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Reservoir Rehabilitations: Seeking the Fountain of Youth

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Reservoir Rehabilitations: Seeking the Fountain of Youth

Aging of reservoirs alters the functions, and associated services, of these systems through time. The goal of habitat rehabilitation is often to alter the trajectory of the aging process such that the duration of the desired state is prolonged. There are two important characteristics in alteration of the trajectory—the amplitude relative to current state and the subsequent rate of change, or aging—that ultimately determine the duration of extension for the desired state. Rehabilitation processes largely fall into three main categories: fish community manipulation, water quality manipulation, and physical habitat manipulation. We can slow aging of reservoirs through carefully implemented management actions, perhaps even turning back the hands of time, but we cannot stop aging. We call for new, innovative perspectives that incorporate an understanding of aging processes in all steps of rehabilitation of reservoirs, especially in planning and assessing.

Rehabilitación de reservorios: en búsqueda de la fuente de la juventud

El envejecimiento de los reservorios altera las funciones y los servicios que están asociados a estos ecosistemas. El objetivo de la rehabilitación de hábitats suele ser alterar la trayectoria del proceso de envejecimiento de manera tal que prolonga la duración de un estado deseable del sistema. Existen dos características importantes cuando se altera dicha trayectoria -amplitud relativa del estado actual y la subsecuente tasa de cambio, o envejecimiento- que últimamente determinan la duración del estado deseado. La mayoría de los procesos de rehabilitación caen en tres grandes categorías: manipulación de comunidades ícticas, manipulación de la calidad del agua y manipulación del hábitat físico. Es posible retardar el envejecimiento de los reservorios implementando cuidadosamente medidas de manejo, e incluso tal vez regresando el tiempo, pero no es posible detener el envejecimiento. Aquí se hace referencia a perspectivas novedosas que incorporan la comprensión del proceso de envejecimiento en todos los pasos de la rehabilitación de reservorios, particularmente en lo que se refiere a planeación y evaluación.

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Reservoirs often contain recreational fisheries that enhance local, regional, and national economies (Wilson and Carpenter 1999; Chizinski et al. 2005; U.S. Department of the Interior et al. 2014). These ecosystems are temporally and spatially complex combinations of biotic and abiotic elements that provide important ecosystem services (Daily et al. 1997; Holmlund and Hammer 1999). Aging of reservoirs alters the functions of these systems through time and likely changes the services provided, especially cultural provisioning (e.g., fish as food, hydropower, etc.; Kimmel and Groeger 1986; Cairns and Palmer 1993; Miranda et al. 2010). Anthropogenic activity is inherent in the creation of reservoirs but can also increase aging rates in natural lakes. However, reservoirs generally have larger ratios of watershed to waterbody area and faster rates of geomorphic processes (e.g., sedimentation) than lakes (Thornton et al. 1990; Wetzel 2001) and, ultimately, aging processes that are more easily observed by humans. Therefore, in this essay, we focus on examples from reservoirs because they age rapidly (e.g., annual to decadal scales vs. century to millennia scales) and many now require specific attention to alleviate aging phenomena, though we believe the principles herein are generally applicable to natural lakes that follow similar aging processes (Rast and Thornton 1996), albeit at longer temporal scales. As reservoirs are filled following construction, new terrestrial habitats are inundated, causing a release of nutrients and creating diverse habitats for aquatic organisms that thrive and increase in abundances—termed "trophic upsurge" (Straskraba et al. 1993). Conditions in the reservoir then rapidly change as the reservoir matures into a desired state. Following trophic upsurge, abundances of many aquatic organisms decline as habitats are degraded by the processes of eutrophication and sedimentation that are often accelerated by human activities (Straskraba et al. 1993). Many rehabilitation efforts strive to mitigate the effects of aging following this trophic upsurge period and attempt to reset reservoirs to earlier, more desirable states—that is, seeking the proverbial fountain of youth.

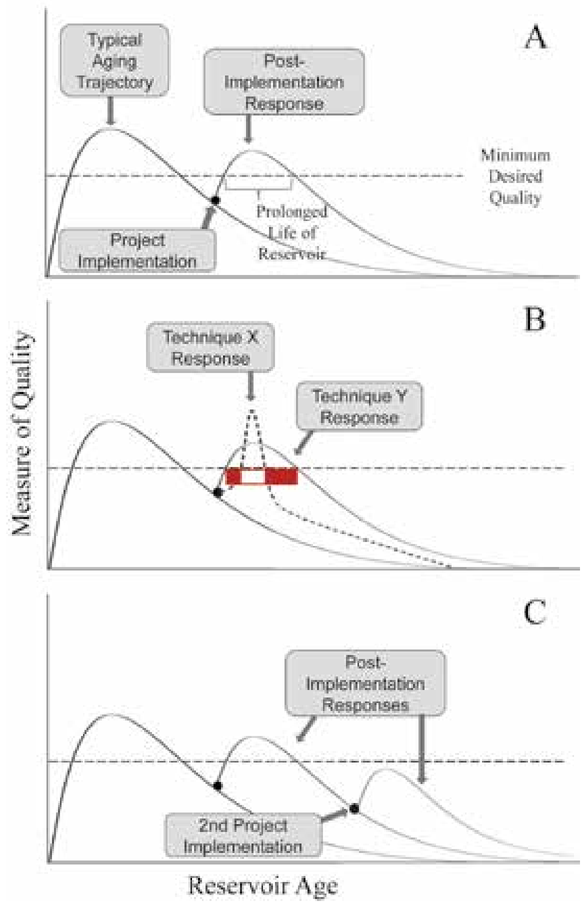

Figure 1. (A) Conceptualization of the aging process in reservoirs and response to implementation of a rehabilitation technique; (B) responses in amplitude, rate, and duration to two different rehabilitation techniques; and (C) potential for diminishing returns from consecutive rehabilitations.

YOUTH SPRINGS ETERNAL

The process of habitat rehabilitation begins with planning (Pegg and Chick 2010). A model of the system's desired state must be developed and must also consider what is attainable given its current state (Palmer et al. 2005). Habitat improvement is an iterative process that requires establishment of predetermined criteria for success and frequent evaluation of objectives through an assessment plan (Pegg and Chick 2010). Knowledge concerning success or failure of management actions can aid in allocating future funds, adjusting methods, and ultimately maintaining healthy aquatic habitats with sustainable fishing opportunities (Palmer et al. 2005). Unfortunately, the political will and financial support to adequately monitor and assess management actions is often lacking, perhaps due to the rapid nature in which rehabilitation projects are generated. Even so, we believe that it is crucial to consider the logistics and appropriate timelines required for proper assessments of management actions.

The goal of habitat rehabilitation is to alter the trajectory of the aging process such that the duration of the desired state is prolonged (Figure 1A). We acknowledge that there are numerous measures of the desired state, including desired nutrient levels, primary productivity, secondary productivity, resilience to invasive species, and many other factors. The onus will be on the shoulders of decision makers to specify characteristics of quality reservoirs in their specific circumstances. Our intent is not to debate the specifics of what meets requirements of reservoir "quality" because that definition will vary by location, management objectives, and capabilities of the system in question. Rather, we emphasize the need to comprehend the aging processes in reservoirs, and we contend that most factors used to determine quality follow a similar response curve like that shown in Figure 1A.

CONCEPTUALIZATION OF RESPONSES TO A REHABILITATION—AMPLITUDE, RATE, AND DURATION

There are two important characteristics to consider when altering the aging trajectory—the amplitude or increase in "quality" relative to current state and subsequent rate of change, or aging, following rehabilitation—that ultimately determine the duration of extension for the desired state. Specifically, we refer to rate of change, hereafter termed rate, as the slope of the descending limb of the aging curve (Figure 1). We typically do not know whether amplitude or rate is correlated with duration; thus, all need to be estimated in current assessments. The combinations of possible responses to amplitude, rate, and duration are extensive. For example, a management action may cause a change that is characterized by large amplitude and a large rate of change such that the duration of the subsequent desired state is brief (Figure 1B; Technique X). In contrast, a management action may cause a trajectory change that is characterized by large amplitude and a moderate rate of change such that the duration of the subsequent desired state is moderately long (Figure 1B; Technique Y). Given the above scenario, we can explore responses to specific rehabilitation techniques like sediment removal. The removal of sediment meets many objectives in improving aquatic habitat within reservoirs; hence, estimating specific responses in terms of how strong an effect (amplitude), how resilient an effect (rate), and how durable an effect (duration) can depend on exactly what is accomplished. Specifically, if 10% of the accumulated sediment is removed from a reservoir, there could be a large amplitude response through increased habitat, but if nothing is done to reduce sediment loading (e.g., Technique X), the removal will not last very long. Alternatively, if sediment removal were coupled with sediment traps in the watershed to prevent sediment from entering the reservoir (e.g., Technique Y), the amplitude would be similar to the more simple action, but the reservoir would benefit from a slower rate of change in functional aging (Miranda and Krogman, this issue), thereby extending the duration of the desired outcome. Clearly, an understanding of interactions among amplitude, rate, and duration would enhance our ability to predict system responses to management actions.

PERSPECTIVE ON REHABILITATION TECHNIQUES—AMPLITUDE, RATE, AND DURATION

Nebraska's Aquatic Habitat Plan (AQHP) was established to address habitat issues in water bodies across the state (Nebraska Game and Parks Commission [NGPC] 1997). The AQHP was authorized by legislative action in 1996 (NGPC 1997). This action established a funding mechanism to support aquatic habitat rehabilitation where the ongoing funding process is strictly limited to aquatic habitat rehabilitation efforts and solely supported through an aquatic habitat stamp required of all anglers who purchase fishing licenses. The US$5 stamp generated $9.5 million through 2006; these funds were then levied against funds from 70 other agencies and organizations to generate $26 million devoted to aquatic habitat improvement projects (Pegg and Chick 2010). The AQHP was the first program of its kind in the United States and is nationally recognized, and a large portion of the program has been devoted to dealing with reservoir aging issues; thus, we use the program as a basis for the examples used herein.

Lake and reservoir rehabilitation processes largely fall into three main categories: (1) fish community manipulation, (2) water quality manipulation, and (3) physical habitat manipulation (Figure 2A). Techniques used to influence specific aspects of one of these categories can influence responses of a reservoir in the other two categories. For example, a complete fish community renovation using rotenone is a common rehabilitation technique used in the AQHP as a means to reestablish targeted sportfish populations that have declined through time (Figure 2B). The objective is typically to remove undesirable species, like Common Carp *Cyprinus carpio*, followed by replacing the fish community with more desirable species, yet removal of Common Carp can also have secondary outcomes specific to a reservoir's desired productivity. Common Carp are known to disturb sediments as they feed (Lougheed et al. 1998; Parkos et al. 2003), so their removal can reduce resuspension of sediment and nutrients into the water column. The secondary responses could include reduced sedimentation rates, improved water quality, reduced primary productivity, and establishment of aquatic vegetation, among other responses, thereby slowing the aging rate.

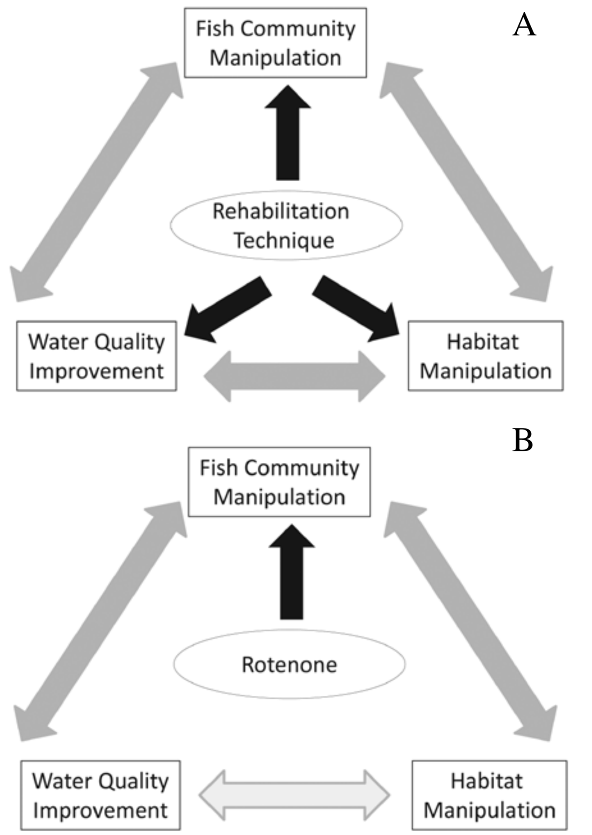

Figure 2. (A) Conceptual response of a reservoir to a rehabilitation technique and (B) an example of a specific response using rotenone to remove all fish to change the overall fish community. Direct responses are indicated with black arrows, whereas indirect responses or secondary outcomes are shown with grey arrows.

There are many approaches used to hold back the afflictions of time on reservoirs. Intuitively, all rehabilitation techniques range in cost as well as benefits realized in amplitude, rate, and duration. The AQHP has predominantly used 12 techniques (Table 1) to functionally "grow younger" (Miranda and Krogman, this issue) a reservoir. As a frame of reference, we summarize the relative cost, change in amplitude, change in aging rate, and change in duration of these techniques to provide a tangible context to the conceptualization (Figure 1A) of how a reservoir rehabilitation may influence the aging process. The relative cost information provided (Table 1) reflects a compilation of activity-specific expenses for 59 rehabilitation projects incurred by AQHP, partners, and stakeholders from 1996 through 2011. Projects often incorporated more than one rehabilitation technique, but as a frame of reference, total costs ranged from about $1,100 for simple applications (e.g., aeration only) to $6.9 million for complex system-based applications (e.g., sediment removal, fish renovation, sediment basin construction, and shoreline stabilization).

Table 1. Relative (1 symbol = low; 4 symbols = high) costs and predicted responses of rehabilitation techniques implemented by the Nebraska Aquatic Habitat Plan (NGPC 1997). See Figure 1 for conceptualization of amplitude, rate, and duration.

Rehabilitation technique	Cost	Amplitude	Rate	Duration
Aeration	$	↑	↓	→→→→
Breakwaters	$$$	↑↑	↓↓	→→→→
Dredging	$$$$	↑↑↑	↓	→→
Fish barrier	$$$$	↑	↓	→→→→
Fish community manipulation	$$$	↑↑↑↑	↓↓	→→
Fringe wetlands	$$	↑	↓↓	→→→→
Headwater wetlands	$$	↑↑	↓↓	→→→
Nutrient sequestration	$$$$	↑↑↑↑	↓↓↓↓	→→
Sediment basins	$$$	↑	↓↓↓↓	→
Shoreline stabilization	$$$$	↑↑	↓↓↓	→→→→
Spawning beds	$$	↑	↓	→→
Water level management	$	↑↑↑↑	↓↓	→→→→

A CALL TO ARMS—MELDING CONCEPT WITH ACTION TO BREATHE LIFE INTO RESERVOIRS

The time is nigh for our profession to embrace new perspectives toward planning, including defining objectives and developing best management practices, of reservoir rehabilitations in the context of the current ages and life spans of these systems. Development of best management practices will be challenging because any one rehabilitation technique will almost surely not provide a uniform response across a given region. However, managers are encouraged to hypothesize or predict changes in reservoir aging trajectories (e.g., rate, amplitude, or duration) that will be affected by proposed management actions. Likewise, scientists are encouraged to quantify and report changes in reservoir aging trajectories that are affected by implemented management actions. It is possible, especially for an old reservoir (e.g., >50 years), that management actions will not result in a shift to the desired state; that is, we believe that responses to rehabilitation efforts are inversely related to reservoir age. It is critical in these situations to consider input from stakeholders and potential funding partners to understand that returns on investments, and associated responses within and across reservoirs will likely not be similar given current and desired states. This further highlights the need for monitoring and purposeful implementation of techniques for proper assessments to ensure that desired endpoints of management actions are realized. Careful elucidation of goals and objectives prior to any management action, specific outcomes of anticipated responses to any management action, and administrative commitment to long-term assessment are needed for successful assessment. The latter perhaps presents the greatest challenge to successful assessment because political pressures tend to favor doing (management action) to learning (management assessment), and political pressures are generally impatient (unable to wait for learning to occur). Doing is admirable and very much needed, yet it is important to understand the return on any investment of resources. Keeping stakeholders informed of expected outcomes and the timeline for such outcomes to occur when prioritizing actions is critical. Indeed, the legislation that formally established the Nebraska AQHP specifically precluded the use of generated funds for assessment purposes. Even so, managers and scientists must be creative and seize opportunities for comprehensive assessments to enhance our learning and ultimately increase the effectiveness of future management actions.

We can slow reservoir aging through carefully implemented management actions, perhaps even temporarily turning back the hands of time, but we cannot stop the processes of reservoir aging. We speculate a diminishing return of reservoir responses through successive rehabilitation projects, especially when projects of similar scope are initiated with the reservoir in different states or functional ages (Figure 1C). Further, we speculate that tipping points (May 1977; Gladwell 2000; Horan et al. 2011) in habitat quality within a reservoir, and hence fish community status, exist and are related to reservoir age or quality. These tipping points, characterized by shifts in fish communities, will require different management strategies to meet goals and objectives. For example, a newly constructed reservoir may be able to sustain a two-story fishery (i.e., a reservoir thermally stratified to allow a cold water fish community below a warm water fish community) for a number of years before accumulation of nutrients becomes an issue, leading to habitat and water quality changes that could eventually eliminate the viability of the cold water fishery (Scheffer et al. 2001). Moving forward in time, the resulting single-story fishery could also shift from one set of species to another (e.g., Centrarchidae-dominated to Cyprinidae-dominated community) based on responses to reservoir aging. This scenario would require understanding the factors that "tipped" the fish community to another state, what it would take to return to a previous state if desired, and possibly how to optimally deal with the new state of the reservoir if nothing is done (Westley et al. 2011). Thus, managers are encouraged to consider strategies for implementing subtle and not-so-subtle changes in management goals and associated objectives and actions as reservoirs age. To that end, Pope et al. (2014) encouraged managers to develop management plans with 5-, 10-, and 50-year horizons that consider changes likely to occur in the social and ecological components of a fishery. The aging processes in reservoirs are important considerations in the development of these mid- and long-term management plans.

Reservoirs are dynamic systems that respond somewhat predictably to a complex set of biotic and abiotic variables through time (Thornton et al. 1990). Human perceptions of these responses can lead to a scenario like the shifting baseline syndrome (Pauly 1995; Pinnegar and Engelhard 2008). Specifically, the general public and biologists may have different perspectives on what is a functional ecosystem in the face of processes associated with reservoir aging. This phenomenon illustrates that the desired minimum quality line (Figure 1A) can fall at different points along the curve that defines most quality measures used to assess the need for rehabilitation of reservoirs. We anticipate that harmony among fishery managers and stakeholders will be greatest when perspectives are similar and efforts are made to enhance communication through forums, such as public meetings, yet we doubt that that scenario is frequently realized given the myriad of interests among stakeholders (Hein et al. 2006; Dallimer et al. 2009). Therefore, we believe that it is imperative that all involved understand the reservoir aging process and what is or is not feasible given the specific state of a reservoir.

The age of managing reservoirs without consideration of life spans is gone. We call for new perspectives that incorporate reservoir aging processes in all steps of reservoir rehabilitation, especially in planning and assessing. These new perspectives need to consider what can or cannot be accomplished during a reservoir rehabilitation effort relative to current reservoir state. A critical component of this call is the development of methods to determine reservoir functional age—see Miranda and Krogman (this issue) for further discussion of possible methods. Rigorous and strategic evaluation of reservoir rehabilitations that account for responses of amplitude, rate, and duration is essential in the search for the fountain of youth as we manage fisheries in reservoirs.

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