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Research article

Adaptive governance of riverine and wetland ecosystem goods and services

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ABSTRACT

Adaptive governance and adaptive management have developed over the past quarter century in response to institutional and organizational failures, and unforeseen changes in natural resource dynamics. Adaptive governance provides a context for managing known and unknown consequences of prior management approaches and for increasing legitimacy in the implementation of flexible and adaptive management. Using examples from iconic water systems in the United States, we explore the proposition that adaptive management and adaptive governance are useful for evaluating the complexities of trade-offs among ecosystem goods and services.

1. Introduction

In the early 21st century, people and societies have developed an unprecedented capacity to manipulate and control ecosystems in order to procure reliable streams of ecosystem goods and services. While humans have altered ecosystems for millennia, it has only been in the past few decades that concepts such as ecosystems goods and services have been proposed as one way to collectively describe the many ways in which humanity and nature benefit from ecosystems (Daily, 1997). A recent global assessment found that many ecosystem services are declining (MEA, 2005).

As our capacity to manipulate the environment has increased, we have also sharpened the focus of how we manipulate the environment to secure ecosystem goods and services. In a gross oversimplification, we seek to control ecosystems by decreasing the natural or inherent variation in ecosystems in order to procure a specified set of ecosystem goods and services. We build dams in river ecosystems in order to control flooding during wet periods and to store water for dry periods. Dams dampen the fluctuations in river flows, by controlling the amount of water released downstream, but also facilitate diversion of water for other types of ecosystem services. In these and many other cases, we stabilize ecological processes in order to achieve economic and social outcomes. In doing so, we optimize for specific goods and services by enhancing efficient production, use and allocation of some at the expense of others. These three objectives; control, stability and efficiency have been achieved in many ecosystems, but not without a cost.

There is a growing body of evidence to indicate that ecosystem management that removes inherent variation, homogenizes spatial patterns and optimizes extraction of a few ecosystem goods increases the vulnerability of these systems to dramatic and unwanted changes (Gunderson and Holling, 2002; Walker et al., 2004; Walker and Salt, 2012). For example, levees, canals and water control structures were put in place to control flooding and to regulate water supply to users in the vast Everglades wetlands of Florida (Light et al., 1995). Development of dams to provide hydropower, irrigation and flood control in the Columbia River basin has evened out flow reducing spring flood and increasing late summer and fall flow (Columbia River Inter-Tribal Fish Commission, 2014; Cosens and Fremier, 2014). Such compartmentalization to control water movement in the mighty rivers of the western U.S. has decreased the variation in flow volumes, slowed the movement of sediments, created new ecosystems, and led to endangerment and extirpation of populations of Pacific salmon as well as non-anadromous species. Similar approaches in fisheries or wildlife

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management also attempt to limit or constrain variability in order to sustain efficient outputs. However, this pattern of ecosystem modification generates an unintended consequence of increased vulnerability (Carpenter et al., 2015), described as the pathology of resource management (Holling and Meffe, 1996). This pathology results from the unexpected response of complex systems to simple management approaches.

While attempts at increasing control over nature have been successful in achieving social and economic objectives, they often have come at the cost of ecological and environmental components. Most regional scale water systems in the U.S. are critical habitat for multiple taxa listed as endangered or threatened. For example, the Everglades system has more than 20 threatened and endangered species (Gunderson and Loftus, 1993). In the Columbia River basin, 8 salmon, 4 steelhead, and 2 resident fish species are listed under the ESA (NOAA, 2012). Other common resource issues that map into ecosystem services include losses in ecosystem functions due to invasive species and water quality degradation (MEA, 2005). In many cases, the changes resulting from intensive management have resulted in new or novel ecosystem configurations (Holling and Meffe, 1996).

The degradation of ecosystem services, such as freshwater provisioning or water quality regulation, or declines in biodiversity can indicate a loss of ecosystem resilience and resulting shift in ecosystem regimes (Folke et al., 2004; Gunderson and Pritchard, 2002). An ecological regime is characterized by a set of structural and functional features, such as shallow, clear water lakes with submerged vegetation (Scheffer et al., 2001), or coral dominated reefs (Hughes, 1994). Regime shifts occur when the dominant structural features of an ecosystem are replaced by alternative ones (Folke et al., 2004). Such regime shifts can be viewed as ecological crises signaling a shift in individual or bundled ecosystem goods and services (Chapin et al., 2009). Ecological crisis may result in unintended and unexpected consequences that substantially alter and reduce services that society has come to rely on. Such crises can reveal failures in policy and management approaches (Gunderson et al., 1995).

By the end of the 20th century in the US, scholars and practitioners were recognizing this loss of resilience and noticing that failures in the top-down governmental approach were leading to new attempts at governance. The NRC (2004) acknowledged the tendency of legislatures to set resource use policy via legislation, and in doing so, decoupled management decisions from local ecosystem dynamics. Such policies led to undesirable outcomes for the ecosystem (collapse of fisheries, crises in forest management) and frustration by stakeholders who depend upon various ecosystem goods and services.

As a result of these crises and failures, new forms of governance emerged;, one of which has been described as adaptive governance (NRC, 2002; Dietz et al., 2003; Bruner et al., 2005; Folke et al., 2005; Gunderson and Light, 2006). Government refers to those arms of the state that make, execute, and amend laws and policies. Governance, on the other hand, includes, but extends beyond the state and state actions to include all persons and groups who try to influence collective action problems (Ostrom, 1990). Governance actors develop and operate by the rules and norms to organize individual and collective actions; these rules and norms include formal laws but also include shared expectations.

Adaptive governance can be contrasted with other forms of governance in key attributes of 1) engaging formal and informal institutions, 2) cross-scale interactions and polycentricity, and 3) focus on knowledge and learning (Chaffin et al., 2014a). Adaptive governance provides space to bring together formal institutions with informal ones to understand, manage and solve complex environmental issues (Schultz et al., 2015). Many formal resource management institutions are geographically defined entities; water management districts in Florida are organized and operate at the scale of a specific watershed, such as the St. Johns River or Suwanee River Water Management District. Spatial boundaries define the power and scope of authority for such agencies and institutions. In addition, many agencies have strictly defined limits on the subject matter they may address. Environmental issues also can involve formal institutions and agents that focus on an idea; such as conservation based NGO's. While this fragmentation in authority and focus may be viewed as inefficient, combined with the capacity to cooperate across boundaries, it sets the stage for polycentricity. Just as many ecological issues cross scales of space and time, adaptive governance is characterized by polycentricity (Dietz et al., 2003). Polycentricity implies that smaller, more local units of governance exist within large, more general ones, and provides institutional diversity and redundancy (Chaffin et al., 2014b). Finally, the third characteristic of adaptive governance is the production and dissemination of new social and ecological knowledge (Pahl-Wostl et al., 2007), thus reconnecting management decisions to ecosystem dynamics. Adaptive governance can provide the co-production and dissemination of knowledge among communities of science, management and resource users (Wyborn, 2015). Such governance engages a broad set of stakeholders and the public.

Gunderson and Light (2006) defined adaptive governance as the set of institutions and framework that facilitates and fosters adaptive management. Adaptive governance compliments adaptive management in that it can address some of the past failures of an adaptive approach that failed to recognize the role of social dimensions of these issues (Lee, 1993; Scholz and Stifte, 2005). Green et al. (2015) suggest adaptive governance as one way of bridging the divide between legal structures that assume away uncertainty and adaptive management that focuses on acknowledging and winnowing uncertainty. Imbedding adaptive management in a process of governance that accounts for the unique needs of a management scheme that continuously evolves provides the means to assure that the legitimacy and cross-sector jurisdiction coordination necessary for acceptance of its implementation by society will be addressed (Cosens, 2010, 2013).

Adaptive management and adaptive governance have been attempted in many large resource systems, such as the Everglades (Gunderson and Light, 2006; LoSchiavo et al., 2013), and Columbia River system (Lee, 1993; Cosens and Williams, 2012). In both of these systems, adaptive management was applied so that managers could address and resolve inherent uncertainty associated with meeting social objectives (Walters, 1986; Chapin et al., 2009). Kai Lee (1993) in writing about experiences with adaptive management in the Columbia River system, was among the first to point out that in such complex systems, managers must confront two different forms of uncertainty. One form of uncertainty involves technical and scientific questions associated with how to resolve resource issues, such as how manipulation of flow regimes influence the recovery of endangered species in the Columbia (Lee, 1993). The second type of uncertainty that Lee (1993) identified lies in the articulation and prioritization of social objectives and goals, an uncertainty he thought was addressed through a deliberative, democratic process. How these different forms of uncertainty are addressed have been critical components to describe the utility and efficacy of adaptive approaches (Gunderson and Light, 2006; Garmestani and Benson, 2013).

As adaptive approaches are being applied to social-ecological systems around the world, there is a shorter history of their application to the framework of ecosystem goods and services (MEA, 2005). The remainder of this article explores linkages among adaptive management, adaptive governance and ecosystem services. We do so by positing that 1) adaptive management can help

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highlight trade-offs among ecosystem goods and services and 2) adaptive governance seems to emerge during times of great uncertainty (such as environmental crises) during which decisions about trade-offs among ecosystem services are evaluated and discussed. We begin with a review of ecosystem goods and services in two complex ecosystems that have histories of adaptive management and adaptive governance; the Columbia River Ecosystem and the Everglades.

2. Ecosystem goods and services

The phrase 'ecosystem goods and services' was proposed in the late 20th century to reflect the manifold ways in which people and societies interact with ecosystems (MEA, 2005). The concept is an attempt to characterize the complex ways in which environmental changes, such as population declines of certain species, would have adverse and less obvious consequences for humanity (Ehrlich and Ehrlich, 1981). Concepts of natural capital, ecosystem goods were also part of the vocabulary, to represent the physical substances of ecosystems that were mostly harvested by humans. One of the first attempts at unifying these concepts was made by Daily (1997) who summarized them as Nature's Services. The MEA (2005) and others (Chapin et al., 2009) categorize ecosystem goods and services in four groups, as described in the following paragraphs.

One category of ecosystem goods and services is described as provisioning services. Provisioning services include the work of nature that supplies water, food, fiber, or chemicals to directly support human populations and society (MEA, 2005). As an example, in the Everglades wetland ecosystem, much of the water management infrastructure and governance has been directed towards a suite of provisioning services (Table 1). Water that created and maintained the wetland ecosystem is now diverted through canals to recharge coastal aquifers that are the primary water source for human populations in southeast Florida (Light et al., 1995). Food production is a major land use in the Everglades; about one third of the historic Everglades wetland currently is used to grow sugarcane and vegetables (Gunderson and Loftus, 1993). Other provisioning services of biological productivity and habitat for wildlife are manifest in the water conservation areas of the Everglades and the Everglades National Park, both created in the late 1940's (Light et al., 1995). Both of these services have declined as a result of successful drainage and flood control efforts during the 20th century (Table 1; Davis and Ogden, 1994). Similar patterns of tradeoffs have occurred in the Columbia River basin. The seasonal pattern of the snow-dominated system provided high flows in spring, yet food provisioning on the arid portions of the basin including the mid-Columbia region and the tributaries of the Yakima and Snake Rivers requires water in summer and early fall. The establishment of reservoirs and canals shifted the hydrograph allowing water to be used for irrigation to improve the provision of food (Table 1). As with the Everglades, such diversions have led to a decline in biological productivity and altered water quality (Cosens and Fremier, 2014).

A second category of ecosystem services includes ecological processes that support other ecosystem services. Soil formation, biodiversity functions and disturbance regimes are all categorized as supporting services (MEA, 2005). In the northern Everglades, the rich organic soils have supported agriculture, designated as the Everglades Agricultural Area. Since the advent of drainage for agriculture, the organic soils have oxidized and continue to subside to date (Snyder and Davidson, 1994). Since Everglades agriculture has and continues to mine the organic soils, this represents a tradeoff in services; the supporting service of soil accretion/maintenance is foregone for food provisioning services. Other supporting services throughout the Everglades and Columbia basins, such as water cycling, biodiversity, and disturbance regimes have all declined over the past century (Table 1).

Another category of nature's work includes a variety of regulating services, such as the complex biogeochemical cycles that move carbon, water and nutrients through the biosphere. These processes provide clean water, regulate climate, and maintain biodiversity (Chapin et al., 2009). The primary objectives of the water management system in the Everglades have been to provide these regulating services, of providing clean water and flood protection for human interests. Both have been successfully procured through the water control and management structures of the system (Table 1). The use of structural measures such as dams and levees to control flood risk in the Columbia basin has decoupled the river from the floodplain altering sediment transport, soil development, and eliminating water quality and habitat services, formerly provided by these areas (Cosens, 2012a; Cosens and Fremier, 2014).

The fourth category or cultural services, describes the nonmaterial benefits of nature, such as aesthetics or recreation. Since the flood control era of water management in the Everglades, the water conservation areas were set aside for recreational benefits, especially hunting and fishing. Tourism is a primary ecosystem service provided throughout the Everglades, both through visitation to Everglades National Park and other state parks, as well as private operations (e.g., airboat tours). Sport fishing, wildland tourism and recreational set of services have grown to be a substantial set of cultural service outputs from the Columbia River basin, however, the steelhead and salmon sport fishery would no longer exist without the presence of over 200 hatcheries in the basin (Cosens and Fremier, 2014).

3. Adaptive governance, adaptive management and ecosystem services

Adaptive governance can emerge as attempts to procure a specific set of ecosystem goods and services leads to a decline or collapse in other services (Chaffin and Gunderson, 2016). Such emergences can occur during and after an environmental crisis, which may signal the failure of extant policies (Gunderson and Holling, 2002). In other cases, new forms of management and governance can occur as new ecosystem services become articulated and formalized following an environmental crisis. The historical development of the social-ecological systems in the Everglades and Columbia provide examples.

The history of water management from the mid to late 20th century in the Everglades has been viewed as a sequence of different management eras (Light et al., 1995) (Table 2a). These eras were created by unforeseen natural disasters that overwhelmed the existing infrastructure and led to either 1) procurement of a new ecosystem service as a social objective or 2) new ways in which those services were procured (Table 2a). An excessively wet year in 1947 led to widespread flooding and to a new plan to manipulate the ecosystem service of flood protection by modifying parts of the SES to better control floods (Light et al., 1995) in agricultural and urban areas. A severe drought in 1961 led to the inclusion of water supply and defined the supply in terms of minimum flow allocations to different water sectors (Light et al., 1995). Another severe drought in 1971, led to more concerns over the provisioning of water supply and led to the formation of a new management era, in which more explicit and defined rules guided water allocation (Light et al., 1995).

In a period referred to by Cosens and Fremier (2014) as the dam building era from the 1930's to 1970's the Columbia River, was harnessed initially to secure the provision services of water for agriculture and hydropower. Following a major environmental

Table 1
Methods and consequences of Procurement of Key Ecosystem Services in the Everglades and Columbia River Social Ecological Systems.

Type of ecosystem service/Good	Everglades water Social-ecological System	Columbia river Social-ecological System
Provisioning services		
Water	Water moved from wetlands through canals to coastal aquifers for human water supply	Reservoir storage and canals for irrigation Urban water supply primarily on tributaries Substantial hydropower production from coordinated dam system
Food	Series of canals, levees pumps to tightly control water levels in agricultural area	River water now irrigates over 2400 km^2 about half of original area (4500 km^2) designated for irrigation.
Biological Productivity	Water diverted through canals to meet urban/agricultural needs, at expense of ecosystem flows	Commercial and recreational salmon fishery substantially affected by dams and habitat loss, supplemented by over 200 hatcheries.
Supporting services		
Soil Formation	Impoundment, instream flow supports soil formation in lower Everglades, drainage in northern Everglades has led to soil oxidation.	Levees and fill combined with use of dams for flood control have substantially reduced connection to floodplains
Water cycling	Diverts overland flow from ecosystem to recharge coastal aquifers to use by urban areas.	3% of river flow diverted to irrigate agriculture.
Biodiversity	Declined due to land use partitioning.	Loss of resilience within salmon populations makes it uncertain whether wild populations could recover even if dams were removed and habitat restored
Disturbance regimes	Complex system to manage fires, fire management along with water management has homogenized landscapes, decreased ecosystem diversity.	Evening out of hydrograph for flood control and power production has altered sediment transport/flushing. Increased fire regime with climate change is likely to lead to increased erosion.
Regulating services		
Water supply	Water moved through canals, pumps to recharge coastal aquifers. Small experiments with aquifer storage and recovery. Regulation schedule decreases flow and water level variation throughout system.	Flow timing substantially altered by operation of the system for hydropower optimization with lower spring flows and higher flows in fall and winter – thus increasing power production, reducing flood risk, and adversely affecting salmon runs, particularly out-migration in the spring
Flood control	Levees, canals, pumps are manipulated using regulation schedule to lower flood risk.	Completely reliant on dams and levees for flood risk management
Water quality	Stormwater Treatment areas, other natural areas (Lake Okeechobee)	Increased temperature due to slack water behind reservoirs is being exacerbated by climate change. In 2015, temperatures in some areas were lethal for salmon. Urban areas dependent on engineered water treatment
Cultural services		
Recreation	Access points for airboats in Water Conservation Areas	Flow still a factor in canoe/kayak recreation on some tributaries. Reservoir development has led to different types of recreation. Sport fishing is strong with hatcheries playing a major role in support.
Tourism	Roads, private and public developments to attract visitors	Substantial fishing and wildland tourism throughout the basin
Traditional	Seminole and Miccosukee tribes rely on Water Conservation Areas for subsistence.	Cultural and subsistence reliance on salmon by indigenous populations substantially altered by decline in the fishery with traditional fishing sites for some Tribes and First Nations blocked from salmon runs by dams. Increasing recognition of indigenous fishing rights in the basin over the past 4 decades has increased focus on habitat restoration.
Navigation	Minimal navigation purposes in project.	Barge and commercial vessel traffic made possible in a substantial portion of the basin through development of locks.

crisis in 1948 in the form of an unprecedented flood, collaboration rose to the international scale and the United States and Canada joined forces to enhance flood control while sharing benefits from hydropower production (Cosens and Fremier, 2014, Table 2b). While such structures provided flood protection and food production for humans, other forms of biological productivity led to the decline and endangerment of anadramous fishes (Lee, 1993). The development of the Northwest Power and Conservation Council (on which Kai Lee was an appointed member), and first attempts at adaptive management characterize a shift in management eras (Table 2b), but also reflect an attempt to resolve emerging tradeoffs among disparate but equally mandated ecosystem services; electrical power generation and flood control contrasted with endangered species (Cosens and Fremier, 2014).

An emergent form of adaptive governance can be ephemeral, in that it appears as an ad hoc organization for a short period of time, and then the governance structure disappears. Such short-term phenomena can arise following a resource crisis, as mentioned above. In the Everglades, during the 1971 drought, the Governor of Florida called together a symposium of stakeholders and water users. This ephemeral group suggested the creation of a new management organization; the South Florida Water Management District (Light et al., 1995). The internationalization of the operation of the Columbia River under the 1964 Columbia River Treaty and establishment of United States and Canadian operating entities that adjust reservoir operation on annual, monthly and even daily cycles was catalyzed by a major flood event. However, the constraints on operation within the limits of optimization for flood control and hydropower and the absence of an adaptive mechanism responsive to changing societal norms may have rendered this approach obsolete (Shurts, 2012). The process of review of the 1964 Columbia River Treaty has given rise to new voices in the basin (Cosens, 2012b), leading to both formal and informal efforts to raise ecosystem function to the third prong of international cooperation (Cosens, 2016). Similar institutional and organizational reformations occurred in Kristianstad wetlands, as a single individual leader led an ephemeral network that changed the perception of the wetland as a national and international asset (Olsson et al., 2006). Similar types of emergent adaptive governance have been described for the Great Barrier Reef Marine Park in Australia (Olsson et al., 2008), the Klamath River basin (Chaffin et al., 2014a,b) and other freshwater ecosystems (Olsson et al., 2006; Schultz et al., 2015).

A well-established component of adaptive management, the

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Table 2a
Ecosystem services associated with four water management eras in the Everglades. Each of these management eras corresponds to different water management objectives (Light et al., 1995; Gunderson and Light, 2006). NA means that each particular ES was not considered as a social objective of that management period.

Management era				
Type of ecosystem service/Good	Drainage 1900–47	Flood control 1947–71	Water supply 1971–1987	Ecosystem restoration 1988- present
Provisioning services				
Water	NA	Became social objective, without definition	Legally defined through legislation	Same as previous era
Food	Nascent Food production	Everglades Agricultural Area established	Food production shifted to a dominant crop: sugarcane	Same as previous era
Biological productivity	Large nesting populations of wading birds	Decline in productivity	Same as previous era	Same as previous era
Supporting services				
Organic soil formation/ stock of organic soils	Agriculture activity located on organic soils	Organic soils oxidized by agriculture, continued decline in amount of soil	Organic soils oxidized by agriculture continued decline in amount of soil	Organic soils oxidized by agriculture continued decline in amount of soil
Biodiversity	NA	Creation of Everglades National Park (ENP)	ENP Allocation of Minimum Water Supply Endangered Species Listings	Same as previous, Invasive species threats
Disturbance regimes	NA	Policies to suppress fire	Same as previous era	Same as previous era
Regulating services				
Water supply	NA	NA	Water Management Districts created	Restoration Efforts to integrate Water Quality and Quantity
Flood control	NA	Establishment of Flood Control District	Became charge of Water Management Districts	Restoration Efforts to integrate Water Quality and Quantity
Water quality	NA	NA	First indicators of decline	Restoration Efforts to integrate Water Quality and Quantity
Cultural services				
Recreation	NA	Establishment of Everglades National Park, Water Conservation Areas	Same as previous era	Same as previous era
Tourism	NA	Everglades National Park	Same as previous era	Same as previous era

adaptive assessment process may also be considered a form of emergent adaptive governance that arose in response to changes in a suite of ecosystem services. By the end of the 1980's scientists and managers in the Everglades were beginning to realize a decline in conservation related ecosystem services. Many ecosystem issues, such as numerous endangered species, spreading invasive species, changes in landscape patterns, decline in wading bird nesting, and loss of soil formation were reflections of an overall erosion or decline in a suite of ecosystem goods and services (Davis and Ogden, 1994). One response to the decline was initiated by a small group of scientists, who undertook an adaptive environmental assessment (Walters et al., 1992). This was in spite of formal institutional gridlock, lawsuits and other failures of formal governance (Light et al., 1995).

The Everglades assessment addressed many of the issues inherent in trying to decide and evaluate tradeoffs involved in procuring ecosystem services. In the workshops, a computer model was developed to articulate hypotheses that led to the decline in ecosystem services. The workshop led to a series of conclusions that the Everglades was smaller, mostly drier, and revealed a fundamental tradeoff of ecosystem services. That is, the workshop suggested that the system operated in such a way to provide water to urban and agricultural parts of the system, and in doing so, decreased the flow of water available for ecosystem productivity, soil formation, and biodiversity conservation.

The Everglades assessment process had many characteristics of adaptive governance. The network that formed was polycentric, in that it involved multiple centers of authority; with national interests from the U.S. National Park Service, U.S. Army Corps of Engineers, and the U.S. Fish and Wildlife Service to state and local interests. The polycentricy was also manifest as cross sectoral-including agricultural, conservation, and water supply interests. The assessment was ephemeral, in that a loose network met in a series of workshops from 1989 through 1991. The process was also participatory and learning based (Huitema et al., 2009). The assessment may be described as a quasi-legitimate project, in that it involved a collaborative effort that perhaps tested the limits of legitimacy, in that it was unlike any previous interagency led planning activity that brought together individuals from inside the various agencies and other interested, public individuals. The assessment was initially funded by agencies, but as a contract to an independent agent; C.S Holling a Professor at the University of Florida. As the process gained interest, the process was held at independent venues and was paid for by independent funding. As a result, generally applied public meeting rules, such as FACA requirements, public notices of meetings were not applied. The sense of the group was that this independence or borderline legitimacy allowed for development of and discussions about new or alternative management approaches.

Institutional forms of adaptive governance have been attempted that involve creating authority to facilitate adaptive management programs (Gunderson and Light, 2006). In the Everglades, the Water Resources Development Act of 2000 authorized the ecosystem restoration process, and mandated that it be done through an adaptive management protocol. LoSchiavo et al. (2013) reflected on lessons from this institutionalization and found that authority was needed for sufficient fiscal resources to implement adaptive management. Efforts to implement adaptive management as part of the Northwest Power and Conservation Council's fish and wildlife program restoration activities within the Columbia River basin initially, and then extention to mainstem flow operations by amendments to the program in 1994 (Blumm, 2002), failed (McConnaha and Paquet, 1996; Blumm, 2002). Possible reasons include adhoc adherence to the steps in adaptive management including lack of resources for monitoring and evaluation of data by policy analysts rather than independent scientists. In addition, absence of a deliberative process underlying the program may have made it vulnerable to changes in leadership (Cosens and Williams, 2012). Indeed, it is a struggle to apply adaptive management, as other processes, such as integration, reflection and learning, and

Table 2b
Ecosystem services associated with four water management eras in the Columbia River Basin. Each of these management eras corresponds to substantial changes in human interaction with and alteration of the water system to achieve different water management objectives (Cosens and Fremier, 2014). NA means that a particular ES was not considered as a social objective of that management period.

Management eras				
Type of ecosystem service/good	Pre-contact before mid-1800's	Post -contact mid-1800's–1930's	Dam building 1930's–1970's	Environmental justice 1970's–present
Provisioning services				
Water	NA	Minor direct diversion	Major objective, federal and state legislation and federal development subsidy	Social change not yet reflected in any major change in water management for consumptive use
Food	Gathering of wild food products including water potato and camus root	Substantial alteration of uplands to monoculture with irrigation in more arid portions of the basin	Major federal development of reservoirs for irrigation	Social change not yet reflected in any major change in water management for food projection
Biological Productivity	Major salmon runs of 12–15 million. Human adaptation to salmon cycle	Industrial scale fishing and canneries led to decline in populations and development of hatcheries	Substantial decline in wild salmon populations and increased development of hatcheries	Continued decline of fishery with listing of 13 salmon and steelhead populations and 1 resident trout species under the ESA
Supporting services				
Organic soil formation/ stock of organic soils	Management of grasslands and organic composition of soil through use of fire	Beginning alteration of soils through monoculture and increased erosion through headwater timber practices	Loss of floodplain connection and sediment transport through system	Continued loss of floodplain connection and sediment transport through system
Biodiversity	Human adaptation to salmon cycle	Loss through development of uplands and commercial fishery. Initial development of hatcheries with little attention to genetic pool	Substantial decline in salmon and steelhead populations. Over 200 hatcheries	Continued decline of fishery with listing of 13 salmon and steelhead populations and 1 resident trout species under the ESA
Disturbance regimes	Some use of fire to manage grasslands	Flooding periodic and floodplain development affected	Floods and fire controlled	Same as previous era
Regulating services				
Water supply	NA	Minor development for household and irrigation	Substantial development for irrigation and hydropower	Same as previous era with some change in flow timing to reduce impact on listed species
Flood control	NA	Local structural measures (e.g. levees) to protect floodplain development. Failure in large floods	Floods controlled through dams. Flow timing substantially altered	Same as previous era
Water quality	NA	NA	Substantial change in temperature, sediment, and human and industrial waste	Changes in tillage, riparian cover and waste water treatment to improve water quality
Cultural services				
Recreation	Games and sports associated with multi-tribal gatherings during major salmon runs	Some continuation of traditional gatherings	Loss of traditional gatherings.	Same as previous era
Tourism	NA	Indigenous people guided the Lewis and Clark Expedition to the Columbia and down it to Astoria on the Pacific Ocean	Substantial river, lake, fishing and wildland tourism	Same as previous era
Traditional	multi-tribal gatherings during major salmon runs	same as previous era although substantial decline had occurred in indigenous populations with Contact	Many traditional fishing sites drowned or blocked by dams	Same as previous era
Navigation	Local canoe traffic	Increasing shipping in lower Columbia, some upriver navigation with development of locks	Shipping up into the Snake River tributary through development of dams and locks	Same as previous era

limits imposed by other regulatory processes can constrain adaptive management experiments (Lee, 1993; Walters, 1997).

4. Discussion

Large, complex social-ecological systems such as the Columbia River and the Everglades provide a range of ecosystem goods and services to humanity. In both social-ecological systems, federal and state governments have invested and constructed large water management systems to procure water related services; primarily provisioning services of water for economic development and growth, as well as regulating services of flood protection and biodiversity conservation. The water management system in both of the systems developed episodically- defined by different eras in which new environmental modifications were made in response to changing social demands. Emergent forms of adaptive governance (Chaffin and Gunderson, 2016) arose and disappeared during the transitions among eras in water management. Some new eras or management periods arose as a result of society wanting to procure new ecosystem services, such as water supply or recreational benefits. Other eras emerged from recognition of system level declines in certain ecosystem goods and services as a result of successful attempts to control and procure other ecosystem services. For example, the control of water flows in the Everglades with respect to flood control and water supply led to economic and social benefits for agricultural and urban populations. However, such changes have resulted in a decline in other ecological and biodiversity related goods and services (Davis and Ogden, 1994). Reversing such declines is among the goals of the current ecosystem restoration program (LoSchiavo et al., 2013) in an adaptive management approach.

Due to the complications in the application of adaptive management, significant attention must be paid to the governance context for a management intervention. For example, climate

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change, ecosystem degradation, and the loss of ecosystem services due to these changes, have the capacity to trigger non-linear change in the Everglades. Uncertainty in these factors challenges traditional approaches to governance, and adaptive governance seeks to remedy this problem via cross-scale linkages and generation of adaptive capacity in order to govern in a more adaptive manner (Garmestani and Allen, 2014). Mismatch between scales of ecosystems and the organizations responsible for managing ecosystems can result in decreased resilience of an ecosystem. Thus, adaptive governance can be an effective method to account for scale, resilience, and the tradeoffs between ecosystem services in the Everglades. A resilience-based governance framework encourages innovation at local scales, with the capacity to scale up, which can help to offset scale mismatches and tradeoffs between multiple ecosystem services (Garmestani and Benson, 2013).

5. Summary

Adaptive management is an integrated, multidisciplinary approach that is being used by many U.S. federal resource agencies (Williams et al., 2009), as well as many state and local land managers. It is adaptive because it acknowledges that the natural resources being managed will always change, therefore humans must respond by adjusting and conforming as situations change. There is and always will be uncertainty and unpredictability in managed ecosystems, both as humans experience new situations, and these systems change as a result of management. Adaptive management acknowledges that policies must satisfy social objectives, but also must be continually modified and flexible for adaptation to these surprises (Holling, 1978), and has been adopted as a framework for facilitating learning to better understand how to meet social objectives (Walters, 1986; Chapin et al., 2009). In the Columbia River, such management has addressed recovery of endangered populations, while in the Everglades, the focus has been on ecosystem scale recovery. Limits on the application of adaptive management can occur when there is a) unacceptable risk of experimental outcomes (as with endangered species), b) lack of leadership, c) lack of stakeholder agreement on actions, and d) societal limits on experimentation (Allen and Gunderson, 2011; Gunderson et al., 2014), all of which constitute elements of adaptive governance.

Adaptive governance encompasses a broad set of institutions, norms and processes that have arisen in cases such as the Everglades, Columbia River and other areas where institutional failures in natural resource management and governance. Some of those failures are a result of an environmental crisis, when the ecosystem exhibits unexpected dynamics and behaviors. Adaptive governance also emerges as a result of shifts in social values, norms, or perhaps lack of institutional diversity, and provides a context for managing known and unknown consequences of prior management approaches and for increasing legitimacy in the implementation of adaptive management.

Adaptive governance may provide one solution to reconciling uncertainties associated with management for a suite of ecosystem services. One such uncertainty is how to value such goods and services for the purposes of decision- making. Efforts, such as those by Costanza et al. (1997) to place monetary values on various ecosystem goods and services continue to be undertaken, in order to make commensurate valuation schemes that fit within rational, cost-benefit management schemes. Pritchard et al. (2000), suggest that economic methods involving monetization within rational frameworks cannot capture the dynamic complexity of ecosystem goods and services. That is, the assignment of monetary values on ecosystem goods and services as a way of guiding decisions about trade-offs can result in large uncertainties about those estimates. Adaptive governance and adaptive management are learning based approaches that can help to systematically resolve key uncertainties of these complex systems. Yet global issues of climate change and economic development that decreases ecosystem services and goods pose great uncertainties for managers. Adaptive approaches may help us learn how to deal with the complexities of trade-offs and uncertainties in evaluating how to provide and sustain multiple ecosystem services. .

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