address this concern the updated USFS National Fish Strategy has set a goal of identifying a network of conservation watersheds prized for their aquatic biodiversity to augment priority watersheds (Shively et al. 2018, this issue).

Another powerful tool to aid in the conservation and restoration of aquatic biodiversity was the passage of the Wyden Authority in 1998 (Public Law 105–83, Section 334) and its permanent establishment in 2009 (Public Law 111-11, Section 3001), allowing the USFS to enter into agreements with partners for actions occurring on non-NFS lands where there are benefits to USFS resources. Because of this authority, it is now commonplace for the agency to collaborate with partners downstream of NFS lands to improve aquatic and riparian habitat, facilitating a whole-watershed approach to restoration. These collaborative restoration efforts are particularly

important to migratory fish species that need NFS lands and private lands to carry out their life cycles. Cooperative landscape-scale conservation is vital to the conservation of aquatic biodiversity, whether in the southeastern United States where USFS lands are fragmented or in the West where NFS lands encompass mainly higher elevation terrain.

Developments in Forest Service Aquatic Monitoring

Understanding and maintaining aquatic biodiversity requires an inventory and monitoring program that is capable of determining the spatial extent of species, evaluating trends in their occurrence or abundance, and assessing the effectiveness of management and restoration efforts undertaken by the USFS, its cooperators, and partners. Monitoring was initially required as part of NFMA in 1976. The USFS was slow to implement monitoring of water, fish, and wildlife, and the failure to detect trends in species populations and aquatic conditions played a role in the need to reassess forest plans during the 1990s. Since then the agency has increased its commitment to an inventory and monitoring program that could better track aquatic biodiversity on NFS lands.

Many of the longer-term USFS monitoring efforts began as forest plans that were modified to improve protection of aquatic habitats. The most active programs are the Aquatic and Riparian Ecosystem Monitoring Program (AREMP), which tracks the progress of the Northwest Forest Plan in western Washington, western Oregon, and northern California (Reeves et al. 2004), and the PACFISH/INFISH Biological Opinion (PIBO) Effectiveness Monitoring Program, which tracks the effectiveness of individual forest plans in the interior Columbia River basin (Kershner et al. 2004a). These programs have evaluated conditions in thousands of stream reaches in the Pacific Northwest and interior Columbia River basin in a manner that allows the USFS to measure progress towards protecting and restoring habitat for aquatic biodiversity (Al-Chokhachy et al. 2010).

Based on data assembled by AREMP, Reeves et al. (2006) demonstrated watershed conditions had improved on NFS lands covered by the Northwest Forest Plan. In the first 10 years of the adoption of the ACS, overall watershed condition scores improved in 64% of the 250 sampled watersheds, primarily as a result of improved riparian conditions. In administrative reports based on data collected by PIBO, Archer and Ojala (2016) reported improved stream conditions within the interior Columbia River basin. Although these monitoring data are informative, their use in revising forest plans and to inform project decisions are uneven across forests. This suggests a better framework is necessary to insure these data inform, and where necessary, change land management practices.

With each of the 154 individual national forests and 20 national grasslands having authority for most local decisions, large-scale monitoring programs are the exception rather than the norm. The lack of coordinated monitoring efforts among USFS units has resulted in most aquatic data being inconsistently collected, rarely in digital form, and scattered among different administrative units. The lack of readily accessible centralized data sets has limited the ability of the USFS to improve management decisions. To overcome some of these difficulties in the Pacific Northwest Region, the USFS created a region-wide database summarizing fish species location on public lands from data collected by the agency and its partners, and a region-wide database documenting fish migration barriers on NFS lands. More of these multiple-forest efforts

and a greater commitment to monitoring are needed to better inform USFS decisions relative to aquatic biodiversity. Though important, increasing monitoring will be difficult as these are often the first programs to suffer when overall funding to agencies decreases (Biber 2011).

There has been recent agency progress on the use of landscape-scale data (Isaak et al. 2018, this issue) in regional models of stream temperatures (Isaak et al. 2014), species distribution models (Wenger et al. 2011; Isaak et al. 2015), thermal niches (Isaak et al. 2017a), and mapping the extent of trout hybridization (Young et al. 2016, 2017b). These studies are directed at informing management decisions that lead to the protection of aquatic biodiversity across jurisdictional boundaries. Efforts to amass and collate large amounts of biodiversity data will likely accelerate with the advent of environmental DNA (eDNA) sampling that permits more rapid and comprehensive assessments of species presence at a reduced cost relative to traditional methods (Carim et al. 2016; Wilcox et al. 2016). Coupling eDNA sampling with the evaluation of stream habitat conditions could provide data for cost-effective models of species occupancy (Young et al. 2017a). Many of the current USFS sampling efforts are directed at individual species of recreational value or conservation concern, which constitutes only a fraction of biodiversity at any location. Eventually, eDNA sampling may make it possible to identify entire biotic communities (Rees et al. 2014) and cryptic taxa that have yet to be discovered and named (Young et al. 2013; Lane et al. 2016; Near and Thomas 2015).

Monitoring of aquatic systems across NFS lands should continue to improve as this is an important component of the 2012 Forest Planning Rule. This rule not only requires monitoring to inform decisions at the forest scale but also at broader scales. This requirement will foster monitoring stream and watershed conditions at a national scale through tools such as Watershed Condition Framework. Broad-scale monitoring of aquatic systems in combination with climate change vulnerability assessments should help prioritize the type and location of future forest management activities (Halofsky et al. 2018) in a manner that fosters the protection of aquatic biodiversity.

Continuing Challenges to Protection and Restoration of Aquatic Biodiversity

As a multiple-use land management agency, the USFS is responsible for conserving aquatic biodiversity while providing other goods and services. Although the USFS has taken significant steps towards protecting aquatic ecosystems, additional actions are needed to mitigate the effects of historical practices and reduce those of current activities. In continuing efforts to improve management outcomes, the agency recognizes the need to protect aquatic biodiversity and also sustain rural economies (Charnley 2006; Eichman et al. 2010). Major management issues continuing to challenge the agency in its quest to protect biodiversity include the USFS road system, livestock grazing, mining, oil and gas extraction, nonnative species, climate change, and monitoring.

The existing road system and expanding demand for off-road vehicle access on NFS lands will be a long-term challenge for the management of aquatic biodiversity. Though vital for many of the multiple-use aspects of the USFS, the presence, maintenance, and use of roads can affect streams by increasing sedimentation, decreasing sinuosity, reducing shade, decreasing wood delivery, and serving as a vector for human-assisted introductions of nonnative species (Furniss et al.

1991; Meredith et al. 2014). Undersized culverts or perched road crossings create barriers to migrating fish (Warren and Pardew 1998) and can fragment populations of native species, thus decreasing their resiliency to events such as fire or drought (Angermeier 1995; Dunham and Rieman 1999). These negative impacts can have repercussion by making it difficult to meet forest objectives or have legal implications through ESA or the Clean Water Act. Although it would be easy to suggest dramatically reducing the size the USFS road network, there is a large segment of the public concerned with any actions that limit access to public lands (Wilson 2008).

In an attempt to increase transparency of road management decisions, the USFS published the Travel Management Rule (USFS 2005). This rule requires each national forest and national grassland to evaluate its road system and identify roads and trails the agency would like to keep open for motorized use. Analysis of the road system suggests benefits and risks. Members of the public that use USFS roads often understand or emphasize the benefits of access but downplay or overlook the damage that poorly managed or poorly located roads can cause to terrestrial and aquatic environments (Gucinski et al. 2001). On many national forests and grasslands, proposals and decisions about the management of the road network are among the most controversial actions undertaken by managers. The USFS, however, cannot afford to maintain its current road systems (Wilderness Society 2012) and overall infrastructure funding for the agency is flat or declining. Given these issues, managing roads so as to reduce risk to aquatic biodiversity will continue to be a challenge to the agency.

To address road and trail-related impacts, Congress created and funded the USFS Legacy Roads and Trails Remediation Program (2008 Congressional Appropriation) in 2008, for which the agency received US\$390 million between 2008 and 2015. Funding provided by this program has been used to decommission 6,700 mi of unneeded roads, storm-proof more than 18,000 mi of open roads, restore fish passage at over 1,000 stream crossings (USFS 2017), and improve nearly 4,400 mi of trails to reduce sedimentation (Wild Earth Guardians 2016). Although progress is being made through these and other funds, there remains a backlog of road projects that, if addressed, would greatly benefit aquatic biodiversity.

Another ongoing challenge to the protection of aquatic biodiversity on NFS lands is the grazing of livestock (Hughes 2014), which can be a primary threat to aquatic ecosystems in rangeland settings (Belsky et al. 1999). Livestock graze on 102 million acres of NFS lands including wilderness areas (US General Accounting Office 1988). Grazing activities are guided by allotment management plans regulating livestock number, duration, and use of a given area. These allotment plans are tiered to individual forest plans stating livestock grazing should only be permitted where this activity is consistent with maintaining the conditions of streams and riparian areas (USDA 1995). Even with these management directions in place, it can be difficult to implement effective grazing strategies across all allotments with streams and riparian areas. When livestock grazing exceeds permitted effects, it can lead to additional sediment entering streams, decreases in riparian vegetation, reductions in water quality, and wider, shallower stream channels (Platts 1991). Although data indicate that there have been improvements in how grazing practices have been implemented, restoration has not occurred universally across NFS rangelands (U.S. General Accounting Office 1988). Some areas subject to improper livestock grazing

practices will likely continue to be problematic to aquatic biodiversity (Knapp and Matthews 1996; Goss and Roper 2018).

Mining activities, governed by the General Mining Act of 1872 (30 U.S.C. §§ 22–42), are another ongoing challenge to the protection of aquatic biodiversity on NFS lands. Roughly 80% of the NFS lands are potentially open to hardrock mining (NRC 1999), with many mines currently operating within national forests boundaries. In 1984, wilderness areas were withdrawn from mineral claims unless the valid rights previously existed. Early mining efforts were unregulated and still affect thousands of stream reaches as chemical pollutants leach from old mining sites or historic dredge piles restrict stream access to floodplains. Many on-going projects pose similar threats.

Oil and gas activities are governed by different laws where the Bureau of Land Management is the agency that approves permits and licenses to explore, develop, and produce energy resources on federal lands. Currently, there is a rapid expansion of oil and gas development on some USFS lands (Baynard et al. 2017). One possible outcome of increased oil and gas development could be lower regional water quality due to contaminated groundwater, wastewater discharge, and accidental chemical spills (Vidic et al. 2013). While the environmental impacts of oil and gas development are better regulated today, future operations are still a concern for maintaining aquatic biodiversity near these developments.

Although not directly related to federal land management actions, one of the biggest on-going threats to aquatic biodiversity is the presence and spread of nonnative species (Adams et al. 2001; Knapp et al. 2001). Even though some nonnative species are specifically managed for recreational fishing, the presence of nonnative species can make it difficult or impossible to maintain or reestablish native biodiversity, regardless of the quality of aquatic habitat. Wilderness areas often serve as reserves of native aquatic biodiversity, but they are not immune to invasions by nonnative species (Hitt and Frissell 2000). In some areas, the presence of nonnative species has caused land managers to build migration barriers that reduce the spread of these species and isolate habitats for native species rather than maintaining connectivity (Fausch et al. 2009). Executive Order 13112 (Clinton 1999) requires federal agencies to prevent and control the introduction of invasive species and minimize their economic, ecological, and human health impacts. In 2004, the USFS developed the National Strategy and Implementation Plan for Invasive Species Management (USFS 2004). The plan includes direction on the prevention, early detection/rapid response, control, and management of invasive species. However, funds designated for aquatic invasive species are seldom available. Where funding exists, the USFS works in partnership with other agencies, including federal, tribal, and state agencies, to control and eradicate invasive plant and animal species populations, but new populations of aquatic invasive species continue to appear on NFS lands.

Another contemporary threat to aquatic biodiversity is climate change. Climate projections are for warmer water temperatures in many locations, emphasizing the value of cooler, higher-elevation waters present on NFS lands (Isaak et al. 2015). Where nonnative species are not an imminent threat, the USFS promotes aquatic organism passage projects, permitting movements by native species to these cold-water areas. Projects restoring stream channel structure (e.g., narrowing and deepening stream channels) and promoting riparian vegetation to increase shade can moderate the predicted future

effects of climate change (McHugh et al. 2017). The agency's management direction to protect aquatic systems can foster the persistence of narrowly distributed endemics, but this task may be more difficult in regions where NFS lands are interspersed among other land ownerships, such as the southeastern United States (Jenkins et al. 2015).

An on-going challenge to the USFS' ability to maintain or improve aquatic biodiversity is the ability to monitor changes in aquatic ecosystems and processes and use the information gained through monitoring to guide future decisions. Previous monitoring efforts have demonstrated that management objectives, standards, and guidelines put in place during the 1990s maintained or improved conditions of aquatic habitat on lands managed by the USFS (Reeves et al. 2006; Al-Chokhachy et al. 2010). What this work has not done is identify which management practices drove those changes. Furthermore, the agency still needs to demonstrate the ability use aquatic biodiversity data (such as that collected using eDNA sampling) in forest, regional, or national analyses. This can only be achieved if there is a framework that relates decisions to follow-up monitoring and assessment that improves future decisions (Williams et al. 2011).

Summary

Although NFS lands were not originally established to safeguard aquatic biodiversity, the mission of the agency has evolved such that it is now a leader in aquatic conservation. The extent of NFS lands makes them vital for protecting many of the wide-ranging aquatic species across the nation. The last several decades have seen significant gains through changes in management strategies that focus on protecting and improving the aquatic habitats necessary to maintain or increase biodiversity. In many areas, the protection provided to aquatic systems within USFS planning documents far exceed those of other entities (Boisjolie et al. 2017). The designation of some watersheds for additional protections in combination with Wilderness and roadless areas, provides locations where natural processes are the primary influence on aquatic biodiversity. Changes in management policies have altered the trajectory of aquatic habitats for the better (Reeves et al. 2006). Even given these successes it will be extremely important for the USFS in the near-term to identify additional locations with high aquatic biodiversity and ensure safeguards and conservation actions are sufficient to maintain or protect these areas.

The USFS will continue to play an important role in conserving aquatic biodiversity as it protects, maintains, and restores aquatic ecosystems. Maintaining aquatic biodiversity will be facilitated by improving species distribution data and by continuing to work across land ownership boundaries. The emphasis on many traditional forest activities such as timber harvest, roads, grazing, and mining at the expense of aquatic biodiversity has declined over the last few decades. An on-going concern is that products from resource extraction activities (e.g., timber and cattle) are easier to track than is aquatic biodiversity so there will continue to be incentives for the USFS to focus on the former (Biber 2009). This could result in management decisions to increase timber harvest in the future. To balance these pressures, there is a need to describe societal, ecological, and economic outcomes on NFS lands in a manner that the public can understand and provide meaningful input on decisions that could affect aquatic biodiversity (Winkel 2014). If USFS land management continues to improve and adapt to these new challenges while maintaining

constructive discussions with the broader public, it is likely that NFS lands will continue to fulfill their dual obligation to provide important natural resource outputs and recreational opportunities while playing a central role in maintaining aquatic biodiversity in the United States.

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