2016

Fishing for ecosystem services

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Journal of Environmental Management 183 (2016) 408–417

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

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A R T I C L E I N F O

Article history:
Received 8 October 2015
Received in revised form
31 March 2016
Accepted 9 April 2016
Available online 25 April 2016

Keywords:
Adaptive management
Angler
Ecosystem management
Recreational fisheries
Social-ecological systems

A B S T R A C T

Ecosystems are commonly exploited and manipulated to maximize certain human benefits. Such changes can degrade systems, leading to cascading negative effects that may be initially undetected, yet ultimately result in a reduction, or complete loss, of certain valuable ecosystem services. Ecosystem-based management is intended to maintain ecosystem quality and minimize the risk of irreversible change to natural assemblages of species and to ecosystem processes while obtaining and maintaining long-term socioeconomic benefits. We discuss policy decisions in fishery management related to commonly manipulated environments with a focus on influences to ecosystem services. By focusing on broader scales, managing for ecosystem services, and taking a more proactive approach, we expect sustainable, quality fisheries that are resilient to future disturbances. To that end, we contend that: (1) management always involves tradeoffs; (2) explicit management of fisheries for ecosystem services could facilitate a transition from reactive to proactive management; and (3) adaptive co-management is a process that could enhance management for ecosystem services. We propose adaptive co-management with an ecosystem service framework where actions are implemented within ecosystem boundaries, rather than political boundaries, through strong interjurisdictional relationships.

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1. Introduction

Fishing and hunting connect aquatic and terrestrial ecosystems with human society (Lubchenco, 1998; Bright and Porter, 2001; Liu et al., 2007). Humans have harvested fish for at least 42,000 years (O'Connor et al., 2011) and wildlife for at least 500,000 years (Wilkins et al., 2012). However, there has been a steady increase in industrial and recreational development of fishing and hunting, especially during the last half of the 20th Century (Arlinghaus et al., 2002; Cooke and Cowx, 2004; Swartz et al., 2010; Anticamara et al., 2011), that commonly manipulates ecosystems to maximize certain human benefits. These manipulations, such as overfishing and introduction of exotic game species, may provide short-term benefits to humans, but can also degrade systems, leading to cascading negative effects that may be initially undetected, yet ultimately result in a reduction, or complete loss, of certain valuable ecosystem services (e.g., Sweeney et al., 2004; Benayas et al., 2009; Biggs et al., 2009). Therefore, it is critical to understand that fisheries and wildlife management actions simultaneously enhance some ecological services and diminish others.

The resulting tradeoffs from management actions are seldom discussed (but see Rodriguez et al., 2006) during the objective-development and implementation stages of management. Ironically, reduction of some ecological services from management in favor of enhancing others has long been recognized, and many have called for ecosystem-based approaches, including governance of resilience in fisheries and wildlife management (e.g., Grumbine, 1994; Folke et al., 2004; Pikitch et al., 2004; Pope et al., 2014), with an emphasis on sustainability to properly manage such

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http://dx.doi.org/10.1016/j.jenvman.2016.04.024
0301-4797/Published by Elsevier Ltd.

resources (Becker and Ostrom, 1995; Dietz et al., 2003; Rammel et al., 2007). Ecosystem-based management is intended to maintain ecosystem quality and minimize the risk of irreversible change to natural assemblages of species and to ecosystem processes while obtaining and maintaining long-term socioeconomic benefits (Tallis et al., 2008). We believe that an unambiguous understanding of the desired and undesired outcomes of actions on ecosystem services when specifying management objectives is a further progression of ecosystem-based management. Though important, managing for ecosystem dynamics alone cannot guarantee successful management of complex, multi-stakeholder systems like commercial and recreational fisheries.

There is a need for wise management of natural resources that is predicated on sound science (Lubchenco, 1998). Much of the management, and hence the science to support it, for recreational fishing and hunting in North America is achieved at the state or provincial level, rather than the national level (Mahoney, 2009; Ballweber and Schramm, 2010). We contend this decentralized level of management often leads to a focus on lower, rather than higher, levels of biological organization. That is, a focus on populations of game animals rather than a focus on ecosystems that contain game animals. Instead, some approaches that provide insights for ecosystem-based management including meta-analyses (Benayas et al., 2009), large (interstate and interprovincial) spatial studies (Lehodey et al., 2008), adaptive management (Allen et al., 2011), and adaptive co-management (Armitage et al., 2007, 2009), or some combination of these could be used. It is important for scientists to complete research focused at the ecosystem level to provide managers a better understanding of the potential intended and unintended consequences of management actions on ecosystem services.

Adaptive management, while actively managing for ecosystem services, maintains open channels of communications between all stakeholders involved. Adaptive co-management takes this one step further, eliciting input from multiple stakeholders and agencies that may span across state and provincial lines and even to non-regulatory groups who are invested in the potential outcomes (Armitage et al., 2009; Plummer, 2009). By involving these essential groups in the management planning stages, adaptive co-management seeks to avoid many of the issues that frequently befall reactionary management techniques.

Westman (1977) discussed the concept of ecosystem services and proposed that quantification of the benefits provided by an ecosystem would facilitate informed decision-making for management of the ecosystem. Westman (1977) termed these benefits as “nature's services; ” Ehrlich and Ehrlich (1981) further refined this term to “ecosystem services.” There are several definitions of ecosystem services, but a commonly referenced definition is “the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life” (Daily, 1997). The Millennium Ecosystem Assessment (MEA, 2005) used four categories to classify ecosystem services: cultural services, provisioning services, regulating services, and supporting services. Cultural, provisioning, and regulating services directly affect humans, whereas supporting services are necessary for the production of the other services. Cultural services are nonmaterial benefits that are obtained from ecosystems, including recreation, religion, aesthetics, and others. Provisioning services are products obtained from ecosystems, including food, fresh water, fuel, and others. Regulating services are the benefits obtained from regulation of ecosystem processes, including water regulation, disease regulation, climate, and others.

Fisheries management techniques, though not often specifically couched in these terms, currently use ecosystem service frameworks in a disjointed capacity that fails to account for the breadth of ecosystem patterns and processes. Management practices have a tendency to focus on population dynamics of single species as opposed to a focus on population dynamics of multiple species as interconnected parts of an ecosystem (Pitcher, 2001; Pikitch et al., 2004) that produce emergent properties of community dynamics. This leads to a focus on socially valuable fish rather than ecologically important species and functional groups (Cooke et al., 2005; Adams and Schmetterling, 2007). This narrow focus can have compounding influences on ecological regimes that are difficult to predict. When management outcomes are realized, new management actions may become necessary to deal with unanticipated, deleterious effects. This reactive management style potentially creates negative feedback loops between the social and ecological components of fisheries.

Inland recreational fisheries are unique examples of tradeoffs in ecosystem services among multiple users (Arlinghaus et al., 2002). These multi-use systems generate competition between opposing policy decisions. Often, policy decisions lead to ecosystem-wide manipulations that drastically alter ecosystem patterns and processes (Arlinghaus et al., 2002) with the intent for positive, institutional gain in well-being. This essay discusses policy decisions in fisheries management related to commonly manipulated environments with a focus on influences to ecosystem services, specifically ecosystem service tradeoffs associated with three case studies of inland fisheries management: (1) dam construction and impoundments; (2) river and stream rehabilitations; and (3) fish-stock enhancement. Within inland fisheries, most management objectives are aimed at sustainable use of natural resources, rehabilitation of negatively impacted systems, and modification of systems to better suit the needs of stakeholders (Arlinghaus et al., 2002; Cowx et al., 2010). We acknowledge the ecosystem services listed and examples presented herein do not comprehensively cover the full breadth of ecosystem services provided by aquatic systems for fisheries management or any other service. Rather, we use examples to illustrate possible trade-offs in decisions as a context to suggest alternate strategies that better anticipate and directly manage resources within an ecosystem service framework.

2. Dam construction and impoundments

Man-made dams provide numerous benefits including flood control, water reserves for cities and farms, production of hydroelectric power, and transportation. In exchange, dams alter the timing and variability of water and sediment flow, and physically block fish migration routes (Baxter, 1977; Bunn and Arthington, 2002). During the last 100 years, rivers within North America were rapidly dammed in favor of civil development, with little consideration given to long-term tradeoffs among ecosystem services. Many dams built in the rapid industrialization following World War II are approaching the end of their functional lifespan (Poff and Hart, 2002), and managers are faced with four choices: create new infrastructure, maintain and retrofit current infrastructure, remove decaying infrastructure, or leave dilapidated infrastructure in place. Increasingly, fisheries biologists recognize the effects of lentic habitat created by dams on native lotic species, causing many biologists to call for dam removal as a preferred management action (Table 1; Blumm et al., 1998; Hart and Poff, 2002). However, growing human populations are increasing the demand for provisionary and cultural services produced by dams. When assessing the construction, management, or removal of dams, managers could assess benefits and costs over the long term (>50 years) to elucidate effective management actions focused on ecosystem services (Table 1). Though the effects dams have on the environment vary considerably (e.g., Poff and Hart, 2002), assessing the tradeoffs in ecosystem services provides an intuitive and

Table 1
Relative (1 symbol = low; 2 symbols = moderate; 3 symbols = high) predicted ("+" = positive; "-" = negative) influences of some management actions on ecosystem services provided by recreational fisheries. Expected changes to a system from management actions may result in numerous amalgamations (Fig. 2) of change in the current combination of ecosystem services recognized (point moves) and change in the associated utility of the combined ecosystem services (contours move). Several of these actions (e.g., stocking, river restoration, and dam removal) are discussed in detail in text.

Management action	Ecosystem services			Point moves	Contours move
	Cultural	Provisioning	Regulating		
Dam construction	++ Reservoirs supply recreational opportunities	++ Water supply for human consumption and power	−−− Altered flow regime, sediment and nutrient transport; Loss of native biota	Yes	Yes
Dam removal	−−− Increased river recreation opportunities; Loss of reservoir recreation activities	−−− Increased river recreation opportunities; Loss of reservoir recreation activities	+++ Natural flow regime restored; Increased sediment and nutrient loads initially	Yes	Yes
Water withdrawal	++ Altered human activity	+++ Increased water supply for agriculture and industrial use	−−− Loss of water for native biota; Sediment and nutrient loading altered	Yes	No
Floodplain reconnection	− Change in land use	−− Loss of agricultural and industrial products	+++ Nutrient cycling restored; Increase in fish biomass and survival	No	Yes
Enhancement stocking	++ Provide fun fishing for anglers	+ Increase number of fish available forharvest	−− Decrease native biodiversity; Increased likelihood of non-native species	No	Yes
Conservation stocking	+++ Local pride; May provide some fishing opportunities	−−− Often coincides with removal of non-natives and change in habitat use	+++ Increase ecosystem resilience; Improve nutrient cycling	Yes	Yes

defensible approach for future actions.

Dams created in developing nations provide a unique insight for assessing ecosystem service tradeoffs because often local populations are reliant on services that will be altered or lost. The Gezhouba Dam in China has provided significant power generation (14,100 GWh annually) and navigation for ships up to 10,000 tons. The tradeoffs for power generation and navigation included changes to abiotic river conditions, reduction in available habitat, and blockage of upstream movement that negatively affected the Baiji (*Lipotes vexillifer*), a freshwater dolphin, and river fishes like the Chinese paddlefish (*Psephurus gladius*). Fish passage mitigation is relatively rare in China, though increasing (Shi et al., 2015), so upstream movement necessary for the survival of many riverine species is impeded. Habitat discontinuity has at least partially resulted in the (probable) extinction of the Baiji and the likely extinction of Chinese paddlefish. The Baiji was a culturally valued species in China; similarly, the Chinese paddlefish was prized for both cultural and provisioning reasons (Chenhan and Yongjun 1988). As the reservoir above Gezhouba Dam ages, the beneficial services of power generation and ease-of-navigation will decline, while the incurred losses in natural biodiversity will further decrease value gained from the ecosystem.

The mere presence of dams in formerly lotic systems creates tradeoffs between ecological services due to continued ecological cost to river dynamics (Table 1). For example, managers installed a fish ladder on the Landsburg Dam at Rock Creek, Washington, USA, to allow recolonization of Coho salmon (*Oncorhynchus kisutch*) (Kiffney et al., 2011). This Coho population continues to recolonize Rock Creek, providing additional provisional and cultural ecosystem services via recreational angling. Thus, maintenance of dams provides continued anthropogenic use of river systems, but often perpetuates the loss of some ecosystem services that were provided by the unaltered rivers (e.g., Sweeney et al., 2004), though forward-thinking adaptive co-management strategies can partially reduce losses of ecosystem services.

Decisions to remove dams are rare, but expected to increase in North America as dams continue to age. Removing dams fosters restoration of connectivity between upstream and downstream habitats and, with thoughtful management actions, can restore riverine processes lost or altered. To date, most removed dams have been small (<5 m in height) (Stanley and Doyle, 2003), though large dam removals may become more common as infrastructure continues to age. Currently, there is no consistent metric to assess the success of removing a dam from a river or stream; rather, assessment is a contentious case-by-case process (WCD, 2001). The largest dam removals to date, Elwha and Glines Canyon dams on the Elwha River in Washington are rare examples where ecosystem valuation played a role in dam removal (Gowan et al., 2006). Following a multi-year removal process, the two reservoirs behind the dams were drained and restored to a free-flowing river that significantly altered sediment dynamics and released 10.5 million tons of sediment (Randle et al., 2015). Much of this sediment was deposited at the river mouth, increasing (Gelfenbaum et al., 2015) and maintaining (Foley et al., 2015) the size of the river delta and creating nursery grounds for valuable fish and invertebrate species. The removal of both dams also restored connectivity to about 105 km of river habitat for anadromous Pacific salmonids (*Oncorhynchus spp.*). The removal of the Elwha and Glines Canyon dams will increase provisioning and cultural services over the long term by increasing habitat for recreationally and commercially harvested species, valued as a fisheries benefit of 3.5 million USD annually (U.S. National Park Service, 1996). Dam removal also restores regulatory services provided by unimpeded riverine connectivity including the building and maintenance of delta habitat through sediment transport.

The removal of dams and the restoration and development of ecosystem services that follow is a long-term process. Restoration of ecosystem patterns and processes may take decades because large quantities of sediment have altered the natural river dynamics. Further, removal of the two dams on the Elwha River (Gowan et al., 2006) came at a cost—the Elwha Dam provided 28 MW of hydroelectric power annually, and the one-time total cost of the removal was estimated at over 75 million USD (U.S. National Park Service, 1996). These one-time removal costs may hinder future dam removals because, unless an aging dam threatens lives or property, the apparent and immediate costs to leave a dam in place and let it deteriorate may be minimal in comparison. However, accrued value of ecosystem services (Reyers et al., 2013) gained following removal of a dam may exceed the one-time costs of removal. The dam removals on the Elwha River are somewhat unique in that most of the river is within the boundaries of a National Park, where, with the exception of alterations caused by damming, the river is relatively pristine (Wunderlich et al., 1994). For most dam removals, managers may wish to consider further restoration of newly connected habitat. These additional costs could be considered as part of a cohesive plan to determine whether dam removal or maintenance and alteration is more economically appropriate.

Creation, maintenance, inaction, and removal of dams will continue into the foreseeable future. All four actions create tradeoffs in ecosystem services, but few actions, to date, have explicitly identified or considered these tradeoffs over broad temporal scales. Dams often provide immediate benefits, but at the cost of some long-term benefits that were previously provided by unaltered rivers (Table 1). Thus, dams are built with the expectation of benefits spread across many (>50) years, and their negative impacts ought to be considered in a similar timeframe.

3. River and stream rehabilitations

River and stream modifications beyond impoundment have followed a similar, historical path where ecosystem services such as nutrient remediation, sediment processing, and fish habitat have been influenced by past management. Management of these systems has often prioritized needs for other sectors over fish-specific ecosystem services (e.g., floodplain use for land development rather than fish production) with a result of negatively influencing availability and quality of fish habitat. The manipulations that occur in rivers and streams highlight just how polarizing prioritizing ecosystem services among stakeholders can be in some instances. For example, provisioning services lost from a fisheries standpoint may be beneficial for other sectors, such as agriculture, to use when a river is no longer connected to its floodplain. This loss of lateral connectivity of a river to its floodplain decreases species diversity and species richness (Ward et al., 1999; Dewson et al., 2007), alters sediment and nutrient dynamics, and can reduce fisheries resources.

Water withdrawn from a river for agriculture, industrial uses, and human consumption alters the river itself as well as the relation between the river and its floodplain. Reconnecting a river to its floodplain to retain or re-establish ecosystem services through artificial connections has had limited success, but it is unclear if this is a viable, long-term option. For instance, the contribution of non-native macroinvertebrates to functional diversity increased at sites with artificial, lateral hydrologic connectivity, while the contribution of native macroinvertebrates at these sites decreased (Paillex et al., 2013). Further, community composition of native fishes positively responded to natural flood events, yet did not respond to artificially managed flood events (Stoffels et al., 2014).

Sediment dynamics in a watershed are changed drastically by flow alteration and runoff from urban and agricultural fields. Reductions in flow allow suspended solids the opportunity to settle, which increases water clarity while altering the substrate composition of a river. In contrast, runoff from agricultural operations often carries a high load of sediment, which decreases water clarity, decreases light penetration into the water column, increases water salinity and alters the substrate composition. Disruptions to sediment dynamics of flowing rivers can have drastic impacts on what biota are able to inhabit an aquatic ecosystem and hence on what ecosystem services can be provided (Shaffer et al., 2009). Further, runoff from urban and rural landscapes often include dissolved nutrients such as phosphorous and nitrogen from fertilizers (Sharpley et al., 1993; Shuman, 2002) and diluted endocrine disruptors such as atrazine from pesticides (Hayes et al., 2003). This culturally driven eutrophication tends to increase frequency of undesirable blue-green algal blooms (Hallegraeff, 1993) thereby altering the conditions of aquatic systems.

There are clear gains in ecosystem services from water use, yet changes in management of rivers and streams can necessitate consideration of the tradeoffs in the variety of ecosystem services provided. Mitigation for some losses can achieve desired cultural, provisioning, regulating and supporting services, yet these occasions are likely serendipitous occurrences when conducted in the absence of proper consideration of what will be gained or lost. Most scenarios demand that there will be tradeoffs in the losses and gains of ecosystem services, such as a loss in agricultural land when a river is reconnected that corresponds with a gain in nutrient remediation and aquatic habitat. These tradeoffs in ecosystem services need to be fully considered, especially across multiple scales of space and time (Rodriguez et al., 2006) and throughout the entire water cycle (Gordon et al., 2008), when making management decisions.

4. Fish-stock enhancement

Inland fisheries management has changed very little in the application of enhancement techniques (Collares-Pereira and Cowx, 2004). Enhancement is generally used as a reactionary response to a management issue that already exists (Table 1). Stock enhancement requires release of hatchery-produced fish to improve or supplement current fish populations for social and ecological health (Bell et al., 2006). Welcomme and Bartley (1998) suggested that there are four types of stocking that can be used in stock enhancement: compensation stocking that mitigates for a disturbance to the environment caused by human activities; maintenance stocking that is used to mitigate for recruitment overfishing in a fish stock; enhancement stocking that is used to maintain fishery productivity of a water body at the highest possible level; and conservation stocking that retains stocks of a species threatened with extinction. All of these types of fish stocking have tradeoffs in ecosystem services that could be considered.

Stocking fish with the intent to mitigate for a disturbance to the environment has been an important management tool in North America (Cowx, 1998; Salonen et al., 1998; Amtstaetter and Willox, 2004). In areas with undesirable effects from competing interests and altered environments for alternate services, supplementing natural production may be the only way to meet demand for a fishery, which leads to positive effects on provisioning and cultural ecosystem services but at a high investment cost by the managing agency (Camp et al., 2014). Economically, natural production of recruited fish stocks and the joint benefits from regulatory services should be preferable to the high-cost of production aquaculture, especially given that indefinite subsidizing of the loss of ecosystem services is not a sustainable approach. Additionally, this form of stocking may conceal other losses to regulatory services because the underlying issues are not addressed and continue to influence the system (Cowx, 1998; Lorenzen, 2008). American Paddlefish

(*Polyodon spathula*) management is a prime example of this form of enhancement because the species has been greatly affected by dam construction (Simcox et al., 2015). Paddlefish reproduction and recruitment has been limited throughout its distribution (Paukert and Fisher, 2001; Simcox et al., 2015) requiring intensive production facilities to supplement populations for commercial and recreational use. Public response to these facilities is generally positive due to the disjointed understanding of the underlying threats to the species and necessary management actions (Dedual et al., 2013). Clearly, the benefits from dam construction have been valuable to North American civic and industrial activities, but often the negative impacts are overlooked in favor of offsetting management (i.e., compensation stock enhancement).

The breeding portion of a fish population is often reduced to critical levels in a fishery where overfishing has occurred. Thus, maintenance stocking is similar to compensation stocking in that it mitigates for negative anthropogenic effects, but it is specifically targeted at recruitment overfishing (Cowx, 1998). Again, provisioning and cultural ecosystem services should be positively influenced by this management action. Though costly, supplementing brood-stock populations allows high exploitation rates to be maintained indefinitely (Lorenzen, 2005, 2008). This reactionary management strategy does nothing to deal with the underlying issue of over-exploitation, but does allow status quo to be maintained at the cost of reduction in quality of regulatory ecosystem services.

Maintenance stock enhancement has been used to great success, and in some cases failure, in marine fisheries management (Arlinghaus et al., 2007). This has led to a precautionary-approach in most inland fisheries when alleviating recruitment overfishing. For example, fisheries in Laos often consist of small lake systems that can easily enter a regime of recruitment overfishing (De Silva, 2001). The recent solution has been intensive stocking programs that subsidize recruitment to levels that allow intensive commercial fishing. Many impoverished Laotians rely on subsistence fishing for their main source of protein and though these programs have been successful, they have detrimental effects on cultural and provisional ecosystem services (De Silva, 2001) because governmental stocking is often accompanied by strict regulation and bans of localized non-commercial fishing (Lorenzen, 2008). This type of paradox creates a need to understand the tradeoffs where provisioning services still exist but are limited in availability.

Enhancement stocking, otherwise known as supplemental stocking, is directed at very specific management outcomes (Table 1). Management actions aimed at enhancement stocking typically prioritize more valuable aspects of a fishery (e.g., sportfish) (Lorenzen, 2008). For example, certain fish are generally more desirable as sportfish so intensive stocking efforts are conducted in direct response to enhancing their population without consideration of the existing population dynamics, interaction with other predatory species, or other food-web dynamics. This action propagates the perspective among stakeholders that the aspect of ecosystem services provided by this species and ecosystem is not fully optimized and must be supplemented to maintain value.

Most recreational fisheries in North America and Europe have programs intended to supplement valuable or popular fishes with varying ages of stocked fishes (Cowx, 1998). The cultural value of these management actions can be great (Table 1), as people perceive each new fish in the waterbody as an additional opportunity of capture available to them. Alternatively, the actual benefits of these stocking events are dependent on the actual contribution of stocked fish. In many cases, stocked fish are actually suppressing wild production that would have naturally occurred (Youngson and Verspoor, 1998). Similarly, pen-raised fish may not be well suited for wild release, which ultimately relegates these stocking events to very costly and unnecessary dietary supplementation for established wild populations (Pouder et al., 2010; Scheibel et al., 2016). Thus, the value of provisioning services may not change despite large sums of money invested. Conversely, cultural services may increase from the socially normative view of supplemental stocking and its perceived impacts on provisioning, but quantifying such an argument is difficult.

Stocking for conservation purposes is generally associated with recovery of endangered species (Lorenzen, 2008), and has a great deal of value to cultural ecosystem services given the emphasis placed on maintaining species diversity. This cultural value often creates a dichotomy between provisioning services that emphasize alternate decisions within environmental policies. Here we see opposing management decisions by decision-makers working within the same systems. In some cases, conservation stocking is conducted in direct response to deleterious impacts from other forms of fishery enhancement (i.e., compensation, enhancement) (Tyus and Saunders, 2000). Reactive management actions create situations of opposing management where the associated tradeoffs in ecosystem services are not considered.

A fifth type of stocking that can occur is unintentional introduction of non-native fish species. Though not a management action per se, it can impart major impacts to ecosystem patterns and processes that must be managed (Table 1). Unintentional introductions occur in several forms such as escapement from production aquaculture, introduction by non-regulatory stakeholders with the intent to establish a population, release by the general public without the intent to establish a population, or release from the activities of a competing industry (Cowx, 1998). These introductions tend to have unintended, negative consequences to important ecosystem patterns and processes that decrease the resilience of the waterbody (Pope et al., 2014).

5. Conclusion

We penned this essay to convey three points: (1) management always involves tradeoffs; (2) explicit management for ecosystem services could facilitate a transition from reactive to proactive management; and (3) adaptive co-management is a process that could enhance management for ecosystem services.

5.1. What to do differently? Be proactive at a larger scale

It seems the status quo for fisheries management is to be reactive once a problem is identified rather than being proactive and directing the system to a desired regime through a goal-oriented framework. Managing for ecosystem services requires us to think of the bigger picture and broaden our focus of management to larger, ecosystem-wide scales (Bennett and Garry, 2009). If we want to manage for a suite or bundle of ecosystem services (Carpenter et al., 2006; Raudseep-Hearne et al., 2010), then we could rid ourselves of the notion of managing for a single species or single water body and embrace ecosystem management. Likens et al. (2009) contends that *ecosystem thinking* includes an *ecosystem approach* to conceptualization of complex problems. If we want to secure ecosystem services from fish populations, we could embrace fish as embedded components of ecosystems and acknowledge that our engineered solutions of fish stockings and nature reserves for declining populations rarely compensate adequately for lost ecosystems services (Holmlund and Hammer, 1999). To move forward, we could become more proactive with our management strategies by developing management plans that focus on measureable objectives and desired ecosystem regimes.

5.2. Cooperative management to optimize ecosystem services

Current management of aquatic resources often fails to encompass the breadth of the problems that caused the resource impairments (Naiman and Turner, 2000). Issues with invasive species, waste disposal, excessive nutrients, sedimentation, water withdrawal, and river regulation are often products of land-use practices intended to optimize economic outputs (Pitcher, 2001). Additionally, aquatic-resource management is often segmented into field-specific management departments. For example, water-quality data are collected, analyzed, and reported separate of fish-community data, which likewise is separate from river-flow data resulting in silos for chemical limnologists, fisheries biologists, and river-regulation engineers. Unfortunately, there is generally limited communication among management departments and among users, monitors, and managers until issues arise. All management departments and user groups envision an "ideal" regime of the aquatic-resource system in which the ecosystem patterns and processes adequately produce the desired services while maintaining the quality of the resource; unfortunately, the "ideal" regime is often very different among the departments and groups. Those differences, at least for departments, can be predicted based on mandated missions and jurisdictional boundaries. Fisheries managers, for example, are often given a single waterbody, river segment, or local region as a management zone (often defined by political boundaries). Even so, taking a more holistic, cooperative view towards management within a watershed will allow managers to incorporate components of ecosystem patterns and processes that are often outside of their defined management area (Biggs et al., 2010).

We propose that management of our aquatic resources incorporate stakeholders across all disciplines with a goal of ecosystem management for a bundle of desired services. This could best be accomplished by restructuring management zones within ecosystem boundaries such as watersheds and ecoregions, which will require cooperation and collaboration across political boundaries such as county, state, and provincial lines. Aquatic and terrestrial resource managers from all disciplines within the management zone could be coordinated such that there is open and frequent dialogue. Change on this scale would likely also require cooperation in the governance of many of our aquatic resources, especially large rivers (Pracheil et al., 2012). Importantly, discussions could focus more on future regimes of resources, especially relative to desired regimes, and less on historic causes of impairments, though an understanding of our past is a prerequisite for understanding potential paths into the future.

One of the greatest issues facing a coordinated "management-zone" type working group is that goals for each stakeholder party can be at odds with each other, and often could be observed as a Tragedy of the Commons (Hardin, 1968). Polarized stances on aquatic-resource use and regulation are often a result of institutionalized operation within each management agency. For example, the U.S. Army Corps of Engineers is federally mandated to prioritize management of certain large rivers for flood control, power generation, and navigation through large-scale river modification (i.e., dams and channelization), which has been detrimental to native fishes within river systems (Dugan et al., 2010). On the other hand, over-fishing is still a common issue within commercial and in some cases, recreational fisheries (Allan et al., 2005) that has likewise been a source for declines in fish populations. If we, as a society, truly value the maintenance and preservation of specific ecosystem services, then we must acknowledge that ecosystem services are not equally valued among all stakeholders and somehow determine a prioritization among the potential services that a specific ecosystem can provide.

Ideal management strategies for aquatic resources will specify the desired ecosystem services (e.g., fish production, aesthetics and human health)—*the desired outcomes of management*— and the mandated uses (e.g., flood control and recreational fishing) by all stakeholders within the system—*the social limitations in which management must occur*—as well as the "quality" components of the system necessary to produce those services (e.g., water-quality standards necessary for fish production and swimming)—*the ecological limitations in which management must occur.* This could be approached quantitatively using tenants of structured-decision making within a phenomenological framework (Figs. 1 and 2). Using proportional ternary diagrams, current and desired ecosystem services may be clearly visualized. Expected changes to a system from management actions may result in a change in the current combination of ecosystem services recognized (Table 1, point moves; Fig. 2B), a change in the associated utility of the combined ecosystem services (Table 1, contours move; Fig. 2C), or both (Table 1, point moves and contours move; Fig. 2D). The exact location of a particular ecosystem service in the proportional ternary diagram is situational and must be determined by managers given their specific situation. The key here is no matter where a specific service falls in the diagram, any action could have ramifications that shift its value to another location within the graph. That shift is neither good nor bad, it just is. Society has to figure out if the shift is tolerable or not. Tenants of structured-decision making described within the adaptive co-management framework are well suited to parameterizing these diagrams.

Adaptive co-management requires stakeholder meetings that proactively outline objectives for desired services of the resource in advance of management decisions. Goals that are proactively defined and objectives that are meaningful and measurable would need to include ecosystem patterns and processes deemed necessary for production of the desired services. Deadlines for achieving objectives would need to be set, allowing for an organized and targeted approach to accomplish objectives. Timely deadlines would be an important component to long-term objectives, as they would facilitate routine evaluations of progress necessary for

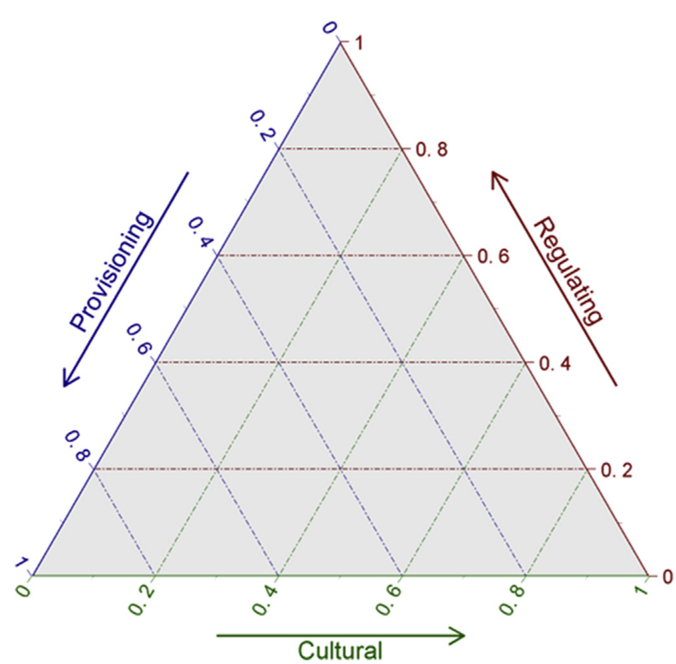

Fig. 1. Proportional ternary framework for depicting tradeoffs, or gains and losses, in ecosystem services from management actions.

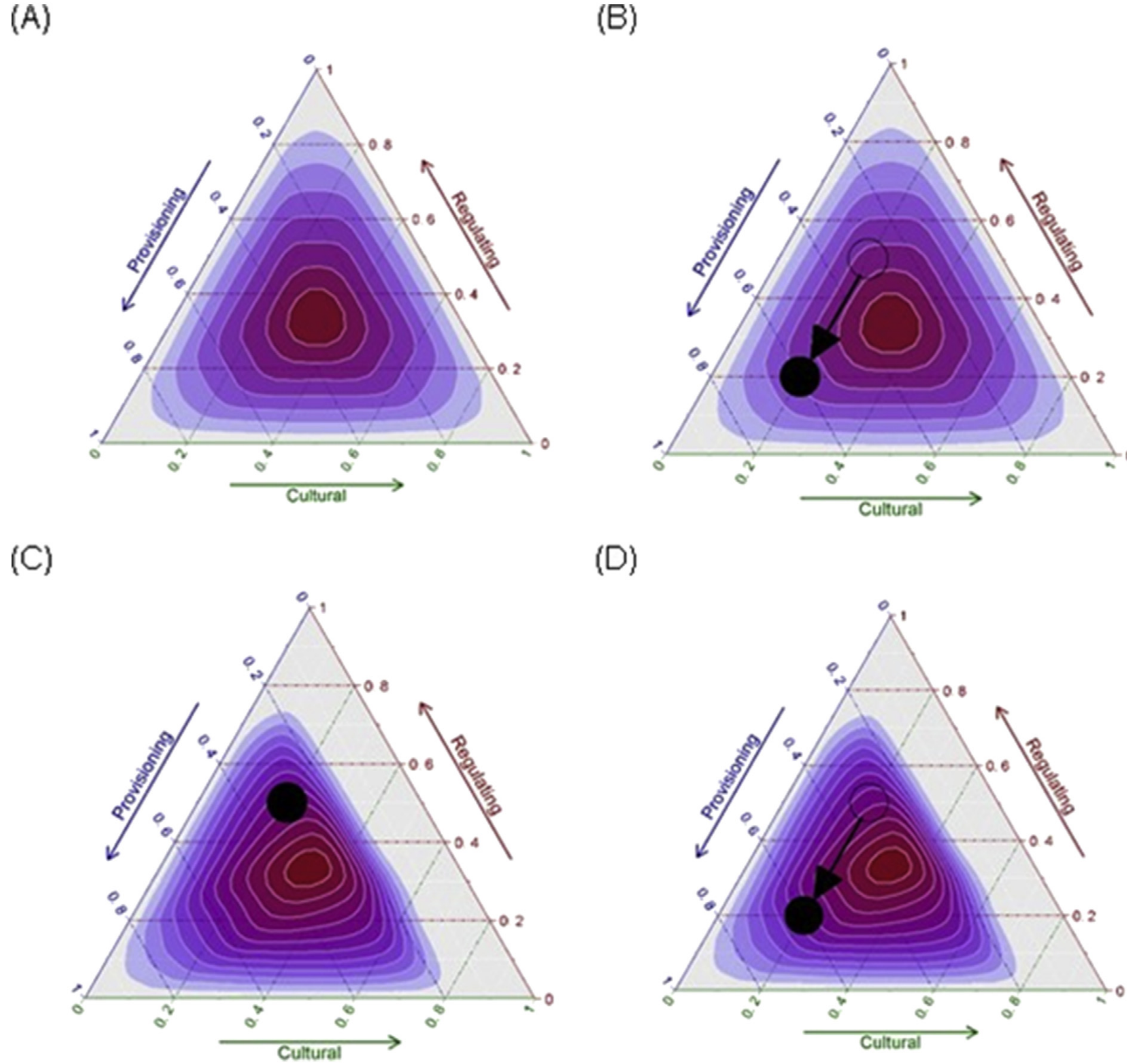

Fig. 2. Conceptual depiction of how ecosystem service tradeoffs may be assessed and compared within a proportional ternary framework. Hypothetical utility associated with proportional tradeoffs is described using contours (A). Thus, with a management action three outcomes are possible: position (point) on chart changes (B); contours change while position remains same (C); both position and contours change (D).

adapting new management techniques to cope with needs. These adaptations could include altering management strategies, redistributing labor and funds, or even resetting initial objectives to a different target.

5.3. Adaptive co-management for ecosystem services

Within the scope of fisheries management practices, we have discussed several common management options and their associated gains and losses with respect to ecosystem services (Table 1). We specifically suggest a philosophical shift from management actions that are reactionary regulations focused on a single ecosystem service in a waterbody to proactive management focused on multiple ecosystem services throughout a watershed. The evolution of this thought process allows actions to focus on solutions for larger management problems, deemphasize short-term issues, and have management longevities much greater than the life of a stocked fish (as well as the career of a fisheries manager). In addition to the production of desired ecosystem services, fisheries managed as components of ecosystems are likely to become more resilient to environmental change. Many of the identified actions (Table 1) are costly, politically charged, and outside of a typical fisheries manager's duties (e.g., dam removal and river restoration). We suggest that management on larger temporal and spatial scales is ultimately more effective for long-term restoration of ecosystem services, and that management goals can be pursued more successfully by incorporating aquatic and terrestrial stakeholders alike.

We envision future management efforts will operate under goals outlined by cooperative management committees. Management committees will consist of all stakeholders invested in natural resource management within the management zone (i.e., state and federal management agencies, public representatives, etc.). Management zones will be determined according to scale of the resource (typically watersheds). Initial objectives for such committees could be to evaluate the current state of affairs, anticipated issues, and ultimate goals (i.e., the desired state of the resource). Management actions to address issues could be selected based on recovering ecosystem function (i.e., services), from sound scientific principles, and agreed upon by all parties to enhance long-term ecosystem function and resilience. Each management action should be followed up with monitoring to determine the success (or failure) of management activities with regard to ecosystem services. Results of management activities should be explicitly stated such that improvements and alternative options can be considered for future efforts. By incorporating all responsible parties (including the public) in restoring ecosystem function through adaptive co-management plans, we expect management actions to have a greater success rate, public approval and ownership, long-term benefits across multiple ecosystem services, and ultimately, more resilient fisheries.

Adopting adaptive co-management programs, based within watersheds, and incorporating all stakeholders in the management of the system will not be an easy process. We will have to temporarily forego current management schemes to focus on larger issues. Losses over the short term will have to be accepted in anticipation of long-term gains from resilient, aquatic ecosystems. Managers and stakeholders will jointly need to determine realistic goals for aquatic systems to provide desired ecosystem services and sustainable multispecies fisheries. Achieving these management goals will be complicated, expensive, and difficult. An honest, open discussion on what we need to accomplish, how we can accomplish it, and when we can achieve these goals can help to foster stakeholder relations and support for ecosystem management. Developing trust with citizens (whom will likely be paying for these management activities) will help to raise awareness for these issues, convince them why these are important, and garner their support to initiate changes. We, as fisheries managers, will have to adapt a new image as aquatic resource managers that focus on issues throughout the watershed that directly affect the fisheries we manage rather than focus on taxa-specific interests.

Acknowledgements

The ideas presented herein were generated by discussions with C. R. Allen and H. E. Birge, and were further developed during a graduate-level course entitled “Managed Aquatic Systems” that was taught during spring 2015. M. Pegg was supported by Hatch Act funds through the University of Nebraska Agricultural Research Division, Lincoln, Nebraska. The Nebraska Cooperative Fish and Wildlife Research Unit is jointly supported by the U.S. Geological Survey, the Nebraska Game and Parks Commission, the University of Nebraska, the U.S. Fish and Wildlife Service, and the Wildlife Management Institute.

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