Beaver and Climate Change Adaptation in North America

A Simple, Cost-Effective Strategy

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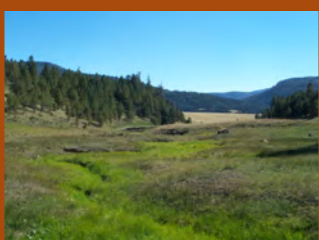

A Report from

WildEarth Guardians
A Force for Nature

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MISSION STATEMENT
WildEarth Guardians protects and restores the
wildlife, wild places and wild rivers of the American West.

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1 EXECUTIVE SUMMARY

The reestablishment of American beaver (*Castor canadensis*; beaver) and its habitat on the National Forest System is a viable and cost-effective climate change adaptation strategy[4]. Statutory and regulatory support for climate change adaptation and beaver reestablishment on national forest lands can be found in the National Forest Management Act (NFMA), the Resource Planning Act (RPA), and the climate change policy of the United States Forest Service (USFS), including the *Strategic Framework for Responding to Climate Change* (USDA 2008) and the *National Roadmap for Responding to Climate Change* (USDA 2010).

Due to the unique hydrological engineering accomplished by dam-building beaver, support and reestablishment of beaver constitute an important climate change adaptation tool for the national forests in the United States. The information presented here demonstrates the critical roles beaver play in ecosystem structure and function and how those roles contribute significantly to the climate change adaptation strategy and goals of the USFS.

There are three components essential for beaver reestablishment and planning on the national forest system:

1. Inventory historic, occupied, and potential beaver habitat on each national forest.
2. Assess threats and challenges to, as well as opportunities for support of beaver reestablishment in suitable habitat.
3. Implement beaver reestablishment pilot projects on at least one subwatershed in each national forest in which 1/3 or less of historic beaver habitat is currently occupied.

2 FOREST PLANNING AND BEAVER REESTABLISHMENT IN THE NATIONAL FORESTS

The USFS should promulgate planning directives instructing each national forest to incorporate beaver reestablishment as a climate adaptation strategy in forest plans and projects. The forests would include three beaver reestablishment actions: an inventory of historic, occupied and potential beaver habitat; an assessment of threats to and opportunities for beaver reestablishment on the forest; and a pilot project for reestablishment of beaver and their habitat in at least one subwatershed

[4] We define *climate adaptation* as it is defined in the USDA Forest Service 2010 *National Roadmap for Responding to Climate Change*: Enhance the capacity of forests and grasslands to adapt to the environmental stresses of climate change and maintain ecosystem services.

on each national forest with one-third or less of historic beaver habitat currently occupied.

A statutory foundation for beaver reestablishment is in the National Forest Management Act (NFMA) and Forest and Rangeland Renewable Resources Planning Act (RPA).[5] The policy foundation is in the *Strategic Framework for Responding to Climate Change* (USDA 2008; *Framework*) and the *National Roadmap for Responding to Climate Change* (USDA 2010; *Roadmap*).

The NFMA requires the Forest Service to develop a land and resource management plan ("forest plan") for each forest that it manages.[6] The forest plan must provide for multiple uses of the forest, including recreation, range, timber, wildlife and fish, and wilderness.[7] The NFMA is a law under which the USFS has a duty to "develop, maintain, and, as appropriate, revise land and resource management plans for units of the National Forest System."[8] In providing for multiple uses, the forest plan must comply with substantive requirements of the NFMA designed to ensure continued diversity of plant and animal communities and the continued viability of wildlife in the forest, including the requirement that wildlife habitat shall be managed to maintain viable populations of existing native and desired nonnative vertebrate species in the planning area.[9]

The RPA, amended by the NFMA, requires the Secretary of Agriculture to prepare a Renewable Resource Assessment every tenth year that includes an "analysis of the potential effects of global climate change on the condition of renewable resources on the forests and rangelands of the United States;" and "an analysis of the rural and urban forestry opportunities to mitigate the buildup of atmospheric carbon dioxide and reduce the risk of global climate change."[10]

The Secretary of Agriculture is also required to prepare and transmit to the President a recommended Renewable Resource Program every five years. The Program includes recommendations, which "account for the effects of global climate change on forest and rangeland conditions, including potential effects on the geographic ranges of species, and on forest and rangeland products." [11]
The *Roadmap* (USDA 2010) clearly creates the impetus for beaver reestablishment directives. The *Roadmap* names three actions: assessing risks, vulnerabilities, policies and knowledge gaps; engaging employees and external partners; and

[5] 16 U.S.C. §§ 1600 – 1687.
[6] 16 U.S.C. § 1604.
[7] 16 U.S.C. §1604(e)(1).
[8] 16 U.S.C. §1604(a).
[9] 16 U.S.C. §1604(g)(3)(B).
[10] 16 U.S.C. §1601 (a) (5) & (6).
[11] 16 U.S.C. §1602(5)(f).

management actions that include adaptation and mitigation - in a continuous cycle of adaptive management informed by monitoring and evaluation (*Roadmap* at 4).

The *Roadmap* states: "The Forest Service will identify shortcomings in its policies, procedures, and program guidance, reformulating them where necessary to align resources with an effective climate change response and to more effectively collaborate with other Federal agencies, States, tribes, and other stakeholders for landscape-scale conservation."

It also suggests:

- Align Forest Service policy and direction with the Forest Service's strategic response to climate change.
- Review manuals and other policy documents to assess their support for the agency's strategic climate change direction. Evaluate current policy direction for its ability to provide the flexibility and integration needed to deal with climate change.
- Develop proposals for addressing critical policy gaps" (*Roadmap* at 12).

The *Roadmap* articulates a 3-part adaptation strategy including, "facilitating large-scale ecological transitions in response to changing environmental conditions" (*Roadmap* at 19).

Finally, the Forest Service Organic Administration Act of 1897 established the National Forest System to improve and protect the forests, furnish a continuous supply of timber, and <u>secure favorable conditions of water flows</u> (emphasis added). Dam-building beaver, more than any other wildlife species, significantly contribute to the third of these responsibilities of national forests.

2.1 Require the incorporation of beaver reestablishment in national forest planning

The Forest Service should insure attention to beaver throughout the National Forest System by providing specific service-wide direction in the *Forest Service Handbook* and *Forest Service Manual* for addressing beaver reestablishment as an adaptation strategy in all national forests where beaver are known to have historically been present (Fig. 1). The intent would be to support and reestablish dam-building beaver and their associated ecosystem services as an effective climate adaptation strategy. Each forest plan would include an inventory of the forest's historic, occupied, and potential beaver habitats; threats to and opportunities for reestablishment of beaver; and actions for support and reestablishment of beaver. The outcome would be an increase in functional beaver populations on national forests, with their unique ecosystem services that effectively and profoundly contribute to climate change adaptation.

2.2 Inventory historic, occupied, and potential beaver habitat on each national forest

Each national forest can inventory historic, occupied, and potential beaver habitat. Occupied habitats should be assessed for features that are allowing for beaver occupation.

Much of North America's stream systems historically supported functional populations of beaver and the USFS should inventory historic, occupied, and potential beaver habitat. The gross features of typical beaver habitat are easily identified and inventoried, as are the signs of both presence and absence of beaver in historically occupied habitat, rendering a forest inventory feasible and inexpensive compared to the economic benefits of functional beaver populations (see Section 6, "Socio-Economic Benefits of Dam-Building Beaver").

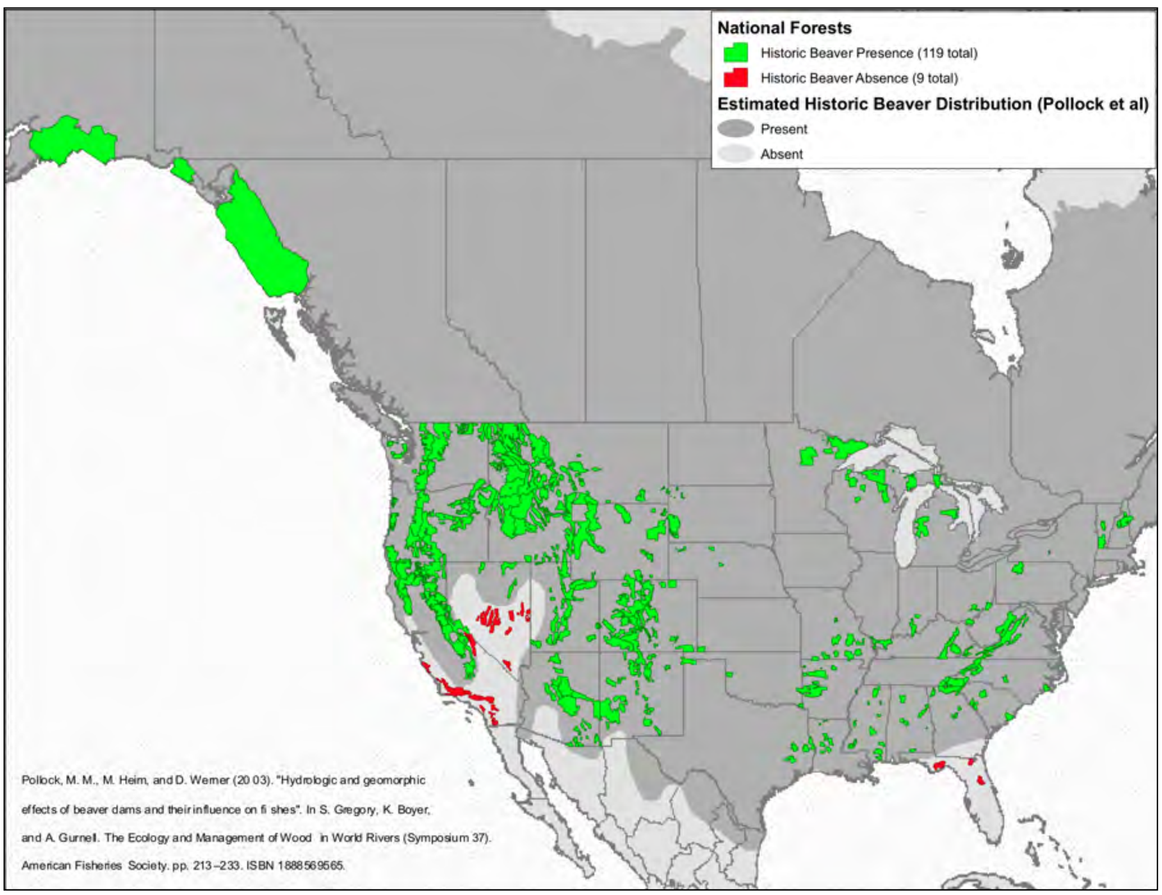

FIGURE 1. Estimated North American historic beaver distribution.

2.3 Assess threats to and opportunities for support and reestablishment of beaver on each national forest

Ongoing and potential threats to establishment, support, and increase of functional populations of dam-building beaver can be assessed in the forest plans so that elimination or mitigation of such threats will be included in forest and grassland management and projects as a climate adaptation strategy.

2.4 Implement beaver reestablishment pilot projects on at least one subwatershed in each national forest in which 1/3 or less of historic beaver habitat is currently occupied.

Beaver reestablishment pilot projects can be initiated in cooperation with state game and fish or wildlife agencies as well as tribal, non-governmental and private partners where appropriate in at least one subwatershed in each national forest in which significant portions of historic beaver habitat are currently unoccupied.

The pilot projects will serve as building blocks for reestablishing functional populations of beaver throughout national forest lands. The pilot projects can serve as valuable public education tools, demonstrating cost-effectiveness as well as new technologies for mitigating beaver conflicts with human infrastructure. Pilot projects can be an opportunity to engage and develop strong alliances and partnerships with federal agencies, state and local governments, tribes, private landowners, non-governmental organizations, and international partners, as is a stated goal of the *Framework* (at 7).

3 CLIMATE CHANGE SCENARIOS REQUIRE CLIMATE CHANGE ADAPTATION

Climate change is certain and caused predominantly by heat-trapping gases produced from the burning of fossil fuels, aided in part by the clearing of forests and agricultural activities. It is evident that increases in greenhouse gases very likely account for most of the earth's warming over the past 50 years. The atmospheric concentration of carbon dioxide, the greenhouse gas produced in the largest quantities, has risen about 35 percent since 1750 to about 390 parts per million by volume, the highest level in at least 800,000 years (NRC 2010 at 1).

Although efforts are underway to reduce global emissions of greenhouse gases, it is fairly inevitable that humans will need to undertake measures to adapt to climate change and the resulting effects on natural systems, including changes in streamflow, wildfires, crop productivity, temperature, and sea level.

The following climate change discussion focuses on change in the western U.S, but both similar and different challenges are being faced throughout North America.

The western United States is already experiencing climate change impacts (USGCRP 2009 at 135). In the Northwest, the regionally averaged temperature has risen about 1.5°F over the past century (with some areas experiencing increases up to 4°F) and is projected to increase another 3 to 10°F during this century (USGCRP 2009 at 135). The U.S. Global Change Research Program ("USGCRP," which includes the Departments of Interior and Agriculture) has identified the effects of this increasing temperature in the Northwest to include:

- Declining springtime snowpack leading to reduced summer streamflows, straining agricultural and municipal water supplies;
- Increased insect outbreaks and wildfires, and species composition changes in forests, posing challenges for ecosystems and the forest products industry;
- Salmon and other coldwater species experiencing additional stresses as a result of rising water temperatures and declining summer streamflows; and
- Sea-level rise along vulnerable coastlines, resulting in increased erosion and the loss of land (USGCRP 2009 at 135).

The southwest U.S. is already experiencing climate change impacts, and effects are commonly accepted in the literature. Warming trends in the Southwest are considered to be swifter than other regions of the country and may be significantly greater than the global average (USGCRP 2009 at 129). The rapid increase in temperatures in this region, particularly summertime temperature, will have drastic effects on hydrology, which in turn may result in severe water supply challenges in the near future (USGCRP 2009 at 129). The U.S. Global Change Research Program has identified effects of this increasing temperature in the Southwest to include:

- Water supplies becoming increasingly scarce, calling for trade-offs among competing uses, and potentially leading to conflict;
- Increasing temperature, drought, wildfire, and invasive species, accelerating transformation of the landscape;
- Increased frequency and altered timing of flooding, increasing risks to people, ecosystems, and infrastructure;
- Unique tourism and recreation opportunities likely suffering; and
- Cities and agriculture facing increasing risks (USGCRP 2009 at 129).

Changes in snowpack and timing of runoff are certain in much of the western U.S. but are especially grave for the southwestern and interior western U.S. river basins. The National Research Council ("NRC") has concluded that runoff in the Rio Grande Basin will decrease by 12% for every one degree of temperature rise, the greatest reduction projected for any stream basin in the U.S. (NRC 2010 at 24). Both the upper and lower Colorado River basin will experience decreases in runoff of more than 6% for every one degree in temperature rise (NRC 2010 at 141). The Great

Basin will experience a decrease in runoff of 5%, California a decrease of 3% and the Pacific Northwest could see an increase of 1%" (NRC 2010 at 141).

Adapting to these changes will require a herculean effort on the part of modern society, and coordination across large landscapes will be critical. An advantage in the West is vast, relatively well-connected holdings of federal lands that can buffer and mitigate impacts of climate change. The Secretaries of Interior and Agriculture have acknowledged these unique opportunities and directed their respective departments to address climate change.

The USFS manages 193 million acres of forests and grasslands in the United States; 142 million acres in the eleven western states. In July 2010, the USFS released a *National Roadmap for Adapting to Climate Change* (USDA 2010). The Department of Interior ("DOI") has also specified unequivocal actions towards science-based adaptation strategies to protect vital ecosystem services, including water quantity and quality, biological diversity, and fish and wildlife habitat (USDI 2009a).

Adaptation to the effects of climate change is an objective that fits with the mission of the USFS. In fact, the federal forestlands were originally reserved at the end of the 19th century in part to protect watersheds and secure favorable flows of water. Approximately one out of five Americans depends on a national forest for drinking water (USFS 2010). In an era of climate change, forests and grasslands will play an increasingly vital role in protecting the nation's watersheds and, as succinctly stated by the USFS: "a successful response to climate change will entail sound stewardship of America's watersheds" (USDA 2010).

Forest Service Chief Tom Tidwell has noted the importance of climate change and water in management of the National Forest System. Specifically, in a November 20, 2009 memo to staff entitled "Responding to Climate Change: Developing Integrated Plans for Landscape Conservation," the Chief stated:

> "Responding to the challenges of climate change in providing water and water-related ecosystem services is one of the most urgent tasks facing us as an agency."

The Chief requested area-specific action plans by March 1, 2010 based partly on the *Framework*. The *Framework* provides the vision, guiding principles, goals, and recommended actions for pursuing the Agency's mission in a rapidly changing climate. The *Framework* guides the integration of climate change into the programs, policies, processes, and partnerships of the Agency.

4 CLIMATE CHANGE ADAPTATION IMPERATIVE OF BEAVERS

Beaver promote dynamic and resilient systems that can better tolerate variation induced by climate change (Appendix A). The current absence of beaver from significant portions of their historical habitat significantly undermines the resilience of riparian/aquatic ecosystems and therefore limits adaptation to climate change.

Because of the hydrological and ecological effects of beaver engineering (specifically, dam-building), functional populations of beaver rapidly and significantly contribute to climate change adaptation. In summary:

- Beaver dams slow snowmelt runoff, which
  - Extends summertime stream flow
  - Restores perennial flow to some streams
- Beaver dams create ponds, which
  - Maintain and create wetlands
  - Provide nurseries for salmonids and other native fish
  - Provide critically-needed amphibian habitat
  - Increase habitat for small mammals, cavity-nesting birds (using drowned trees)
  - Contribute to establishment of deep-rooted sedges, rushes, native hydric grasses, and woody riparian vegetation
  - Improve downstream water quality by trapping and storing sediment
  - Create mesic meadows in sediment behind abandoned dams
- Water enters groundwater upstream of, beside, and downstream of dams which
  - Sub-irrigates the valley
  - Allows water to re-enter creeks/streams downstream as cooler seeps, which
    - is critically important to cold-water fish, e.g., salmonids
    - reduces evaporative loss
  - Expands and restores riparian vegetation, which
    - Shades creeks/streams, which
      - Reduces water temperature
      - Provides hiding cover for fish
    - Buffers banks against erosion during high flows
    - Provides critical fish and wildlife habitat
  - Restores and expands deep-rooted riparian vegetation, which
    - Increases bank integrity during high flows
    - Increases critical wildlife habitat
- A series of beaver dams can function as “speed bumps” during high water flows, which

    - Spreads water outward on the floodplain
    - Recharges groundwater near stream
    - Locally reduces flood force and gouging
    - Increases stream complexity, including creation of backwater and pools
    - Expands the presence of water for riparian plant communities
    - Prevents or reduces headcutting
- Beaver dams capture sediment, which
    - Raises incised streambeds, reconnecting them with their
    - Provides soil for mesic meadows
    - Reduces losses of sediment from the forest and into water facilities
    - Reduces the conversion of complex stream and riparian habitat to straightened ditches
    - Heals headcuts
- Beaver increase large woody debris in creeks, due to
    - Tree-cutting
    - Dam-building
    - Existing dams and their remnants which
        - Increase complexity of streams
        - Increase bank integrity during high-flow
        - Increase habitat for fish, otter, amphibians, and other aquatic species
        - Reduce expense of human construction/maintenance/repair of instream structures or placement of large, woody debris in streams

Research increasingly demonstrates the adverse consequences of the loss of beaver and the ecosystem services provided by dam-building beaver (Naiman et al. 1994, Gurnell 1998, Wright et al. 2002, Butler and Malanson 2005, Westbrook et al. 2006, Stevens et al. 2007, Bartel et al. 2010, Westbrook et al. 2010). Concomitantly, there has been a call for the proactive restoration and management of beaver throughout historically occupied watersheds (Fouty 2003, Stevens et al. 2006, Cunningham et al. 2007, Pollock et al. 2007, Stevens et al. 2007, Bonner et al. 2009, Chandler et al. 2009). Beaver restoration can be an effective solution for many types of problems in aquatic and riparian ecosystems, and it is generally far less expensive than alternatives (Scheffer 1938, Leidholt-Bruner et al. 1992, Fouty 2003, Müller-Schwarze and Sun 2003).

Restoration of riparian ecosystems has been deemed more important than ever in the wake of anticipated climate change (Seavy et al. 2009). This is because healthy riparian zones can promote ecological adaptation to changing climate through natural ecological resiliency, connectivity across habitats, linkages between aquatic and terrestrial ecosystems, and expanded thermal refugia (Seavy et al. 2009).

Ecosystem benefits commence immediately when dams are built in suitable habitat (Figs. 2 and 3) and often continue long after dams are abandoned, in the form of retained ponds, wetlands, and/or meadows, and expanded riparian habitat, with the associated climate-adapting ecosystem services these provide.

FIGURE 2. Strawberry River, August 2002. Eroding banks occur on 60-70% of stream length. Bank heights locally exceed 5 feet. The present active floodplain is at an elevation 3 or more feet lower than the high banks (USDA 2004).

FIGURE 3. Strawberry River Reach 30, October 2003. Beaver dam has raised water level to within 6-12 inches of 1938 water level. Wetted width has been expanded from 88 to 300 feet. Potential riparian area is expanded by 3-5 acres adjacent to the pond (USDA 2004).

Since at least the 1930s when beaver were translocated to degraded areas, it has been recognized that beavers can help control soil and water loss (Scheffer 1938). Beaver reintroduction is a form of active restoration and this may be necessary to insure a return to a natural dynamic system (Kauffman et al. 1997). Beaver can dramatically accelerate restoration processes, and this may be maximized where suitable beaver habitat exists (Kauffman et al. 1997).

Severely degraded systems may not have existing suitable habitat for beaver. In situations with marginal habitat, beaver releases can be augmented by supplying the beaver with suitable trees they can use for food and building material (Apple 1985). Further, until systems stabilize, beaver dams can be reinforced with net wire, truck tires, and other materials to prevent blowout during runoff events (Apple 1985). Such methods have been used successfully on severely degraded, gully-cut streams with only remnant willows in Wyoming (Apple 1983, 1985, Apple et al. 1995). Beavers established dams on these streams and the systems became self-supporting within three years (Apple et al. 1995).

At no point will all historic habitats be occupied simultaneously, as beaver move within and between watersheds in response to fire, floods, depletion of food supply, predation or trapping (Burchsted et al. 2010). However, beaver populations are currently depressed from historic levels, and populations are often so small and/or ephemeral that their potential for beneficial hydrological engineering is unrealized.

Explicit efforts to support and restore beaver populations will greatly increase their contribution to climate change adaptation.

5 ECOSYSTEM SERVICES OF DAM-BUILDING BEAVERS

The North American beaver is a highly interactive species capable of creating and maintaining profoundly beneficial changes to stream and riparian ecosystems and is therefore an ideal means of climate adaptation. Stream and riparian systems are rare on the landscape, and yet they are vitally important to the well being of humans and a vast array of plants and animals. However, most riparian areas in the western U.S. have been severely degraded by human actions and loss of functional riparian zones has approached 99% in some areas of the arid West (Briggs 1996, Goodwin et al. 1997, Kauffman et al. 1997). One important cause for this deterioration is the historical near extermination of beaver across most of its former range (Fouty 1996, Fouty 2003, Wohl 2005).

Besides humans, the North American beaver (*Castor canadensis*; beaver) is one of few species that can significantly alter physical and biological aspects of a landscape (Rosell et al. 2005). This ecosystem engineering is primarily a result of dam-building activities that create ponds, although other behaviors, such as felling trees, selective foraging, and constructing burrows and canals, can contribute (Jones et al. 1994, Rosell et al. 2005). Beaver are semi-aquatic and use deep water as protection from predators; water must be deep enough ($\geq$ ca 1 m) to cover the entrance to living quarters (Collen and Gibson 2001). Thus, in large rivers and lakes beaver do not need to build dams because deep water habitats already exist and dams built on larger streams (i.e., > 4^{th} order) may be more prone to failure during high water flows (Rutherford 1953, Naiman et al. 1986, Hillman 1998). Consequently, beaver dams primarily occur on small (i.e., first to fifth order) streams (Naiman et al. 1986, Beier and Barrett 1987).

Beavers (including the Eurasian beaver, *Castor fiber*) are unique among animals in their ability to cut down trees. They use trees both as a source of food and as structural material for building dams (Müller-Schwarze and Sun 2003). In the western U.S. the most important woody species used are aspen, cottonwoods, and willows (Rutherford 1964, Slough and Sadleir 1977). However, beaver are choosy generalists in diet and other types of plants can be used for food, as well as for dam building material (Jenkins and Busher 1979, Müller-Schwarze and Sun 2003). Herbaceous plants are important in the summer diet, while cached tree parts are important in the winter diet (Jenkins and Busher 1979). Despite a need for adequate food resources, most studies in the western U.S. have found that while beaver can occupy a wide range of conditions, preferred habitat is in valleys with relatively low gradients and wide floors; rocky substrates are less favored (Retzer et al. 1956, Beier and Barrett 1987, McComb et al. 1990, Gurnell 1998, Suzuki and McComb 1998, Pollock et al. 2003, Beck et al. 2010).

Beaver live in family groups called colonies that usually consist of an adult pair along with the young of the current and previous years (Olson and Hubert 1994, Longcore et al. 2007). In situations where beaver are not exploited, densities may average one or two colonies per mile on stream reaches with suitable habitat and some studies have estimated that their activities can influence up to 40% of the total length of 2nd-5th order streams (Naiman et al. 1986, Olson and Hubert 1994, Müller-Schwarze and Sun 2003). Each colony may create several ponds, which may range in size from small pools up to several hectares (Collen and Gibson 2001). In the western U.S., reported dam densities in pristine, remote, and protected areas have varied from ca 10 to 74 per kilometer (Pollock et. al. 2003). In ideal situations, beaver ponds can essentially fill valley bottoms in stair-stepped patterns along narrow reaches or form complex networks in broader reaches (Yeager and Rutherford 1957).

Once built, a beaver pond may be actively maintained for years or decades, and sometimes even several centuries (Lawrence 1952, Howard and Larson 1985, Gurnell 1998). Abandonment of sites is often attributed to floods on larger streams or depletion of food resources on smaller streams (Warren 1932, Lawrence 1952, Rutherford 1953). Although sites may only be intermittently occupied, habitat alterations caused by beaver can exist as part of the landscape for centuries (Naiman et al. 1988). Beaver dams create ponds that trap sediments and accumulate organic matter and nutrients (Naiman et al. 1986, Butler and Malanson 1995). When a beaver dam is abandoned, the pond drains and a meadow generally grows on the exposed soil. In forested regions, complex biotic interactions inhibit conifer invasion such that beaver meadows may persist for decades (Terwilliger and Pastor 1999). Eventually, the site reverts back to an unaltered stream channel if no beaver reoccupy the area (Naiman et al. 1988, Fouty 2003). Thus, temporal and spatial variation in the physical characteristics of landscapes, food resources, and beaver pond age and succession, result in a shifting mosaic of habitats throughout a drainage network (Naiman et al. 1988, Fouty 2003).

5.1 Abiotic Impacts

5.1.1 Hydrology

Beaver can dramatically alter the hydrology of a stream because dams function to control both surface water and groundwater flow patterns. At its most basic, beaver dams retain water in ponds, which increases the stream width and the area of slow, deep water, thereby increasing the volume and surface area of water. By slowing the velocity of water and widening the stream, beaver ponds increase retention time and dissipate stream energy (Pollock et al. 2003). Transient storage (i.e., short term water retention) is considered a key aspect of the hydrological cycle that influences stream ecosystems because it allows for more time for biogeochemical processes to occur (Jin et al. 2009). For example, a catchment with a beaver pond was capable of retaining all runoff resulting from a rainfall event, whereas a catchment without beaver runoff was a significant contributor to peak flow (Burns and McDonnell 1998). One study found that stream reaches with dams of coarse woody debris retained water at least 50% longer than stream reaches without debris dams (Ehrman and Lamberti 1992). Transient storage in a stream increases with both increasing numbers of beaver dams and pond volume (Jin et al. 2009).

Reduction in stream energy due to the slowing of water velocity by beaver dams is important in moderating the effects of high stream flows. Beaver dams are resistant to floods, particularly when preferred building materials are available (Smith 2007). Thus, during floods, stream energy is dissipated as water becomes impounded in ponds and as water flows through beaver dams and riparian vegetation (Pollock et al. 2003). Beaver dams cause a relatively greater reduction in stream energy on streams with steeper gradient (Hammerson 1994). Willow growth that is stimulated by beaver dams can be particularly effective in causing flow resistance (Smith 2007). Willow carrs protect watersheds by both spreading flood waters across shrubby floodplains and by retaining debris that can otherwise destabilize downstream areas (Smith 2007). As a consequence, during flooding, water will rise more slowly and the flood peak will be dampened on beaver-influenced streams (Beedle 1991, Gurnell 1998). A series of beaver dams will have a more profound impact on attenuating flood waters (Gurnell 1998, Smith 2007). For example, simulation models showed that while a single beaver pond would reduce peak flows of a 2-year flood event by 5%, a series of five ponds would dampen the peak flow by 14% (Beedle 1991). One example described the attenuation of a flood wave by 94% when it passed through a beaver wetland complex (Hillman 1998). Thus, well-maintained beaver dams can dramatically reduce loss of water to runoff (Woo and Waddington 1990).

Beaver dams can influence groundwater hydrology by increasing groundwater recharge and retention (Lowry 1993, Pollock et al. 2003). Beaver activity has been shown to enhance the water table over large areas during the summer months (Westbrook et al. 2006). One consequence of this is that stream flow can increase during the warm-season low-flow period. Structures built in stream channels promote perennial stream flow by trapping sediments which store storm water and then slowly release it (Debano and Schmidt 1990). Although different types of beaver dams influence hydrology differently, some beaver dams can sustain a more uniform downstream flow (Woo and Waddington 1990). A number of studies have reported higher flows on streams influenced by beaver dams as compared to streams without beaver, and some studies have reported that small streams became perennial when beaver activity was present (Stabler 1985, Pollock et al. 2003).

Beaver activities can create complex drainage patterns. For example, water spilled from dams can cause diversion channels that may flow hundreds of yards downstream before merging with the original channel (Woo and Waddington 1990). On broad floodplains, beaver often dig canals to access food resources (Müller-

Schwarze and Sun 2003). The result can be a complex network of channels and ponds with multiple surface flow paths that can spread water across a valley (Westbrook et al. 2006).

Finally, the water in the ponds reduces the available channel capacity by substituting water for sediment as the space filler. The result is that streams become hydrologically reconnected to their valley floors even in the absence of sediment. This additional contribution of beavers is critical because the magnitude of stream channel erosion that has occurred in the West is such that the stream-valley floor hydrologic reconnection can not occur solely through the fluvial processes of sediment aggradation and accretion (Fouty 2003). For example, Bryan (1928) estimates that the Rio Puerco in New Mexico lost 487,144,150 cubic meters of sediment over a 42-year period as a result of channel incision and widening.

5.1.2 Geomorphology

A key effect of beaver dams is to slow the flow of water, particularly at the pond. This slowing causes sediments that were suspended in flowing water to sink to the pond floor. The deposition of sediments (i.e., aggradation) caused by beaver activities can be extensive and has profound impacts on watersheds both in the short-term and long-term (Naiman et al. 1986, Butler and Malanson 1995, McCullough et al. 2004, Pollock et al. 2007). In the western US, erosional downcutting of streams and destabilization of stream banks have been attributed in part to the removal of beaver (Parker et al. 1985, Fouty 1996, Fouty 2003). Beaver control erosion both through trapping sediments above dams and through decreased water velocity which otherwise would scour banks (Parker et al. 1985). On one Wyoming creek, silt load was reduced 90% by beaver activity (Brayton 1984). In another case, six years after beaver had colonized a steam, aggradation had raised the streambed high enough to connect it to formerly abandoned terraces (Pollock et al. 2007). As ponds fill with sediments, the growth of emergent plants is promoted, which further accelerates the trapping of sediments. Through these processes, channel gradients can achieve a stair-stepped profile (Naiman et al. 1988). Beaver dams can also promote overbank flooding, which is recognized as a driver of key hydrological and ecosystem processes in floodplain riparian zones (Westbrook et al. 2006, 2010).

Over the short-term, aggradation of sediments in a beaver pond can contribute to the conversion of the pond to a “beaver meadow” (Pollock et al. 2003). This occurs when the pond is abandoned by the beaver, either due to complete filling of the pond with sediment, resource depletion in the immediate pond area, or other factors (Ives 1942). Wetland plants such as sedges and willows quickly colonize the exposed sediments forming the beaver meadow, which can continue to trap additional sediments (Johnston and R.J. Naiman 1987, Pollock et al. 1998, Westbrook et al. 2010). However, the degree to which aggradation can occur varies as a function of the amount of sediment available to enter the stream system and be trapped and the number and spacing of the beaver dams. In one study in Montana, a cross-section within 6.5 meters of a beaver dam had 1.75 meters of sediment deposited over a three-year period while cross-sections in the same study area but more distant from a beaver dam showed little aggradation over the same time period (Fouty 2003). As sediment is a limiting factor in many systems and the volume eroded is great, the ability of beaver ponds to reconnect streams to their valley floor via the water-for-sediment substitution and set in motion the desired ecological recovery becomes more apparent (Fouty 2003).

Modern beavers have been present in North America for many thousands of years (perhaps as long as 24,000 years (Ward et al. 1991), and they are known to have occupied areas soon after the retreat of the Wisconsin glacial ice ca 13,000 years ago (Garrison 1967). Beaver were ubiquitous and common throughout most of temperate western North America prior to intensive human exploitation from the 1790s to the early 1900s (Hill 1982). Several lines of evidence indicate that many of the fertile alluvial level valley floors found throughout deglaciated regions of North America were a product of the accumulation of thousands of years of sediments in beaver ponds (Ruedemann and Schoonmaker 1938, Ives 1942, Westbrook et al. 2010). Recently, the first empirical test of this hypothesis based on stratigraphic and geochronologic data found that net aggradation over the last 4,000 years was not large (Persico and Meyer 2009). However, that study focused on small headwater streams that probably had water flows too low to support beaver during at least several hundred years of drought and where aggradation was limited by stream power (Persico and Meyer 2009). In contrast, another study found that beaver dams on larger streams caused overbank flooding which resulted in significant aggradation and formation of expansive beaver meadows on floodplains and terraces (Westbrook et al. 2010). It was concluded that this process, in addition to the formation of in-channel beaver meadows, provides a more powerful explanation for how beaver can help form alluvial valleys (Westbrook et al. 2010). One potential consequence of beaver creating and maintaining low-gradient valley floors, is that the elimination of beaver contributed to rapid channel incision, dewatering of riparian zones, loss of perennial flow, and increased water temperatures that are often observed on streams in the western US (Parker et al. 1985 Fouty 1996, Fouty 2003, Pollock et al. 2003, Butler and Malanson 2005, Pollock et al. 2007, Persico and Meyer 2009).

5.1.3 Biogeochemical processes

5.1.3.1 Suspended sediments

The influence of beaver dams on sediments is linked to the role beaver play in enhancing water quality and nutrient cycling. Water pollution derived from nonpoint sources is recognized as a major water quality issue in the western US and it is more difficult to control than point sources of pollution (Maret et al. 1987). Sediments are a type of nonpoint water pollution that enter water through erosion processes. Suspended sediments cause turbidity which can cause a number of direct negative impacts to plants and animals, such as inhibiting plant growth, clogging gills of aquatic animals, and inhibiting feeding by fish (USEPA 2010). As previously discussed, beaver dams are remarkably efficient at sequestering sediments through aggradation processes. On incised streams in the western US, beaver dams improve water quality both through trapping particles and by reducing water speed, which in turn decreases erosive input of pollutants (Maret et al. 1987).

5.1.3.2 Temperature

Reduction in water turbidity caused by beaver dams could help reduce water temperature because suspended particles absorb heat (USEPA 2010). Most studies have shown that beaver ponds increase water temperature in summer and decrease water temperature in winter (Shetter and Whalls 1955, Collen and Gibson 2001, Rosell et al. 2005). In contrast, some studies have shown that upwelling below beaver dams can result in cooler water downstream of ponds (Pollock et al. 2007). Studies have also shown that beaver ponds stabilize water temperature because ponds are less influenced by air temperature than the stream (Gard 1961). However, stream water temperature is influenced by many factors that vary by time and reach, and its effect on an ecosystem will be influenced by geographic location (McRae and Edwards 1994). Studies in the eastern US where habitat may be more marginal for cold-water fish, have reported negative impacts of beaver on water temperature (Hill 1982, Collen and Gibson 2001). In contrast, in montane regions of the western US, water temperature change due to beaver activity is usually not regarded as a problem and studies have found that warmer waters associated with beaver ponds are a benefit to salmonid production (Collen and Gibson 2001).

5.1.3.3 Oxygen

Another potential consequence of the reduction in turbidity caused by beaver dams is to increase dissolved oxygen in the water. One mechanism by which this can happen is through reduction in water temperature, because cooler water can hold more dissolved oxygen. In addition, by clarifying the water, aquatic plants are able to more efficiently photosynthesize, which releases oxygen as a by-product into the water. Dissolved oxygen can be reduced in beaver ponds under some circumstances, such as sites with high bacterial decomposition and under ice (Naiman et al. 1986, Collen and Gibson 2001). However, most values are much higher than required by fish and complete reoxygenation of the stream occurs a short distance below the dam. Stretches of low oxygen would not be expected in streams with clean water (Smith et al. 1991).

5.1.3.4 Energy flow

Energy flows through ecosystems in the form of organic molecules (i.e., carbon-based molecules). Beaver dams dramatically alter energy flow patterns in a stream by trapping and accumulating organic sediments in the pond. Input to beaver ponds of organic molecules occurs via beaver feeding activities, plant litter fall, bank vegetation, drift in the stream, runoff, and photosynthesis, while output of organic molecules from ponds occurs by drift and respiration that release carbon dioxide (Hodkinson 1975b, Naiman et al. 1986). In beaver ponds, energy inputs are primarily from drift, rather than production in situ via photosynthesis. One study showed that inputs were more than twice the energy outputs and hence organic matter was rapidly accumulating in the sediments where it breaks down at a slow rate (Hodkinson 1975b). A beaver pond may exhibit more than 15 times the aerobic respiration and anaerobic methane production as found in the stream (Naiman et al. 1986). Thus, beaver ponds function to hold and process energy that would otherwise be lost downstream (Naiman et al. 1986).

5.1.3.5 Nutrient cycling

Beaver ponds are focal points of nutrient cycling processes in watersheds. For example, nitrogen availability determines the rate of key ecosystem processes such as primary production and decomposition. Although nitrogen is the most common element in Earth's atmosphere, plants and animals primarily use nitrogen in the form of nitrates. Nitrogen is converted to nitrates through a complex series of steps beginning with atmospheric nitrogen, to ammonium, to nitrite, and finally to nitrate. Special kinds of bacteria in soil and sediments cause these conversions. Because beaver dams accumulate sediments, the nitrogen cycle is radically altered in the beaver pond (Naiman and Melillo 1984). For example, one study showed that a beaver pond stored 1,000 times more nitrogen than an equivalent reach of stream (Naiman and Melillo 1984). The primary input of nitrogen into a beaver pond occurs through bacterial-mediated fixation in the sediment. In contrast, the primary input of nitrogen in the stream is leaf litter. Consequently, beaver ponds serve as long-term storage areas for nitrogen, whereas streams lacking beaver rapidly lose nitrogen downstream (Naiman and Melillo 1984). The stored nitrogen in beaver pond sediments that is released after a dam is abandoned and the pond converts to a beaver meadow used by plants and ultimately the animals that eat those plants. Similar processes occur with other nutrients, explaining why beaver meadows are such fertile and productive habitats.

5.1.3.6 Water purification

Beaver ponds can help clean water of pollutants and toxic compounds from agriculture, human sewage, and livestock, including excess nutrients such as nitrates and phosphates (Collen and Gibson 2001). It has been estimated that the purification capacity of a stream with beaver dams was ten times higher than a similar stream without beaver dams (Collen and Gibson 2001). Pollutants such as nutrients and heavy metals can attach to sediment particles. Beaver dams purify water by trapping and accumulating these sediments. One study found that beaver ponds were more effective in improving water quality during periods of runoff, when more particles are being eroded and contributing to the sediment load (Maret et al. 1987). Another study found that a stream with more beaver ponds had significantly lower numbers of harmful bacteria, including fecal coliform and streptococci (Skinner et al. 1984).

5.1.3.7 Acid neutralization

Beaver ponds might be capable of neutralizing some effects of acid precipitation in streams (Müller-Schwarze and Sun 2003). Acid forms when sulfur dioxide and nitrous oxide exhaust from automobiles and power plants combine with water. Processes in lakes can increase alkalinity to counteract the acid by either diffusing cations (calcium and potassium) from the sediment or removing anions (sulfate and nitrate) from the water. These processes take place in the bacteria-laden top layer of sediments that accumulate at the bottom of bodies of water. Sediments and anoxic zones of beaver ponds are important producers of acid neutralizing capacity, which reduces the sensitivity of water to inputs of acid (Smith et al. 1991, Cirmo and Driscoll 1993). A solution becomes more acidic as the concentration of hydrogen ions gets higher. Thus, headwater stream are made less acidic after passing through beaver ponds primarily due to retention of sulfate in the sediments, which consumes hydrogen ions (Driscoll et al. 1987, Naiman et al. 1988, Smith et al. 1991).

5.2 Biotic Impacts

As a highly interactive species, beaver profoundly affect the plants and animals with which they occur (Soule et al. 2003, Soule et al. 2005). For aquatic species, these impacts are primarily a consequence of the changes to hydrology and geomorphology caused by beaver dams. On the other hand, terrestrial riparian plant communities are impacted not only by beaver activities that cause changes to hydrology and geomorphology, but also as a consequence of altered biogeochemical processes and direct effects of beaver foraging behavior. Terrestrial animals primarily respond to changes in riparian vegetation as an indirect consequence of beaver activities.

5.2.1 Plants

5.2.1.1 Altered forest composition and succession

Beaver dams can cause long-term changes in an ecosystem. When beavers build dams in forested areas, trees are killed by the impounded water. In addition, beavers are unique among non-human mammals in their ability to cut mature trees and hence they can affect forest overstory (Donkor and Fryxell 2000). Beavers are central place foragers that search for food only a short distance (usually < 60 m) from the safety of water where their lodge or den is located (McGinley and Whitham 1985, Naiman et al. 1988, Rosell et al. 2005). Studies have estimated that in northern regions beaver can cut a metric ton of wood within 100 m of the pond (Naiman et al. 1988) and in Minnesota each beaver felled 1.3 kg/ha/year resulting in a 40% decrease in biomass after 6 years (Johnston and Naiman 1990). Beaver first use small trees located nearest the water, but as these are used they eventually seek both larger and more distant trees (Jenkins 1980, Donkor and Fryxell 2000). Together, these factors can increase the area of open canopy and allow for the growth of different kinds of plants, particularly those intolerant of shade (Naiman et al. 1986, Johnston and Naiman 1990, Pastor and Naiman 1992). In addition, since beaver primarily select certain types of hardwoods such as aspen, foraging activity can shift the forest composition and structure (Naiman et al. 1988, Rosell et al. 2005). In the riparian zone, beaver can promote early successional species such as willow and alder by creating light gaps and by increasing nutrients in moist soil (Donkor and Fryxell 2000). In contrast, further from water beaver foraging can accelerate succession by releasing conifers from understory competition (Johnston and Naiman 1990, Rosell et al. 2005). Beaver can influence ecosystems in different ways from other herbivores because most of the biomass cut is mature trees (Donkor 2007). Further, beaver were found to facilitate regeneration of both preferred (e.g., aspen and willow) and non-preferred (e.g., conifers) foods resulting in a peak in plant diversity at intermediate distances from the pond (Donkor and Fryxell 2000).

5.2.1.2 Pond succession

Following abandonment of a beaver dam, the pond drains and a succession of riparian plant communities develop on the former pond site, which is then known as a "beaver meadow". The details of pond succession vary by geographic location but in general the process is started through the accumulation of a seed bank in the beaver pond that leads to new plant growth when soils are exposed (Le Page and Keddy 1998). Usually, newly exposed soils are rapidly colonized by sedges and other herbaceous wetland plants (Wilde et al. 1950, Bonner et al. 2009). In some cases abandoned ponds develop into shrubby swamps dominated by alder (Wright et al. 2002). Usually, the pond gradually drains, first exposing soil at upstream and lateral locations while the area near the dam may continue to hold water. Thus, the recently abandoned pond will exhibit a mosaic of habitat zones (McMaster and McMaster 2000). The emergent wetland stage may last for years or several decades depending on soil type (Wilde et al. 1950). Riparian shrubs, such as willows and alders, are next to colonize the beaver meadow (Wilde et al. 1950). Inundated pond soils destroy mycorrhizal fungi, which are essential for tree growth. Consequently, succession of the beaver meadow to forest requires the gradual reinoculation of the soil with mycorrhizal fungi (Wilde et al. 1950, Terwilliger and Pastor 1999).

5.2.1.3 Increased riparian area

Dam building by beavers dramatically increases the area of wetted habitat by both expanding the width of the stream and increasing the water table (Naiman et al. 1986, Hammerson 1994). For example, a study in Wyoming found that average stream width was three times wider on streams with beaver as compared to streams without beaver (McKinstry et al. 2001). In Minnesota, beaver impounded

13% of a large peninsula (Naiman et al. 1986). In Acadia National Park, there was an 89% increase in ponded wetlands since beaver recolonized the area (Cunningham et al. 2006). The hydrological changes associated with beaver activity serve to enhance the growth of riparian vegetation (Olson and Hubert 1994). In arid regions, degraded streams have woody vegetation only at water's edge, while with beaver, the band of woody vegetation may be expanded outward 30-40 feet from water's edge (Müller-Schwarze and Sun 2003). On a stream in Oregon the sub-irrigated grassy meadows used for pasturage declined from 15,000 tons to a few hundred tons after beaver were removed (Finley 1937). Another study found that productivity was reduced from 5,000 pounds/acre on beaver streams to 200 pounds/acre on degraded streams without beaver (Müller-Schwarze and Sun 2003).

5.2.1.4 Willow mutualism

The relationship between beaver and willow has been described as a mutualism wherein both species benefit from the interaction (Baker et al. 2005). Although herbaceous plants are the preferred food of beaver in summer, willows serve as the primary riparian zone source of food because the leaves and twigs are eaten in summer and the limbs and trunks are cut for food during winter (Hall 1960, Müller-Schwarze and Sun 2003). However, beaver also benefit the willows. Beaver dams create situations that are favorable for the growth of willow, which occurs through a number of mechanisms. First, willows are more tolerant of flooding than most other trees. Consequently, when a beaver pond is flooded, many willows survive while other trees are killed. In forested areas, the cutting of trees and the creation of beaver ponds opens the canopy which allows light to penetrate. Light fosters growth of willows but inhibits growth of most conifers (Donkor and Fryxell 2000). Beaver dams cause an expansion of the area of wetted soils and a rise of the ground water table, which facilitates growth of willows (Apple 1983). Moist soil is needed for seed germination and seedling survival (Baker et al. 2005). Sediments trapped by beaver dams enhance nutrient levels which further facilitate growth of willows (Donkor and Fryxell 2000). In addition, willows respond to beaver cutting with a burst of growth that increases stem production both in terms of numbers of stems per plant and rate of elongation (Kindschy 1985, 1989). In an area with no competing browsing by livestock, prolonged heavy use of willows by beaver did not cause a reduction or deterioration of willows (Kindschy 1985). Under natural conditions beaver and willow are capable of coexisting on a stream reach indefinitely because beaver shift centers of foraging which allows willows to recover in a continuing cycle (Hall 1960, Baker et al. 2005, Smith 2007).

The decline of riparian habitats, particularly the loss of willow, has been recognized as an important problem in the western U.S. Ungulate browsing can disrupt the mutualistic relationship between beavers and willows, which can reduce or eliminate willows in riparian zones (Smith 1980, Baker et al. 2005, Smith 2007). Beavers primarily cut willows in fall when they are dormant, while ungulate use often occurs during the summer growing season which inhibits subsequent growth

(Kindschy 1989). One example of a disruption of the willow-beaver mutualism is the ecological extinction of beaver on the Yellowstone northern range, which was due to ungulate browsing that destroyed willow and aspen communities (Kay 1994, Kay 1997). Willow browsing by ungulates can cause beaver populations to decline which causes a feedback mechanism that further reduces beaver and willow populations (Kay 1997, Baker et al. 2005). Thus, beaver-willow communities have declined or failed to recover in many regions due to unnaturally high competition for willow by livestock and elk (Baker et al. 2005). The beaver-willow mutualism likely evolved with limited competition for forage due to a more predator-rich environment and lower ungulate densities and use of riparian zones (Kay 1994, Baker et al. 2005, Beschta and Ripple 2010).

5.2.1.5 Plant Diversity

Beaver wetlands can be important in maintaining populations of rare plants. Wetlands are among the most endangered ecosystems because they represent a fraction of terrestrial habitat area, these areas are often isolated, and unique species have evolved to occupy these habitats. For example, in Pennsylvania more than 50% of all plant species of concern are considered wetland species (Davis 1993). A study of the impact of beaver ponds on rare plants found that young ponds ≤ 6 years had higher species richness[12] than older ponds (Bonner 2005, Bonner et al. 2009). However, the oldest ponds (> 56 years) had twice as many rare plants as young ponds (Bonner 2005, Bonner et al. 2009). On a large river floodplain, beaver impoundments had higher plant species richness compared to either riverine wetlands that were freely connected to the river and hence exhibited high levels of disturbance from flooding or to railway-impounded wetlands that were fully disconnected from the river (Bayley and Guimond 2008). Studies have reported that beaver have a negative impact on invasive salt cedar (Baker 1995, Albert and Trimble 2000, Longcore et al. 2007).

The impacts of beaver on diversity are most profound at the landscape scale. Under natural conditions of beaver occupation, a watershed will form a shifting mosaic of different habitat conditions, including unoccupied stream reaches, active beaver ponds of various size and age, and beaver meadows of various stages of succession (Naiman et al. 1988). These conditions will vary through time as beaver occupy and abandon local sites, and these time scales may range from years to centuries. It is this exceptional spatio-temporal complexity that can drive high biodiversity, high productivity, and ecosystem resilience. For example, studies have found that beaver wetlands supported some plant species that could not survive elsewhere and that these plant communities were unique (Wright et al. 2002, Bartel et al. 2010). One study found that only 17% of plants occurred in both beaver wetlands and unmodified areas (Wright et al. 2002). Thus, while beaver wetlands only occupied a small proportion of the riparian zone, they increased the number of plant species by

[12] Richness is sometimes used as an interchangeable term with diversity.

33% at the landscape scale (Wright et al. 2002). These responses are most easily observed for plants, but the impacts affect animals as well (Wright et al. 2002, Bartel et al. 2010).

5.2.2 Animals

5.2.2.1 Aquatic animals

5.2.2.1.1 Aquatic invertebrates

The vast majority of research concerning the impacts of beaver on animals has been aimed at aquatic organisms, especially invertebrates and fishes. Beaver dams increase the amount of still, deep-water habitats on a stream. Substrate type is the main factor that controls distribution of benthic insects (Hodkinson 1975a). Thus, as a response to both the slowed water and silt accumulation, aquatic invertebrate communities living in the substrate shift from flowing-water species to pond species (Naiman et al. 1988). One study found that the invertebrate communities shifted trophic functional groups from shredders and scrapers to collectors and predators, which reflected increases in finer particulate matter and potential prey types in the pond (McDowell and Naiman 1986). Beaver ponds have higher density, biomass, and diversity of invertebrates than stream sites (McDowell and Naiman 1986, Longcore et al. 2006). Overall, the invertebrate communities in beaver ponds resemble those that occur in slow water habitats in larger (i.e., higher order) rivers. Thus, while species are not unique to beaver ponds, the stark differences in invertebrate communities between beaver ponds and unaltered stream channels can result in higher overall diversity at the landscape scale.

5.2.2.1.2 Fish

A number of studies have evaluated the relationships between beaver activity and fish, particularly in the eastern U.S. (Grasse and Putnam 1950, Collen and Gibson 2001, Müller-Schwarze and Sun 2003, Pollock et al. 2003, Rosell et al. 2005). To a large extent, results of these studies are dependent on the geographic location where the study occurred. For example, many studies conducted in the eastern US have concluded that beaver activity is detrimental to cold water fish because beaver actions can warm these already marginal waters (Hill 1982, McRae and Edwards 1994). In contrast, most studies conducted in the western U.S. have found a positive effect of beaver on fisheries (Grasse and Putnam 1950, Rutherford 1964, Collen and Gibson 2001).

Importantly, beaver can modify the hydrology and geomorphology of streams to create habitat for fish where no suitable habitat previously existed (Apple et al. 1995). For example, beaver restoration in a stream reach in Wyoming resulted in the colonization of the area by trout and several species of suckers (Apple 1983).

Beaver-induced changes on small streams that either increase low flows or make intermittent streams perennial have obvious implications for fish (Finley 1937). Beaver ponds can serve as refugia that maintain fish during drought or allow fish to overwinter (Jakober et al. 1998, Collen and Gibson 2001).

On cold-water streams in the western U.S., beaver ponds enhance fish production due to increased water temperature and increased abundance of aquatic insects (Huey 1956, Neff 1957, Gard 1961, Rutherford 1964, Hodkinson 1975a). For example, in New Mexico streams with beaver had four times more trout and the trout averaged larger size (Huey 1956). In Colorado, brook trout were larger in beaver ponds than in streams and new beaver ponds produced greater numbers and volume of brook trout as compared to older ponds (Rutherford 1955). In California, a local trout population fell from 103 to 19 trout after a beaver dam was removed (Gard 1961). Beaver ponds can benefit coho and sockeye salmon as habitat for juveniles and during low flow condition (Collen and Gibson 2001). For example, in Oregon the number of coho fry in beaver ponds was three times the number in other types of pools (Leidholt-Bruner et al. 1992).

Beaver dams can hinder spawning by non-native trout (i.e., brown trout, brook trout) in the western U.S. because these trout spawn in fall when water flow is low and beaver dams are in best condition (Collen and Gibson 2001). In contrast, although how a particular dam will affect fish varies, beaver dams do little to obstruct native cutthroat and non-native rainbow trout spawning because these fish spawn in spring during snowmelt runoff (Collen and Gibson 2001). In high gradient streams, beaver activities can create sediment beds used for spawning while streams with high silt loads might benefit from sedimentation in beaver ponds (Collen and Gibson 2001). Beaver contribute to the conservation of the severely imperiled razorback sucker and bonytail chub in a unique way: hatchery-raised imperiled fish are released into beaver ponds to protect them from larger fish downstream of the beaver dam (Cohn 2001).

As with other organisms, the influence of beaver activity on fish diversity is most apparent at a landscape scale because many species may prefer either pool or riffle habitats (Snodgrass and Meffe 1999, Collen and Gibson 2001). For example, in Wyoming, trout tended to use beaver-created habitat that provided deep water near the bank and close to cover (Young 1995). An exceptionally large population of the imperiled Salish sucker occurred at an aging beaver pond where it was associated with deep pool habitats (Pearson and Healey 2003).

5.2.2.1.3 Amphibians and reptiles

Beaver create vital habitat for many species of frogs and toads. For example, in Alberta, frogs and toads only bred in streams with beaver activity (Stevens et al. 2007). Based on this relationship it was proposed that beavers could be used as a surrogate for amphibian conservation (Stevens et al. 2007). Juvenile production of wood frogs was ten times higher in beaver ponds than other kinds of pools (Karraker and Gibbs 2009). Older beaver ponds supported more breeding wood frogs (Stevens et al. 2006). Occurrence of mink frogs was strongly associated with presence of beaver and pond size (Popescu and Gibbs 2009). In Maine, presence of beaver wetlands was a key predictor of a high diversity of frogs and salamanders (Cunningham et al. 2007). In South Carolina, beaver ponds had more frogs, toads, lizards, and turtles and higher diversity of reptiles than unimpounded streams (Metts et al. 2001).

5.2.2.2 Terrestrial animals

5.2.2.2.1 Terrestrial invertebrates

The endangered Saint Francis satyr butterfly primarily occurs in beaver wetlands and decline of the endangered Mitchell's satyr butterfly is possibly linked to suppression of beaver activity that can maintain fens, which is its sole habitat (Barton and Bach 2005, Kuefler et al. 2008). Beaver-created wetlands were able to maintain populations of Saint Francis satyr butterfly by creating new habitat patches and increasing the abundance of sedges, which are its presumed host plant (Bartel et al. 2010). Leaf beetles that fed on cottonwood that had resprouted following beaver cutting had faster growth (Martinsen et al. 1998).

5.2.2.2.2 Birds

A number of studies have documented higher bird abundance and diversity associated with beaver activity in comparison with sites without beavers (Medin 1990, Grover and Baldassarre 1995, McKinstry et al. 2001, Bulluck and Rowe 2006, Longcore et al. 2006, Aznar and Desrochers 2008, Cooke and Zack 2008, Chandler et al. 2009). For example, a study in Wyoming found that species richness and abundance of riparian birds were associated with beaver dam density (Cooke and Zack 2008). One study showed that beaver meadows had more species of birds than active ponds (Aznar and Desrochers 2008). Woodpeckers used beaver ponds more frequently than river bottom habitat, perhaps due to the snags created by flooded trees (Lochmiller 1979). The area of the beaver wetland was most important in predicting woodpecker abundance (Edwards and Otis 1999). Beaver activity was associated with greater diversity and abundance of neotropical migratory birds (Bulluck and Rowe 2006).

Disturbance-dependent birds, such as those that depend on scrub-shrub habitats, have been in decline and are of conservation concern (Hunter et al. 2001, Chandler et al. 2009). Beavers create these scrub-shrub habitats and scrub-shrub bird abundance was shown to increase with both increasing complexity and area of these beaver habitats (Chandler et al. 2009). In a study in Idaho, beaver pond habitat dominated by willows had three times the density and richness of birds in comparison with an unmodified stream reach that lacked willows (Medin 1990).

Because beaver promote the growth of willows, they can create habitat suitable for endangered birds such as the southwestern willow flycatcher and least Bell's vireo (Longcore et al. 2007).

In the western U.S., beaver ponds are especially important habitat for waterfowl (McKinstry et al. 2001). In the high country of Colorado, ducks used only beaver ponds, including for nesting, to the exclusion of all other water types (Rutherford 1955). In Wyoming, there were 7.5 ducks/km on streams with beaver ponds compared to 0.1 ducks/km on streams without beaver (McKinstry et al. 2001). One study found that the vast majority of brood production by water birds was in beaver-created wetlands, likely due to greater macroinvertebrate abundance (Longcore et al. 2006).

5.2.2.2.3 Mammals

Not surprisingly, beaver enhance habitat for other semi-aquatic mammals including muskrat, mink, and river otter (Leighton 1933, Rutherford 1955, Neff 1957, Dubuc et al. 1990, McKinstry et al. 1997, Rosell et al. 2005). For example, river otters select watersheds with high proportions of beaver wetlands because these provide key habitat factors such as stable water levels, cover, and abundant food (Dubuc et al. 1990). Otters are considered commensal with beaver and beaver activities are thought to play a major role in allowing expansion of otter into smaller streams and preventing extirpation of otter in Arkansas (Tumlison et al. 1982). In Idaho, beaver benefitted otters by providing the primary sites for denning and resting, which were primarily in beaver bank dens and lodges (Melquist and Hornocker 1983).

There are few quantitative data on the impact of beaver activities on small mammals, although it is expected that beaver would enhance habitat for species associated with riparian habitats. Studies have found higher densities of shrews, voles, and jumping mice at beaver-modified areas as compared to unmodified stream reaches (Medin and Clary 1991, Suzuki and McComb 2004). In one study, the number of small mammals captured at a beaver pond was three times higher than at the unmodified stream, primarily due to exceptional response of montane voles, which were 80% more abundant at the pond (Medin and Clary 1991). Long-tailed voles and western jumping mice were found only at beaver ponds (Medin and Clary 1991). The water shrew and meadow jumping mouse were found to be closely associated with beaver dams in Manitoba (Wrigley et al. 1979) and water shrews have been found as commensals in a beaver lodge (Siegler 1956). In the American Southwest, a dramatic decline in the distribution of the meadow jumping mouse was attributed, in part, to the loss of beaver (Frey and Malaney 2009). Beaver improve habitat for bats by creating still pools used for drinking, snags used for roosting, and openings used for hunting (Menzel et al. 2001, Brooks and Ford 2005).

Beaver create food for large mammals including raccoon, bears, deer, elk, and moose (Rosell et al. 2005). In forested areas, beaver meadows are important sources of succulent plants used by ungulates and bears (Kay 1994). Beaver ponds and meadows are important sources of aquatic plants for moose (Müller-Schwarze and Sun 2003). The beaver-willow mutualism results in abundant riparian willows, which are used as browse by ungulates (Coady , Kay 1994, Kay 1997, Baker et al. 2005). Moose may be more likely to not harm willows than other ungulates because they have lower population densities and they feed high up in the shrubs rather than lower on new shoots (Smith 2007). During fall and winter ungulates make use of bark and branches from trees that have been felled by beaver (Rosell et al. 2005). Beaver ponds can provide a source of drinking water for wildlife during drought. Several species of carnivores have been reported using beaver lodges as dens and utilizing beaver for prey (Rosell et al. 2005). The high diversity and density of small mammals at beaver ponds would provide abundant prey for carnivores.

6 Socio-economic Benefits

Beavers' impacts on the goods and services society derives from healthy ecosystems provide a useful perspective for understanding the socioeconomic importance of protecting and restoring beaver populations on western national forests (Appendix A: Framework for Economic Evaluation of Ecosystem Services).

6.1 Beaver Ecosystem Service Values

In general, beavers interact with the surrounding ecosystem by felling trees, eating tree and shrub material, and often building dams with the felled trees, shrubs, and other debris. These activities either directly or indirectly impact the ecosystem around them. The impacts can be separated into four categories: water quality, water quantity, ecosystems, and habitat. Figure 4 describes the various ecosystem impacts beaver activities have upstream and downstream of their dams. Table 1 (ECONorthwest 2011) illustrates economic values for some of the types of ecosystem service that can be generated by beaversThe dams beavers build directly and indirectly impact the water quantity both upstream and downstream of the dam. Beaver dams impede the flow of water and create pools of very slow-moving water directly upstream. At times of low base flows, beaver dams can hold 30 to 60 percent of available water (Kay 1994). In systems with seasonal water shortages, this storage and subsequent slow release can be crucial to maintaining minimum baseflows for downstream habitat, and valuable late season flows for irrigators and other water consumers. Furthermore, decreased water velocity and more consistent water volume result in decreased severity of flooding events and increased groundwater recharge in downstream waterways (Gurnell 1998). Healthy beaver populations can reach densities sufficient to have significant effects on the landscape for water storage and flow. Observed landscape densities achieve one colony per square kilometer, increasing the area of land inundation by 1 to 13

FIGURE 4. Beavers' Potential Impacts on Streams and Related Ecosystems

Beavers' Potential Impacts on Streams and Related Ecosystems	Upstream Impacts	Downstream Impacts
Water Quantity	↑Precipitation Storage ↑Water Depth	↓Velocity ↓Flooding Severity ↑Consistency of Flow ↑Groundwater Recharge ↑Late Season Flow
Water Quality	↑Methane Production ↑Carbon Production ↑Aerobic Respiration ↓Oxygen Concentration ↑Other Nutrients ↑Sediment Retention	↓Sediment Retention ↓Temperature
Ecosystems	↑Wetland Area ↑Riparian Area ↑Open Canopy Area	↑Riparian Area ↑Open Canopy Area
Habitat	↑Big Game Habitat ↑Fish Habitat ↑Insect Habitat ↑Bird Habitat ↑Small Mammal Habitat ↑Amphibian Habitat	↑Big Game Habitat ↑Fish Habitat ↑Insect Habitat ↑Bird Habitat

Source: ECONorthwest (2011) with data from: Gurnell 1998; Naiman, Melillo and Hobbie 2006; Naiman, Johnston and Kelley 1988; Rosell, Bozser, Collen and Parker 2005.

percent in Minnesota and up to 50 dams per stream mile in Idaho (Johnston and Naiman 1990).

The value of water quantity is well documented. One review of water-rights acquisitions, for example, found that purchasers of water in areas receiving streamflow from national forests have paid $96 per acre-foot, on average (Brown 2004.) Communities across the United States are evaluating and implementing costly new water supply options, such as water reuse and desalination, with prices from $300 to $1300 per acre-foot for water reuse, and from $2000 to $3000 per acre-foot for desalination (Fryer 2010). Beavers offer alternatives for increasing water supply at much lower costs. The potential density of beaver and the potential extent of inundation identified above demonstrate that beaver can have a substantial impact on the amount of water available in water-scarce watersheds, particularly those with dry seasons. When small communities spend well into the millions to expand their water supply, the potential avoided costs provided by beaver are substantial.

6.1.1 *Water Quality*

Beaver dams have several impacts on water quality, both upstream and

TABLE 1. Illustrative List of the Value Derived from Water-Related Ecosystem Services

Ecosystem Service	Unit of Change	Economic Importance	Method of Valuation	Value
Stormwater Retention	Cubic foot of stormwater flow	Avoided cost of increasing stormwater retention capacity	Avoided Cost	$2.50 / cubic foot[1]
Water Quality	Change in value of water quality index	Change in economic well-being	Contingent Valuation	$30 - $150 / household[2]
Regulation of Disturbances	Change in acres of wetland habitat	Avoided cost of increasing floodwater storage	Avoided Cost	$500 - $2,700 / acre / year[3]
Water Clarity	Change in water clarity	Change in lakefront housing prices	Hedonic Analysis	$1,700 - $14,700 / meter of clarity[4]
Recreational Opportunities	Change in water quality	Change in economic well-being derived from recreating and change in number of trips	Contingent Valuation and Revealed Preference	$73 - $102 / trip[5]
Groundwater Quality	Risk of groundwater contamination	Change in economic well-being derived from decreased risk of groundwater contamination	Contingent Valuation	$240 - $2,000 / household[6]
Fish Habitat	Change in quality of habitat and population	Change in consumer surplus from fisheries	Bioeconomic Model	$0.30 – $0.80 / acre of drainage basin[7]

[1] American Forests. 1998.
[2] Carson and Mitchell. 1993.
[3] Leschine,. Wellman, and Green. 1997.
[4] Gibbs, Halstead, Boyle, and Huang. 2002.
[5] Whitehead 2000.
[6] Sun, Begstrom and Dorfman. 1992..
[7] Knowler, MacGregor, Bradford and Peterman. 2003

downstream of the dam. A beaver dam's impacts on water quality stem primarily from sediment capture in pools of very slow-moving water upstream of the dam. As water slows, sediment sinks to the bottom of the pool. The sediment is typically a mix of organic and inorganic components. Once the sediment has settled, a number of biogeochemical processes occur, changing the nutrient composition of the pond floor. Many of these nutrients remain on the bottom of the pond and are not released into downstream waterways. Downstream, the increased sediment retention results in decreases in the concentration of certain harmful nutrients. Furthermore, the delayed water flow the dam causes decreases the water temperature of downstream waterways. With a more consistent quantity of water flowing at a lower velocity for a longer period of time, the numbers of high-temperature days downstream of the dam decrease as mentioned in the previous section.

As beaver dams capture sediment and other material, they can generate multiple economic benefits. Communities downstream, for example, can realize cost savings of not having to filter the material from water supplies, fish managers can see improvements in fish habitat, and the owners of human-built dams can realize extensions in the life of reservoirs and water storage facilities. Beaver ponds have observed siltation rates from 1 to 40 cm per year across the area of the pond (Butler and Malanson 2005). Beaver ponds in one study averaged 225 m^3 of captured sediment per pond, and as much as 5000 m^3 (Butler and Malanson 2005). By capturing sediment, beaver dams also can lower dredging costs in downstream waterways and reservoirs.

Examples of values for improving water quality through avoided costs via ecosystem services abound. Clean Water Services, a water-resource management utility in northwestern Oregon, avoided investing in a chiller for a water treatment plant on the Tualatin River by planting riparian vegetation to shade and cool the river, for a savings of $50 million (Niemi, Lee and Raterman 2007). Portland, Oregon avoided purchasing a $200 million filtration treatment system for its water supply by protecting 102 square miles of its watershed. This avoided cost constitutes an economic benefit of $3,000 per acre for water filtration services (ECONorthwest, and Krieger 2001). The cities of Portland and Auburn, Maine are each saving over $20 million in a similar fashion, while New York City saves over $4 billion in water treatment costs through watershed function protection and restoration (Postel and Thompson. 2005.) Clearly, if beaver activity can contribute significantly to improvement of a watershed's water quality, the cost savings can rise well into the millions of dollars.

6.1.2 Habitat

Beaver activity can play important roles in maintaining valuable habitat, as described in the previous section. Wetlands are a particularly valuable ecosystem and habitat type because of the range of valuable services they provide, and the significance of the plant and animal species they support. Table 2 (ECONorthwest 2011) illustrates some of the values reported in the literature for ecosystem services associated with wetland habitat, showing average values and the range of values across 39 wetland studies. Efforts to protect and restore wetlands range across the country with limited success, and high-demonstrated costs, such as through wetland mitigation banks. The cost-savings and success-rate improvements offered by beavers under the proper conditions are again significant avoided costs and benefits.

Beaver dams can prevent and reverse stream incision, which separates rivers from the floodplain, lowers water tables, and carries sediment downstream. All these effects have significant, detrimental effects on downstream water quality, available water quantity (both instream and groundwater) and habitat viability. One U.S. Forest Service review of costs to restore streams with incision found restoration costs exceeding $60,000 per stream mile, with costs potentially exceeding $100,000 per mile (Bair 2004).

6.1.3 Recreation

Improvements to water quality, water quantity, habitat, and wildlife populations all contribute to substantial improvements in the quality and quantity of recreation

TABLE 2. Value of Ecosystem Services Associated with Wetland Habitat ($/Acre/Year)

Single Service Wetland Type	Mean Value	Range of Values
Flood Attenuation	$645	$146–$2,865
Water Quality	$684	$207–$2,260
Water Quantity	$208	$10–$4,216
Recreational Fishing	$585	$156–$2,201
Commercial Fishing	$1,276	$177–$9,214
Bird Hunting	$115	$41–$323
Bird Watching	$1,988	$866–$4,562
Amenity	$5	$2–$23
Habitat	$502	$156–$1,609
Storm	$389	$18–$8,433
Base Value of Net Primary Productivity		$2,400–$4,800

Source: Woodward and Wui 2001.

opportunities, and thus the resulting level of demand for recreation activities in beaver-influenced areas. Economists frequently estimate outdoor recreation values, looking at recreationists' expenditures and travel costs, to demonstrate the economic value of natural resources. Considering the wide range of their impacts on water and on related vegetation and wildlife, beavers can have broad and significant effects on recreation values. Table 3 (ECONorthwest 2011) illustrates some of the values associated with different types of outdoor recreation that might be affected by beavers. The economic value represents the net economic benefit of outdoor recreation, i.e., the difference between what a recreationist is willing to pay and what he or she actually pays. Data in Table 3 represent the mean value for one person participating in a recreational activity for a portion of one day.

7 EXISTING STATUS OF SPECIES

TABLE 3. Value of Recreation ($/recreation-day)

Activity	Pacific Coast Mean	National Mean	National Range
Biking	–	$61.74	$24.08–$85.98
Fishing	$50.55	$49.07	$2.37–$288.43
Hiking	$36.52	$50.09	$2.13–$298.59
Nonmotorized boating	–	$84.19	$20.56–$360.54
Sightseeing	$69.24	$49.06	$0.74–$239.03
Swimming	$31.09	$28.82	$2.50–$67.11
Wildlife viewing	$40.66	$41.94	$3.23–$220.95

Source: Rosenberger and Loomis 2001.

The protection and management status of beaver vary dramatically by state and federal agency as well as across states. This varied status presents a challenge for federal land managers and state wildlife agencies, but also an opportunity for USFS to engage federal and state wildlife agencies in cooperative management and restoration of beaver as an adaptation to the effects of climate change.

7.1 Status Under State and Federal Policy, Law

Beaver are managed under a variety of protective status and trapping regulations. Only two western states, Utah and Oregon, have developed species-specific management plans for beaver. The *Utah Beaver Management Plan,* approved by the Utah Division of Wildlife Resources Wildlife Board in 2010, states as its goal, "Maintain healthy, functional beaver populations in ecological balance with available habitat, human needs, and associated species" (UDWR 2010).

Most states label beaver as a furbearer and regulate trapping through the state's wildlife agency. Beaver are managed to provide recreational and commercial fur harvest, and take for damage control is regulated (Table 4; ECONorthwest 2011). Killing or relocation of animals considered a nuisance on private property is allowed, but in some states a permit is required. Each state has slightly different trapping regulations applicable to beaver, but most restrict trapping seasonally and geographically, and some have bag limits (Table 5). Arizona, New Mexico and Oregon ban trapping of beaver on most national forests and several other states have closed particular streams and rivers on federal lands.

Food and habitat availability may be the major limiting factor in present day distribution of beaver rather than trapping or management to mitigate damage to human developments. However, beaver continue to be lethally removed by the federal government in all western states (See Section 8.3).

Colorado is unique in that voters passed Amendment 14 (CRS 33-6-203) to the state Constitution in 1997, banning lethal methods of trapping beaver and effectively halting sport and commercial harvest of beaver (Boyle and Owens 2007).

7.2 Comprehensive Wildlife Conservation Strategy Plans

Each state has a Comprehensive Wildlife Conservation Strategy (CWCS). Table 5 identifies the three states that have designated beaver a Species of Greatest Conservation Need (SGCN) or similar status. In Oregon, Washington and Vermont beaver is discussed frequently in the CWCS with regard to its keystone role in ecosystem structure and function, but is not designated any special status.

7.3 APHIS: Lethal Beaver Removal

The USDA Animal and Plant Health Inspection Service (APHIS) Wildlife Services conducts animal damage control in response to requests for assistance across the nation. Wildlife Services Annual Program Data Reports provide information about its wildlife damage management activities, including the number of beaver lethally removed, typically by trapping or firearms. In 2009, the latest year numbers were published on the web, 26,104 beavers were lethally removed in the U.S.[13] In the states we examined in the year 2009, 19,077 beaver were lethally removed by APHIS Wildlife Services. Wildlife Services killed the greatest number of beaver (4,568) in North Carolina, while none were killed in Arizona (Table 6). Over the last decade the total number of beaver lethally removed by APHIS Wildlife Services across the United States was greater than 230,000.

[13] http://www.aphis.usda.gov/wildlife_damage/prog_data/prog_data_report_FY2008.shtml

TABLE 4. Beavers Trapped Commercially or for Sport by State in the Last Year Reported[a]

State	Beavers[b]
AK	2,146
AR	4,686
AZ	10
CA	160
ID	2,803
IN	3,744
MI	12,819
MN	49,000
MS	10,544
MT	7,420
NC	8,370
NH	2,709
NM	83
NV	684
OH	2,859
UT	500
WI	31,049
WV	783
WY	3,329

[a]States listed are a sample of those with National Forest System lands.
[b]Numbers are as reported by state and some are estimates.

TABLE 5. Status Under State Comprehensive Wildlife Conservation Strategy (CWCS) and Trapping Regulations[a]

State	CWCS Status	Hunting and Trapping Regulations
AK	Admiralty Island beaver only	Some areas closed, no bag limit
AL	None	Year-round, no bag limit
AR	None	Seasonal, no bag limit
AZ	Species of Greatest Conservation Need (SGCN)	Seasonal, leg-hold and instant kill traps banned on public lands including national forests
CA	None	Seasonal, no bag limit, closed areas, "no body-gripping traps for recreational trapping or commerce in fur"
CO	None	Seasonal, no bag limit, leg-hold traps must be padded
GA	None	Year-round, no bag limit
IN	None	Year-round, no bag limit
ID	None	Seasonal, bag limits, trapping units
KY	None	Year-round, no bag limit
LA		Seasonal, no bag limit
MI	None	Year-round, no bag limit
MN	None	Year-round, no bag limit
MS	None	Seasonal, no bag limit
MT	"Species of Concern"	Seasonal, bag limits, trapping units/districts
NC	None	Year-round, no bag limit
NH	None	Year-round, bag limit of 10
NM	SGCN	Seasonal, closed areas including the Gila, Cibola, Lincoln and Apache-Sitgreaves national forests
NV	None	Seasonal, open statewide
OR	None	Seasonal, national forests closed, mandatory trapper education course
OH	None	Seasonal, no bag limit
SC	None	Year-round, no bag limit
TX	None	Seasonal, no bag limit
UT	None	Seasonal, no bag limit, some closed areas, device restrictions
VA	None	Seasonal, no bag limit
VT	SGCN	Seasonal, no bag limit
WA	None	Seasonal, leg-hold and body-gripping traps banned for recreational trapping or commerce in fur
WI	None	Seasonal, no bag limit
WV	None	Seasonal, no bag limit
WY	None	Seasonal, some closed areas, bag limits

[a] States listed are a sample of those with National Forest System lands.

TABLE 6. Beavers Killed by USDA APHIS Wildlife Services in 2008 and 2009.[a]

State	Beavers Killed 2008	Beavers Killed 2009
AK	5	None Reported (NR)
AL	1,408	1,453
AR	NR	NR
AZ	NR	5
CA	1,210	1,288
CO	124	189
GA	338	205
ID	75	65
IN	NR	NR
KY	282	175
LA	1,196	1,001
MI	NR	NR
MN	558	308
MS	3,390	3,721
MT	10	NR
NC	4,697	4,568
NH	NR	NR
NM	37	14
NV	5	5
OR	434	668
SC	1,344	1,561
TX	2,070	2,739
UT	15	10
VA	567	405
VT	NR	NR
WA	461	301
WI	1,125	1,149
WV	NR	NR
WY	27	56
Total	**19,447**	**19,077**

[a]States listed are a sample of those with National Forest System lands.

7.4 NFMA and Management Indicator Species

The National Forest Management Act (NFMA) of 1976 is the primary statute governing the administration of national forests.[14] The NFMA requires the USFS to "provide for diversity of plant and animal communities."[15] The Department of Agriculture (USDA) Forest Service rules for planning (planning rule) were first promulgated in 1982. Considered to be out of date, a revision of these rules commenced in 2000. The USFS is currently operating under the transition provisions of the 2000 Planning Rule that allows forests to develop, revise and amend land and resource management plans ("forest plans"), as required by NFMA, using the procedures of the 1982 Rule. All existing forest plans have been developed using the 1982 Planning Rule procedures. Subsequent rules promulgated in 2005 and 2008 were enjoined in legal actions.

The 1982 NFMA planning regulations require the identification and monitoring of management indicator species (MIS).[16] Unique MIS are identified in the forest plans of each national forest and are generally identified because they were thought to be sensitive to management activities and indicate changes in forest conditions.

In the western states, thirteen percent (6 of 76) of national forest units name beaver as an MIS in their forest plans. National forests could effectively and efficiently contribute to their NFMA obligation to provide for diversity of plant and animal communities, particularly for freshwater aquatic and riparian systems, with the identification of beaver as an MIS and the support and re-establishment of functional beaver populations.

7.5 NEPA and Climate Change Adaptation

The National Environmental Policy Act (NEPA) of 1970 establishes national environmental policy and goals for the protection, maintenance, and enhancement of the environment and provides a process for implementing these goals within the federal agencies.[17] The NEPA also established the Council on Environmental Quality (CEQ). The CEQ promulgated regulations implementing NEPA in 1978.[18] The NEPA regulations are binding on all federal agencies and address the procedural provisions of NEPA and the administration of the NEPA process, including preparation of Environmental Impact Statements and Environmental Assessments.

[14] 16 U.S.C. §§ 1600-1614.
[15] 16 U.S.C. § 1604(g)(3)(B).
[16] 36 C.F.R. § 219.19, 1982.
[17] 42 U.S.C. 4321 et seq.
[18] 40 CFR Parts 1500-15081.

On February 18, 2010, CEQ issued "Draft NEPA Guidance on Consideration of the Effects of Climate Change and Greenhouse Gas Emissions." The draft guidance notes that in the process of analyzing the environmental impacts of a proposed action, a federal agency such as the USFS, "...may assess the extent that the effects of the proposal for agency action or its alternatives will add to, modify, or mitigate [climate change] effects. Such effects may include, but are not limited to, effects on the environment . . . and on vulnerable populations who are more likely to be adversely affected by climate change."

A proposal to support, increase, or reintroduce beaver (or not) on a national forest should be assessed in forest plan and project NEPA documents for its consequences for adaptation to climate change in light of relevant beaver ecosystem services such as summarized and referenced in this report.

The USFS has issued guidance documents for incorporating climate change into land management planning and projects.[19] The guidance documents, entitled "Climate Change Considerations in Project Level NEPA Analysis" and "Climate Change Considerations in Land Management Plan Revisions," provide the USFS with the support needed to integrate climate change into land management planning and project-level NEPA documentation.

This USFS guidance notes, "the Agency may propose projects to increase the adaptive capacity of ecosystems it manages. Also, proposals may include adaptation proposals and adaptive management strategies to allow for uncertainties in environmental conditions resulting from climate change."

As demonstrated in the extensive literature on the ecological and abiotic effects of dam-building beaver summarized and referenced in this report, the support and restoration of functional beaver throughout the National Forest System would provide a significant measure of adaptation to predicted and observed climate change in the form of increased native biodiversity, restoration of riparian resilience, and hydrological benefits.

8 CONCLUSION

Based on the scientific information presented here, it is clear that the USFS has a highly efficacious adaptation strategy readily available in the form of inventory and reestablishment of historic, range-wide beaver populations on national forests.

The information provided in this report demonstrates the critical functional roles beavers play in adaptation of aquatic and forested ecosystems to climate change as

[19] http://www.fs.fed.us/emc/nepa/climate_change/index.htm

well as socio-economic benefits associated with inventory and reestablishment of this wildlife species.

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10 APPENDIX A: FRAMEWORK FOR ECOSYSTEM SERVICES

Ecosystem services and market-based approaches to their development are currently gaining increased focus by the federal government. In 2008 the Secretary of Agriculture established the Office of Ecosystem Services and Markets. The office is intended to help the Secretary meet requirements "to establish technical guidelines that outline science-based methods to measure the environmental services benefits from conservation and land management activities in order to facilitate the participation of farmers, ranchers, and forest landowners in emerging environmental services markets" (Schafer 2008). Similarly, in 2008 Congress also recognized the importance of ecosystem goods and services by chartering of the Conservation and Land Management Environmental Services Board, chaired by the Secretary of Agriculture and including the Secretaries of Interior, Energy, Commerce, Transportation and Defense, the Chair of the Council of Economic Advisors, the Director of the White House Office of Science and Technology; the Administrator of the Environmental Protection Agency; and, the Commander of the Army Corps of Engineers. These actions, along with multiple task forces and interagency efforts focused on ecosystem services demonstrate the new concerted use of ecosystem services to identify and value natural areas, and prioritize actions that protect, improve, and incentivize provision.

FIGURE 1. Ecosystem Services as Described by the USEPA

"Ecosystem services are the direct or indirect contributions that ecosystems make to the well-being of human populations. Ecosystem processes and functions contribute to the provision of ecosystem services, but they are not synonymous with ecosystem services. Ecosystem processes and functions describe biophysical relationships that exist whether or not humans benefit from them. These relationships generate ecosystem services only if they contribute to human well-being, defined broadly to include both physical well-being and psychological gratification. Thus, ecosystem services cannot be defined independently of human values."

- USEPA. 2009. *Valuing the Protection of Ecological Systems and Services*. p. 12

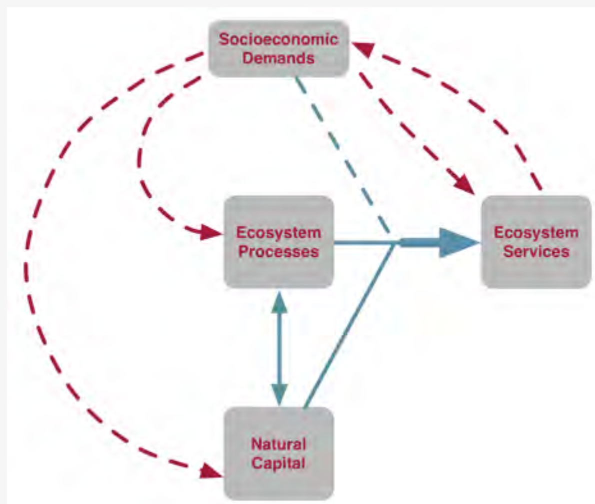
Beavers, as described in Section 5 above and Appendix A, are unique in the magnitude and range of their impacts on structures and processes within ecosystems. In this section, we connect these impacts with the benefits they provide to society, and provide a sample of the values corresponding to these benefits. Together, they demonstrate the potential leverage provided by beavers as a focal point for maintaining and improving the function of natural systems in service to society and wildlife.

10.1 Ecosystem Services

The term, ecosystem services, describes the set of goods and services produced by ecosystems. Figure 1 provides the U.S. Environmental Protection Agency's (USEPA) definition of ecosystem services. Like any good or service, ecosystem services require human demand to be considered valuable. Identifying the value of ecosystem services provided by beavers requires aligning the changes in ecological structures and processes resulting from beavers' presence in a landscape with the socioeconomic demands.

Beavers provide a large portfolio of services without payment, but their doing so does not decrease their socioeconomic importance relative to comparable human impacts that involve payment. Markets capture some of the socioeconomic importance and, consequently, there exist price-related data for estimating the value of beavers' impacts on specific services. This is the case, for example, when beavers provide a service, such as increasing the water supply, that enables a community to avoid expenditures to purchase an equivalent service. Some services provided by beavers do not meet the criteria for well-functioning markets, however, and, therefore, there exist no price-related data for estimating the value of these services.[20] In these cases, economists have developed means to estimate willingness-to-pay for goods and services based on evidence about how ecosystems affect consumers' behavior, such as the prices they pay for homes with natural amenities or their travel expenditures to enjoy recreational opportunities associated with natural amenities. These research techniques provide tangible and recognizable benefit estimates that can be as accurate and defensible as those linked to market prices. Employing non-market valuation techniques is essential to capture the full socioeconomic value of beavers' impacts on land and water resources. Beavers provide these types of services without payment, but that does not decrease the value of the benefit.

FIGURE 2. Approach to Ecosystem Services



Source: Adapted from: De Groot, Wilson and Boumans. 2002; Kusler 2003; Postel and Carpenter 1997; USEPA 2009.

[20] Beaver-sourced ecosystem services typically do not have excludability and rivalry of benefits, or accessible information about the value of benefits, and consequently, markets fail to properly value them.

The supply of and demand for ecosystem services have four basic components: natural capital, ecosystem processes, socioeconomic demand, and ecosystem services (Figure 2). A thorough description of the socioeconomic value of beavers' impacts on ecosystem services must address all four.

10.2 Natural Capital

This term describes the inventory of nature's basic building blocks and includes vegetation, water, minerals, wildlife, and other physical structure. Beavers' activities change the quality, quantity, and location of natural capital. Introducing large woody debris into waterways, capturing and storing water and sediment, increasing surface water area, and preventing/reversing stream incision and water table decline are some of the more direct and substantial physical effects beavers have on natural capital. These components of natural capital have direct benefits to society, particularly by increasing water storage during wet seasons and, hence, downstream water availability and quality during subsequent dry periods. In addition, these structural effects contribute to impacts on ecosystem processes. While relevant literature does not directly address the value of beaver activities, *per se*, there exists a substantial literature on the economic value of the natural capital, particularly for water resources, affected by beavers.

10.3 Ecosystem Processes

While some forms of natural capital have value as stand alone goods, their value increases when linked together through ecosystem processes. Ecosystem processes "are the characteristic physical, chemical, and biological activities that influence the flows, storage, and transformation of materials and energy within and through ecosystems" (USEPA 2009). Nutrient cycles, biogeochemical cycles, water cycles, population cycles for other species, etc. all contribute to the maintenance and accumulation of natural capital and help shape what we view as nature. The relationships between natural capital and ecosystem processes allow for the accumulation and appreciation of natural capital over time. Natural capital and ecosystem processes are difficult to consider in isolation. Both are necessary to produce and maintain a viable ecosystem. Therefore beavers' activities generate indirect benefits via maintaining and improving the quantity, quality, and regularity of valuable processes. These functions include aquatic and riparian habitat provision, nutrient cycling, and water filtration and water temperature regulation.

10.4 Socioeconomic Demand

Demand exists when humans are willing to pay some positive amount of money to acquire a good or service. If there is demand for specific goods and services provided by natural capital and ecosystem processes, then those goods and services have value and benefit society. Oftentimes in the case of beavers, the willingness-to-pay relates to the capital or consequence of a process rather than the beaver or their actions themselves. Much of this is based on the fact that beavers are not the only source of these services, and the lack of information concerning beavers' impact on them. When beaver populations and activity are nonexistent or below potential, the lack of or limited awareness of the potential benefits beavers can provide can hinder willingness-to-pay to restore or expand beaver populations.
As populations and consumption grow, and natural resources become more scarce or susceptible to climate change, the demand for ecosystem goods and services will grow. In some cases, technological replacements, such as water treatment plants, water reuse and desalination, are available, although costly. Other, more direct effects, such as habitat provision, can be very difficult or impossible to replace, particularly in a self-sustaining manner. The costs of these replacements and existing efforts to provide these goods and services through other means reveal society's willingness to pay, and are discussed below.

Scarcity is a primary driver for the value of a service. It determines the price of services traded in markets. It similarly influences the value of non-market services. If a particular service is readily available or inexpensively replaced, it will be less valuable to society than one that is scarce and not easily replaced. In many situations, beavers can enable an ecosystem to provide services for which low-cost substitutes are no longer technically, financially, legally, or politically available. For example, they can provide water storage and flood protection that otherwise would require construction of human-built dams in locations where they are not feasible. Hence, without beavers, society must forgo these services, even as growing human populations make the services ever more valuable. The combination of increasing demand and decreasing substitute options make opportunities for ecosystem service provision such as via beaver conservation more attractive than historically.

11 APPENDIX B: BEAVER PROJECT REVIEW

Below is a small sample of beaver assessment, inventory and reintroduction projects from the field. The USFS and BLM as well as many state wildlife agencies and Native American tribes are involved in these projects.

11.1 Government Assessments

- **US Forest Service Region 2 beaver conservation assessment from 2007.**

This assessment addresses the biology of the beaver throughout its range and in Region 2.

Boyle, S. and S. Owens. (2007, February 6). North American Beaver (*Castor canadensis*): a technical conservation assessment. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/northamericanbeaver.pdf

11.2 Inventory

- **Bridge Creek beaver multi-year inventory (BLM), Oregon**

BLM, Prineville, Oregon inventory of beaver after cattle pressure was reduced and trapping eliminated on Bridge Creek in central Oregon.

Demmer, R. and R.L. Beschta. 2008. Recent History (1988-2004) of Beaver Dams along Bridge Creek in Central Oregon. Northwest Science, Vol. 82, No. 4.

- **Bighorn National Forest beaver cache survey, Wyoming**

"The Wyoming Game and Fish Department conducted six beaver cache surveys on the Bighorn National Forest of Wyoming between 1986 and 2002. A seventh beaver cache survey was conducted in 2003 with funding provided by the Bighorn National Forest. In response to declining populations and the absence of this keystone species in some drainages, the agencies are collaborating with the Rocky Mountain Elk Foundation, Wyoming Governor's Big Game License Coalition and Bow Hunters of Wyoming to transplant beaver to previously occupied habitats. We prioritized release sites by considering model outputs such as patch size and connectivity. We also considered historic activity, watershed activity and suitable habitat conditions. Based on our analysis, we recommend that beaver be transplanted to at least fourteen sites."

Emme, T.J. and B.A. Jellison. 2004. Managing for Beaver on the Bighorn National Forest. Wyoming Game and Fish Department Habitat
September 2, 2004. Gf.state.wy.us/downloads/pdf/habitat/**Beaver**Plan_final.pdf

11.3 Federal Lands Reintroduction Efforts

- **Beaver reintroduction on BLM lands in New Mexico**

In 2005 the BLM Rio Puerco Field Office announced a beaver reintroduction effort in Cebolla Creek, New Mexico. Wetland restoration at Cebolla Springs began in 1995 with great success.

- **Beaver relocation on national forests in Washington**

Colville and Okanogan-Wenatchee National Forest, The Lands Council

"Our experience on the Colville National Forest (CNF) in eastern Washington has been very good. One of their biologists has created a database of all active and inactive (i.e. previously active) beaver areas in the CNF and has shared the data with The Lands Council. Based on that information the biologist suggested two priority locations for beaver re-introduction. In 2010, The Lands Council moved a family of seven beavers to a meadow along Wilson Creek. The beaver family is currently maintaining an abandoned dam upstream of the release site. We are monitoring that site and have installed groundwater-monitoring equipment that will track changes in groundwater levels as the beaver build more dams in the creek. We are also monitoring vegetation changes near the beaver activity to try to capture the rate at which the degraded riparian area changes to a healthy wetland ecosystem. In 2011, we have selected Pierre Creek as an additional site for beaver re-introduction and will apply the same vegetation-monitoring scheme. We believe our relationship with the Colville National Forest is excellent and will continue into the future."

"We are also starting to work with the Entiat District of the Okanogan-Wenatchee National Forest. The Entiat watershed contains Spring Chinook and Steelhead runs, and is a priority system for restoration. The area has a restoration plan that lists beaver restoration as one of the steps that could benefit the diminished salmon runs. Okanogan-Wenatchee National Forest biologists are eager to work with us and The Lands Council has identified several tributaries in the Entiat watershed that are likely candidates for beaver re-population and has that as a goal for 2011. Locations for re-introduction will be decided following a visit to Entiat District by Lands Council staff in the spring of this year."

- **Methow Valley reintroduction effort (USFS and other agencies), Washington State.**

Ninty-five beaver have been relocated to 27 locations in the Methow Valley. Partners: Methow Conservancy, Winthrop National Fish Hatchery, US Forest Service, Washington Department of Fish & Wildlife, Yakama Nation, Washington Department of Ecology, Audubon Washington, Wenatchee Forestry Sciences Lab.

- **Beaver reintroduction on Custer National Forest in Montana for post fire sediment control.**

"The Stag Wildfire of 2000 resulted in the stand-replacement of about 70,000 acres of ponderosa pine forest. As part of post-fire restoration, beaver were relocated to establish dams for sediment control and to improve wildlife habitat. Beaver were relocated from the Tongue River to small streams on the Ashland Ranger District from 2003 to present resulting in the establishment of several colonies, numerous dams, and an elevated water table."

- **Radio transmittered beaver reintroduction Umpqua National Forest in Oregon**

The ability to successfully reintroduce beavers in Oregon is widely governed by land ownership. In July 2009, 40 transmittered beavers were released throughout the Umpqua River basin of southwestern Oregon. The project goal is to scientifically document rates of population expansion, dispersal distances of relocation beavers, and the effects of reintroduced beavers on aquatic and riparian ecosystems.

The project proved successful and served as the framework for western Oregon's new beaver relocation guidelines. In compliance with the new Oregon Dept of Fish and Wildlife guidelines the below listed partners will continue beaver relocation and beaver habitat restoration projects throughout the Umpqua Watershed.

Project partners include the Oregon Department of Fish and Wildlife, United States Forest Service Umpqua National Forest, South Umpqua Rural Community Partnership's Beaver Advocacy Committee and The Cow Creek Band of the Umpqua Indian Tribe.

- **Wallowa-Whitman National Forest Watershed Restoration Project**

A riparian habitat restoration project has been initiated on Camp and Gimlet Creeks, two headwater tributaries of the North Fork of the Burnt River to establish abundant willow, cottonwood, and aspen stands capable of supporting beavers. The objective is to establish a core zone of stable beaver dam complexes such that beaver can expand their water storage and habitat modification influence outwards into other tributaries. The project goals are to increase the amount of surface and groundwater stored in the watershed, trap sediment, stabilize eroding stream banks, decrease stream temperatures, expand the width and complexity of the riparian habitat, improve fish and wildlife habitat, restore perennial flow to intermittent streams, and create increased habitat diversity and complexity in the watershed. These changes in the condition and function of the stream/riparian corridor will increase the watershed's stability and resilience to climate change. Currently the streams are over-wide, incised, and straightened as a result of past land use activities, riparian vegetation is confined to narrow zones along the streams, and many streams exceed the State's water quality standards.

The project involves removal of encroaching conifers on the active floodplains and point bars, willow plantings, removing encroaching conifers around three and possibly four riparian aspen stands, fencing the aspen, and removing some conifers from around old cottonwood trees. Elk utilized the two tributaries and livestock utilized portions of the tributaries via active grazing allotments. Beaver are present in the watershed having been reintroduced in the 1990s.

Work done to date includes willow plantings on Camp and Gimlet Creeks, conifer thinning on Gimlet Creek on the active floodplains and point bars, and some removal of conifers around old cottonwoods. Scheduled for this summer/early fall is the removal of the conifers from the aspen stands by a contractor. Depending on when the conifers are removed, fencing will occur either Fall 2011 or Summer 2012,

Project partners include Oregon Department of Fish and Wildlife, Powder Basin Watershed Council, Whitman College, Oregon Watershed Enhancement Board.