Environmental Impact Analysis

EFFECTS OF AN ANTICIPATED ILLEGAL INTRODUCTION OF WALLEYE INTO BLUE MESA RESERVOIR, COLORADO

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Executive Summary

- The unauthorized introduction of fishes is a widespread problem, costing North American management agencies and the public many millions of dollars every year. These introductions represent one of the gravest threats to sustainable fishery management and to the persistence of native fish assemblages in freshwater ecosystems.

- The illegal introduction of yellow perch into Blue Mesa Reservoir (BMR) in the late 1990s prompted concern that other sport fishes, particularly walleye, might follow. Here, we document our investigations into habitat suitability, ecological impacts, and socioeconomic ramifications that can be expected should walleyes be introduced into the reservoir.

- In general, we found that the habitat in BMR is slightly cooler and clearer than optimal for walleyes but there are no habitat barriers preventing the species from establishing a self-sustaining population.

- Because habitat in BMR is suboptimal, walleye growth would be modest and thus its fishery would be inferior to most on the Front Range, where growing degree days are about twice as high as at BMR.

- We estimated trophic impacts by computing consumptive demand for three hypothetical walleye population abundance scenarios: 4.8 fish/ha (1.9 fish/ac), 14.8 fish/ha (6.0 fish/ac) and 23.9 fish/ha (9.7 fish/ac).

- Annual consumptive demand of salmonid prey by walleyes in the nominal scenario (12.1 kg/ha, 10.8 lbs/ac) was about equal to that recently estimated for lake trout in BMR (Johnson and Oplinger 2003). Walleye consumptive demand was four times higher than that by lake trout under the boom scenario (64.9 kg/ha, 57.9 lbs/ac).

- The entire coldwater fishery in BMR would probably be severely impacted if walleye are introduced.
    - The kokanee population in BMR would probably be eliminated if walleyes invade the reservoir. This would result in a $5.2 million annual loss of revenue for Gunnison County. Loss of the BMR kokanee fishery would also jeopardize the State's kokanee egg supply and hence all of its kokanee fisheries, which we valued at more than $29 million per year.
    - Agencies would have to stock larger (catchable) rainbow trout to avoid walleye predation and sustain a rainbow trout fishery. Stocking current numbers of catchable rainbow trout would cost an additional $2 million per year. Without kokanee or subcatchable rainbow trout as prey, lake trout would no longer achieve trophy proportions.

- Walleye fishing is unlikely to compensate for lost kokanee and trout fishing at BMR, given the reservoir's suboptimal characteristics and distance from population centers. Fewer than 12,000 people live within 50 miles of BMR, whereas about 2.5 million people live within 50 miles of an outstanding walleye fishery on the Front Range. Thus, it seems very improbable that many anglers would choose to travel several hours beyond many excellent walleye fisheries to fish at BMR.

- If a walleye population became established in BMR dispersal beyond the reservoir is likely. Walleyes are known to travel >60 miles in rivers and can survive passage through hydropower dams.

- Likelihood of downstream escapement would be greatest in early spring when surface elevation is minimal and discharge is high, or during periods when spillways are used.

- Downstream from BMR, temperature and turbidity of the Gunnison River below Delta, appear to be nearly optimal for walleye growth and feeding. In this reach nonnative piscivores are rare and walleyes represent a potentially novel predatory threat to the currently robust populations of native fishes, some of which are endangered.

- While tributaries above BMR support outstanding trout fisheries, and some populations of rare Colorado River cutthroat trout, these waters are high gradient, clear and cold, and thus, are inhospitable to walleye.

- Predictions of emigration from BMR are highly uncertain but a reproducing population in the reservoir will likely serve as a source or "stepping stone" facilitating further illegal transfers of the species throughout the region.

- Mitigation options include: water level manipulation during egg incubation, mechanical removal by netting or other means, chemical reclamation with piscicides, and containment to prevent dispersal from BMR, which might include closing the reservoir to fishing.

- Because of the size of BMR, all available options to eliminate, suppress or contain walleye would be extremely expensive, impractical or minimally effective.

- Given the severity of potential adverse impacts and lack of practical mitigation options we recommend that an immediate and vigorous prevention effort is the most prudent course of action. We offer suggestions for actions that may assist the CDOW in mounting an effort to prevent walleye introduction in BMR and to stem the tide of illegal fish introductions throughout the state: a) inform stakeholders in the region, b) adopt policies that discourage illegal stocking, c) inform the general public, d) increase rewards for information about violators, and e) substantially increase penalties for illegal stocking.

Contents

1. Project Background

Scope and Purpose

Invasions by nonnative fishes pose one of the greatest challenges to sport fisheries managers and one of the gravest threats to the persistence of native fishes today (Rahel 2000; Rahel 2004; Eby et al. 2006). Nonnative fishes have proven to be particularly troublesome west of the Rockies where the native fish fauna is composed of few species and habitat alteration, primarily associated with water management, has favored introduced species (McMahon and Bennett 1996; Johnson et al. In review).

While government agencies initiated the spread of nonnative species throughout the United States in the late 1800s, today fishery management agencies worldwide have largely stopped introducing new species and are more careful about mixing genetic stocks within a species (Johnson et al. In review). However, anglers continue to transfer nonnative fish to new waters illegally, apparently out of ignorance of the harm they can cause or simply stimulated by a selfish desire to create new fishing opportunities close to home. These actions by a minority of the fishing public are jeopardizing native fish populations, decimating spectacular sport fisheries, and creating perpetual control projects that are costing license buyers and taxpayers billions of dollars.

Unfortunately, current interdiction efforts have not been adequate and fisheries agencies have been unable to prevent illegal fish stocking. We believe that greater awareness of the severity of the problem, both within agencies and among stakeholders, will increase resolve for seeking creative solutions and instill greater vigilance for catching violators. The overall goals of this document are to present a range of potential impacts of a very possible, indeed anticipated, illegal introduction of walleye into one of Colorado's most valuable and important fisheries, and to urge management authorities to implement greater prevention measures.

Our analysis is in the form of an "Environmental Impact Analysis" (EIA), which can be defined as a process to predict the environmental consequences of an action or event. In general, an EIA a) inventories existing resources, b) extrapolates from scientific knowledge to assess the consequences of some human intervention on nature, and c) presents recommendations to reduce adverse impacts. We evaluated ecological impacts, socioeconomic impacts (potential adverse and beneficial), and management implications (including mitigation options). We conclude with a set of recommendations pertaining to the situation at Blue Mesa Reservoir and more generally to the problem of illegal fish stocking.

This project was initiated as a semester-long group study project in Johnson's senior-level Fishery Science course (FW401) at Colorado State University, in fall 2006.

Walleye Biology

Some background knowledge of walleye is required to understand the basis for concern about their introduction, and to interpret our biological predictions. The walleye *Sander vitreus* (formerly *Stizostedion vitreum*) is a member of the family Percidae native to the north-central United States and from Quebec to the Northwest Territories in Canada (Fuller 2006). The species has been introduced widely and is currently found throughout the continental United States (Figure 1.1).

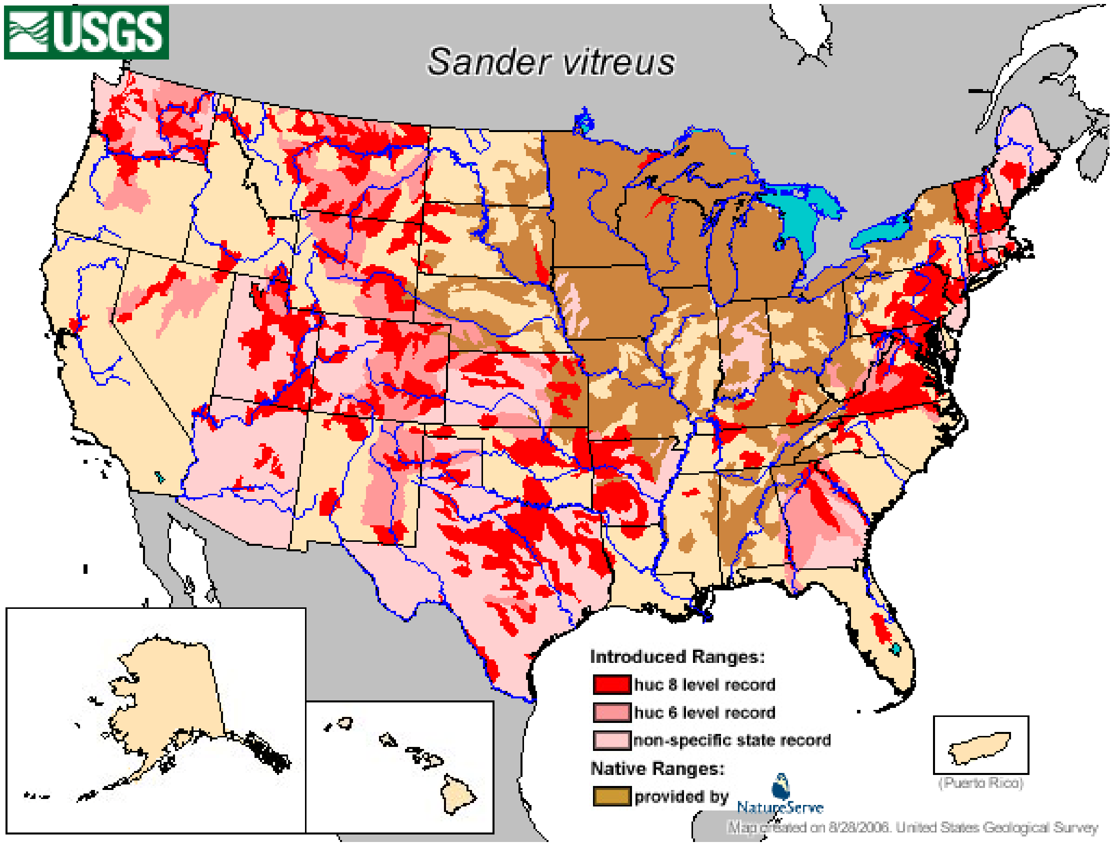

Figure 1.1. Distribution of walleye *Sander vitreus* in the United States (Fuller 2006).

Walleye have a maximum reported lifespan of 29 y (Fishbase 2006); more typically they live 10-12 y (Scott and Crossman 1973). Their mean asymptotic length L_∞ = 73.4 cm, K = 0.27yr^{-1} and M = 0.15 yr^{-1} (Fishbase 2006). The world record walleye was caught in Greers Ferry, AR in 1982 and weighed 24.9 lbs. There are two standard weight (W_s, g) equations for walleye:

(1) $Log_{10}W_s = -4.804 + 2.869*Log_{10}TL$ (30 - 149 mm TL; Flammang et al. 1999),
(2) $Log_{10}W_s = -5.453 + 3.180*Log_{10}TL$ (> 150 mm TL; Anderson and Neumann 1996).

Male walleyes typically become sexually mature at age 2-4, and length about 28 cm TL, while females mature 1-2 y later at about 36 cm TL (Fishbase 2006). In reservoirs walleyes spawn on rip rap along dams or they may migrate upstream to spawn in tributary rivers. They are non-guarding broadcast spawners, depositing adhesive eggs over rock/gravel substrates (Becker 1983). Spawning usually occurs at water temperatures of 6.7 - 8.9 °C and their eggs typically hatch in 12-18 days (Scott and Crossman 1973); survival is best with steadily increasing temperature during incubation (McMahon et al. 1984). Larvae are pelagic, juveniles are usually demersal, and adults may be demersal or pelagic (Scott and Crossman 1973); all prefer relatively low current velocities (Houde 1969, Jones et al. 1974).

Walleyes are visual feeders; their name derives from the glassy appearance of the eyes attributable to the tapetum lucidum of the retina. This structure gives the fish extraordinarily sensitive low-light vision. They prefer moderate water clarity and in clear lakes they may seek cover during the day (McMahon et al. 1984) and feeding may be confined to twilight and dark periods (Scott and Crossman 1973). While some populations subsist on invertebrates, walleye are well-adapted as piscivores and they may become piscivorous as larvae if sufficiently small fish prey are available. The species is a member of the coolwater thermal guild with a preferred temperature range of 20-24°C (McMahon et al. 1984).

Walleye Fishing in Colorado

Walleye fishing is popular in Colorado, second only to trout in a recent survey of angler preferences (CDOW 2006). Natural reproduction does not occur in the vast majority of waters that the CDOW manages for walleye. Hence, the CDOW has a large-scale and highly effective culture program for walleye and walleye x sauger hybrids ("saugeyes"). About 96 waters have been stocked with walleye or saugeye since 1973; 42 waters were stocked in 2006 (K. Kehmeier, CDOW, unpublished data).

Due to concerns about adverse impacts on endangered fishes, stocking of cool- and warmwater gamefish is restricted west of the Continental Divide. Walleyes have only been stocked by CDOW in six waters on the West Slope (Narraguinnep, Puett, Rifle Gap, Summit, Totten, and Vallecito reservoirs). Narraguinnep and Puett reservoirs, near Cortez, are the only West Slope waters to have been stocked since 1982. Walleye populations persist in all but Summit Reservoir, which was reclaimed with rotenone and is no longer managed with walleye (Mike Japhet, CDOW, pers. communication, August 8, 2008). In 2008 CDOW began stocking sterile triploid walleye in Naraguinnep and Puett reservoirs. Walleye are known to have been illegally stocked by individuals in the following West Slope reservoirs: Juniata, Crawford, Harvey Gap, McPhee, and Stagecoach. Walleyes have also been captured periodically by sampling crews in the lower Yampa River, and in the Colorado River near Rifle, Colorado.

Colorado may not be known as a "walleye state" but it hosts outstanding walleye fishing nonetheless. The state record, caught from Standley Lake in Westminster, is at 18 lb 13 oz., a full pound heavier than Minnesota's, the archetypical walleye state (Ed Dentry, Rocky Mountain News, 3/6/07). The fastest growing populations, and best fisheries, occur at low elevation (mean = 4,676 ft), on the Front Range and eastern plains (Table 1.1). Generally speaking, these reservoirs have nearly ideal conditions for walleye growth: they are productive with abundant forage fish (e.g., gizzard shad), they are moderately turbid, and they experience a long growing season with nearly optimum temperatures. Growing degree days (base = 50°F), an agricultural index of the length of the crop growing season, averaged 2,986 (Table 1.1). Most walleye fisheries in Colorado are regulated with a 15" minimum size limit and 5 fish daily bag limit, but only one fish may be over 21". Some fisheries are managed with an 18" minimum and the one over 21" rule, and a few special regulations also exist on select waters.

Table 1.1. Colorado's top 15 walleye and saugeye (asterisks) reservoirs (Ken Kehmeier, CDOW, pers. comm., September 15, 2006). Growing degree day units were computed as the difference between the daily average temperature and the base temperature (50°F). Climate data (WRCC 2008) were gathered from the meteorological station closest to each reservoir, in most cases < 10 km (6 miles) away.

Water Body	County	Elevation (ft)	Growing degree days	Area (ac)	Maximum depth (ft)
Bonny	Yuma	3,672	3,131	1,924	35
Carter Lake	Larimer	5,759	2,307	1,145	180
Chatfield	Jefferson	5,432	2,551	1,087	50
Cherry Creek	Arapahoe	5,548	2,634	860	30
Horsetooth	Larimer	5,430	2,337	1,899	212
Jackson	Morgan	4,438	2,818	2,967	21
John Martin*	Bent	3,851	3,777	22,325	80
Jumbo	Logan	3,705	3,078	1,570	27
Nee Gronde*	Kiowa	3,876	3,398	3,490	60
Nee Noshe*	Kiowa	3,928	3,398	3,696	40
North Sterling	Logan	4,060	2,840	2,880	55
Pueblo	Pueblo	4,881	3,370	4,500	155
Queens*	Kiowa	3,875	3,398	1900	25
Standley Lake	Jefferson	5,506	2,879	1,250	80
Trinidad	Las Animas	6,230	2,870	1,426	115
Mean	--	4,679	2,986	3,528	78

Walleye in Blue Mesa Reservoir?

We are concerned that walleye will be introduced to BMR for several reasons. There is demand for walleye angling on the West Slope and some individuals are inclined to create illegal fisheries locally rather than drive to existing fisheries on the Front Range. More and more illegal populations of walleye are appearing on the West Slope creating more sources for transplants to BMR. And, In 2001 illegally introduced yellow perch *Perca flavescens* were discovered in BMR. This species is closely related to walleye, with similar habitat requirements and the two form a classic prey-predator system throughout their native range. Many anglers associate one species with the other. Thus, it is easy to imagine an angler seeing the recent perch introduction as setting the stage for the introduction of walleye; Helfman (2007) calls this sequence a "serial introduction" and there are many examples. Further, the perch population has expanded and CDOW estimates it is costing them an additional $125,000/year in hatchery costs to attempt to compensate for kokanee consumed by yellow perch. A well-intentioned but misguided angler could easily consider introducing walleye as a potential predator to control yellow perch. In following sections of this report we document what's at stake if walleye are introduced into BMR, how likely they are to become established there, and the ecological and socioeconomic impacts that are possible from such an event.

2. Site Description

The Gunnison River Basin

Blue Mesa Reservoir (Figure 2.1) is an impoundment on the Gunnison River, in southwestern Colorado. The Gunnison basin drains an area of approximately 8,000 square miles, extending from the Continental Divide in the east to the Gunnison River's confluence with the Colorado River at Grand Junction in the west; the basin has a population of about 80,000 people (CGS 2003). Elevations in the basin range from approximately 13,000 ft along the Continental Divide, to less than 4,600 ft at Grand Junction. Primary tributaries of the Gunnison River include the Uncompahgre, North Fork Gunnison, Lake Fork Gunnison, East, and Taylor Rivers; and Ohio, Tomichi, and Cochetopa Creeks. The average annual discharge of the Gunnison River into the Colorado River is approximately 1.9 x 10^6 ac-ft (CGS 2003).

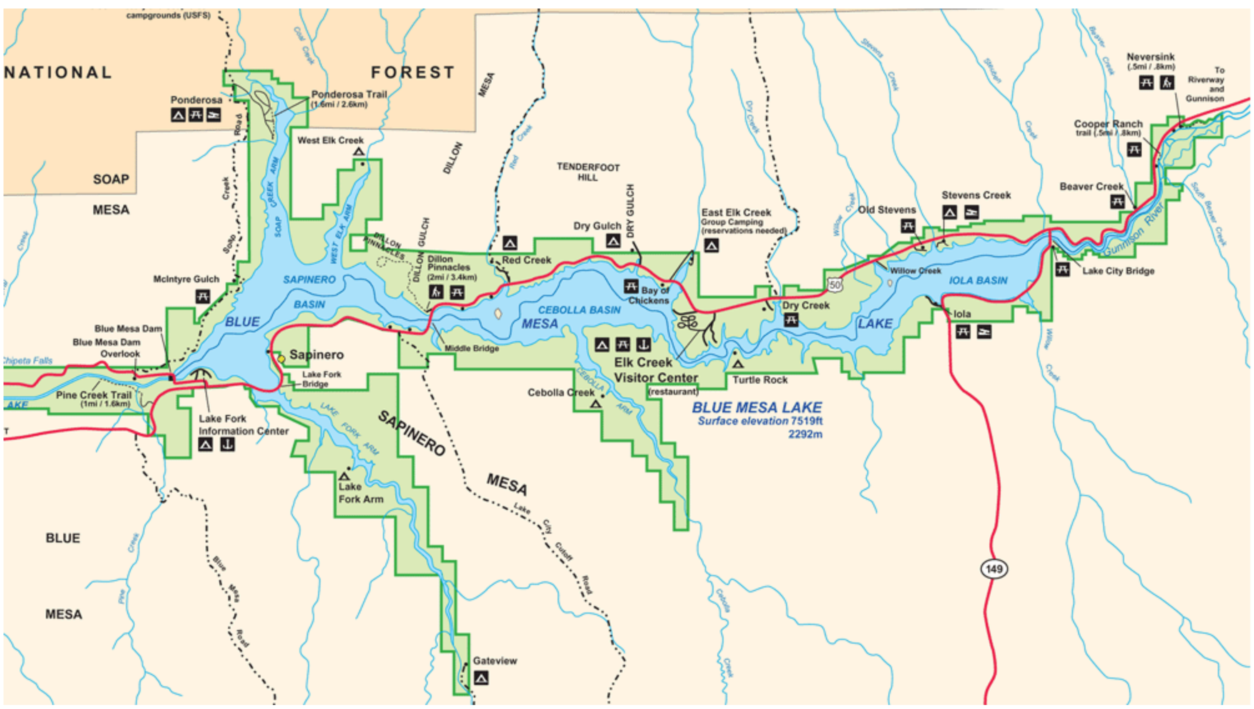

Figure 2.1. Map of Blue Mesa Reservoir and vicinity (National Park Service).

Historically, the Gunnison Basin harbored a depauperate native fish fauna of only nine species: Colorado River cutthroat trout *Oncorhynchus clarki pleuriticus*, roundtail chub *Gila robusta*, bonytail *G. elegans*, Colorado pikeminnow *Ptychocheilus lucius*, speckled dace *Rhinichthys osculus*, razorback sucker *Xyrauchen texanus*, flannelmouth sucker *Catostomus latipinnis*, bluehead sucker *C. discobolus*, and mottled sculpin *Cottus bairdi*, (R. Behnke, unpublished manuscript). Today, the reach of the Gunnison River below Delta is designated as critical habitat for the federally endangered razorback sucker and Colorado pikeminnow. This reach is isolated from the Colorado

River by the Redlands Diversion Dam and selective fish passage, which prevents nonnative piscivores from moving upstream into the Gunnison River. Bluehead suckers, flannelmouth suckers and roundtail chubs remain abundant there (Anderson 2005).

A few headwater streams, both above and below Blue Mesa Reservoir, contain some of the last remaining populations of Colorado River cutthroat trout, a state of Colorado species of special concern. The Gunnison River below the three Curecanti Unit dams and above the Gunnison River's confluence with the North Fork of the Gunnison River is classified as a "gold medal" trout fishery, and the Gunnison and Taylor rivers upstream of BMR have noteworthy trout fisheries as well.

The earthen dam forming Blue Mesa Reservoir was completed in 1965 and rises 340 ft above the streambed of the river (Reclamation 1975). Two 43,000 kW generating units operate at the base of the dam. The penstocks are located 164 ft below the surface at full pool. Blue Mesa Reservoir is the upstream-most of three reservoirs in the Curecanti Unit of the Colorado River Storage Project, providing flood control and water for irrigation, power generation, and recreation. With a storage capacity of 940,700 ac-ft (Table 2.1), BMR is the largest reservoir in the state.

The reservoir inundated a valley of meadows and sage-covered slopes (Reclamation 1975). Sedimentary rocks overlie granites that are exposed in scattered outcrops. Development along its shores is minimal; most of the reservoir is within the Curecanti National Recreation Area. About 60% of Blue Mesa Reservoir's watershed is forested and only 0.14% of that is developed (Gurdak et al. 2002).

BMR Hydrology and Dam Operations

The mean total inflow to the reservoir during 1965-2002 was 983,000 ac-ft per year (Figure 2.2); most of the annual inflow occurs during spring in a pattern characteristic of a snowmelt hydrograph (Figure 2.3). Mean daily releases have averaged about 1,375 cfs since 1965 but the seasonal pattern of discharge changed in 1993 (Figure 2.2, 2.3) when spring releases were increased to create a more natural hydrograph for endangered fishes downstream (McAda 2003).

Mean annual content (storage plus dead storage) showed an increasing trend during the period before new operations (Figure 2.2). The mean annual content during that period was 659,425 ac-ft compared to 713,797 ac-ft during WY 1993-2002. With the exception of the severe drought of 2001-2002, reservoir content was above the long term average during the study period. Mean water residence time since impoundment was 0.79 years. Mean annual surface elevation before operations changed was 7,484 ft above sea level (ASL) and after, the mean was eight feet higher, or 7,492 ft ASL (Figure 2.2).

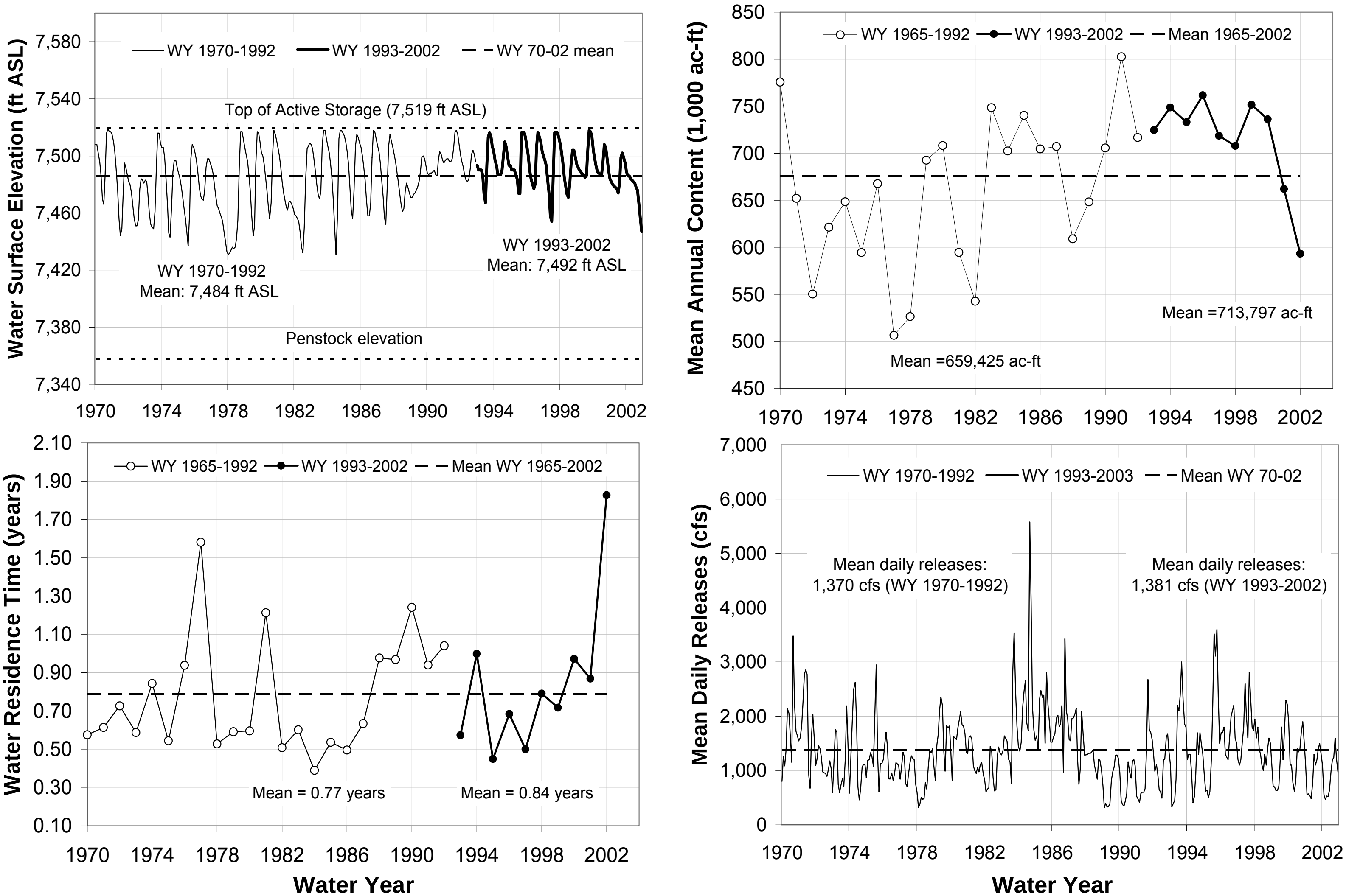

Figure 2.2 Summary of reservoir operations showing surface elevation (top left), mean annual content (top right), water residence time (lower left), and mean daily releases (lower right) at BMR during 1970 to 2002.

Table 2.1. Morphometric characteristics of Blue Mesa Reservoir and dam, Gunnison County, Colorado (measurements refer to reservoir condition at full pool).

Parameter	Value	Units	Source
Surface area	9,370	ac	Reclamation (1999)
Total capacity	940,700	ac-ft	Reclamation (1999)
Length	26	mi	Cudlip et al. (1987)
Maximum depth	330	ft	Reclamation (1975)
Mean depth	92	ft	USEPA (1977)
Surface elevation	7,519	ft	Reclamation (1999)
Penstock elevation	7,356	ft	Reclamation (1999)
Hydraulic retention time	0.8	y	Johnson and Koski (2005)

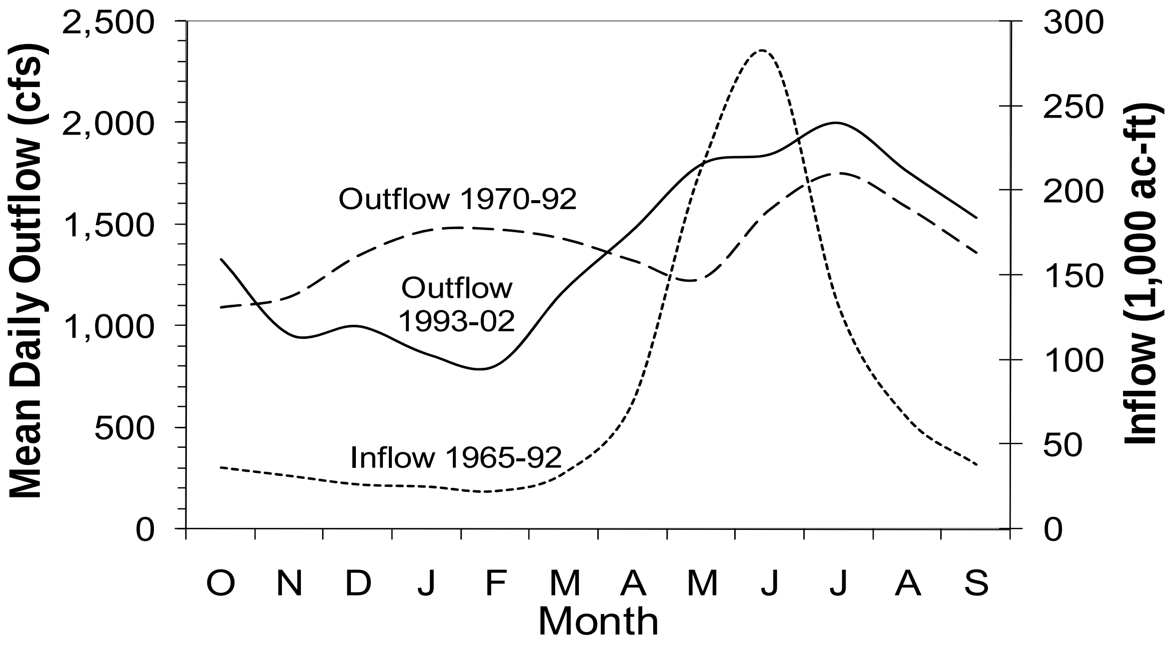

Figure 2.3. Seasonal pattern of inflow (ac-ft) and outflow (dam releases in cfs) at Blue Mesa Reservoir, Colorado. Dam operations changed beginning in 1993 when more water was released in spring to create a more natural hydrograph for endangered fishes downstream.

BMR Limnological and Food Web

Summer limnological conditions in BMR vary annually and spatially, but in general the reservoir stratifies every summer, beginning in early May and surface temperatures in August reach 18-20°C. Hypoxia occurs in the hypolimnion, especially by September. Fall mixing usually occurs during late October or early November. Summer conductivity averages about 200 µS/cm; Secchi depth in July has averaged about 4.1 m since 1983. Epilimnetic chlorophyll in August has varied between 1 µg/liter and 6 µg/liter since 1975. The reservoir is mesotrophic with a mean TSI of about 42 (mean of phosphorus, Secchi and chlorophyll models; Carlson 1977). The primary macrozooplankton include the cladocerans *Daphnia pulcaria/pulex and Daphnia galeata mendotae*, *Bosmina* spp., *Ceriodaphnia* spp., the cyclopoid copepod *Diacyclops spp.* and the calanoid *Diaptomus* spp.

Diet and stable isotope studies (Johnson et al. 2002; Johnson and Oplinger 2003) indicated that both pelagic and benthic energy pathways are important to fish production (Figure 2.4). Although large annual water level fluctuations preclude a productive littoral zone crayfish, amphipods and chironomids are important prey for trout, suckers and yellow perch. Kokanee and rainbow trout diets consist primarily of cladoceran zooplankton produced in the pelagic zone.

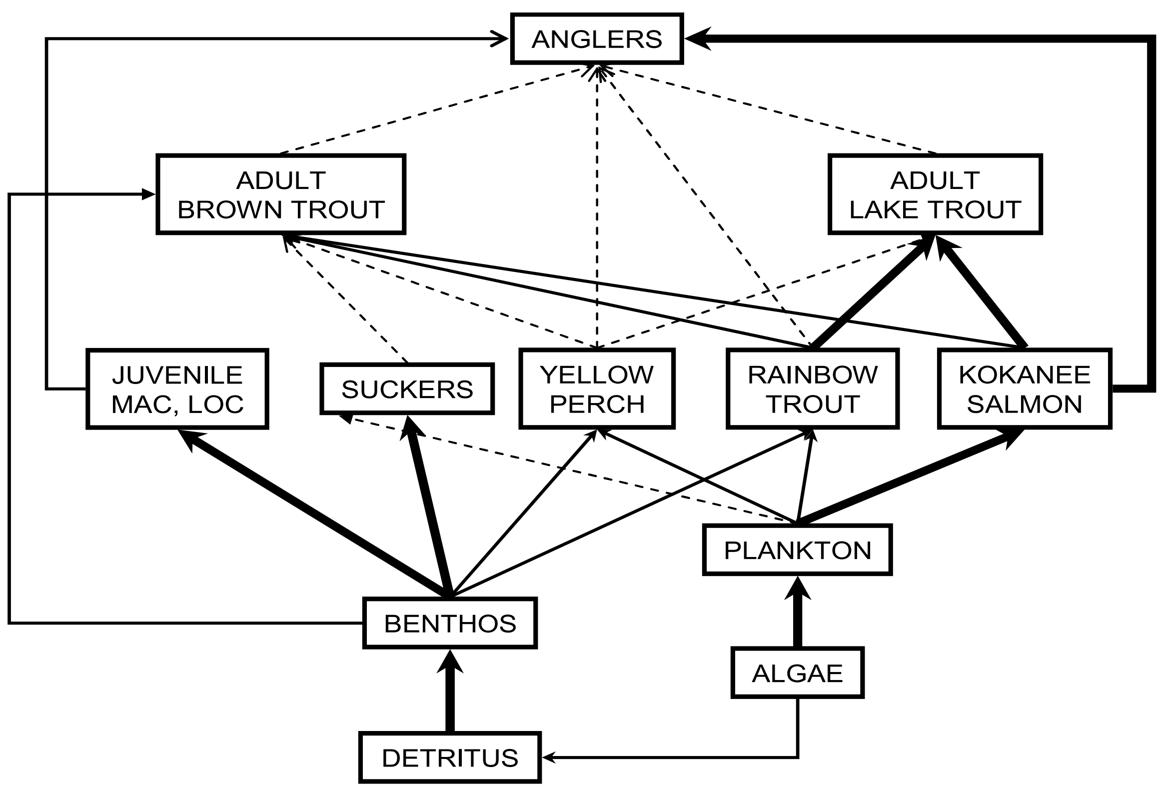

Figure 2.4. Configuration of the present day food web in Blue Mesa Reservoir (Johnson and Koski 2005; MAC and LOC are CDOW species codes for lake trout and brown trout, respectively).

Sport Fishery

Wiltzius (1978) reported that for at least 80 years prior to the construction of the Aspinall Unit, the upper Gunnison River was a world-renowned trout fishery, first consisting entirely of Colorado cutthroat trout *Oncorhynchus clarki pleuriticus* and later of rainbow and brown trout. After impoundment, the fish community in BMR has consisted primarily of kokanee *Oncorhyncus nerka*, rainbow trout *O. mykiss*, lake trout *Salvelinus namaycush*, brown trout *Salmo trutta*, longnose sucker *Catostomus catostomus*, and white sucker *Catostomus commersoni*. Coho salmon *O. kisutch* were stocked shortly after the reservoir filled but those attempts to establish the species were unsuccessful (Wiltzius 1971). Cutthroat trout *O. clarki* continue to be stocked periodically but are rarely seen in the reservoir; longnose dace *Rhinichthys cataractae* and northern pike *Esox lucius* are present and yellow perch *Perca flavescens* were illegally introduced into the reservoir, apparently in the late 1990s.

The sport fishery at BMR is clearly one of the largest and most valuable in Colorado, and kokanee are the centerpiece (Figure 2.5). Rainbow trout are also an important component of the fishery because that species is typically more accessible to shore-based anglers than kokanee. Neither species reproduces in the reservoir and in recent years approximately 1 million rainbow trout and nearly 3 million kokanee have been stocked by USFWS and CDOW, respectively, each year to sustain the fishery.

Figure 2.5. A fine catch of kokanee from BMR. The reservoir's kokanee fishery has been called one of the best anywhere (photo: B. Johnson).

Kokanee (Figure 2.6) comprise over 80% of the openwater catch, and in May-October 1993 for example, anglers fished 350,000 hours, primarily for kokanee. Historically, the BMR fishery has generated a multi-million dollar input to the local economy annually, and the actual economic value of the fishery is higher (Johnson and Walsh 1987). The kokanee fishery is thought to be one of the primary factors driving visitation at the Curecanti National Recreation Area (M. Malick, NPS, personal communication).

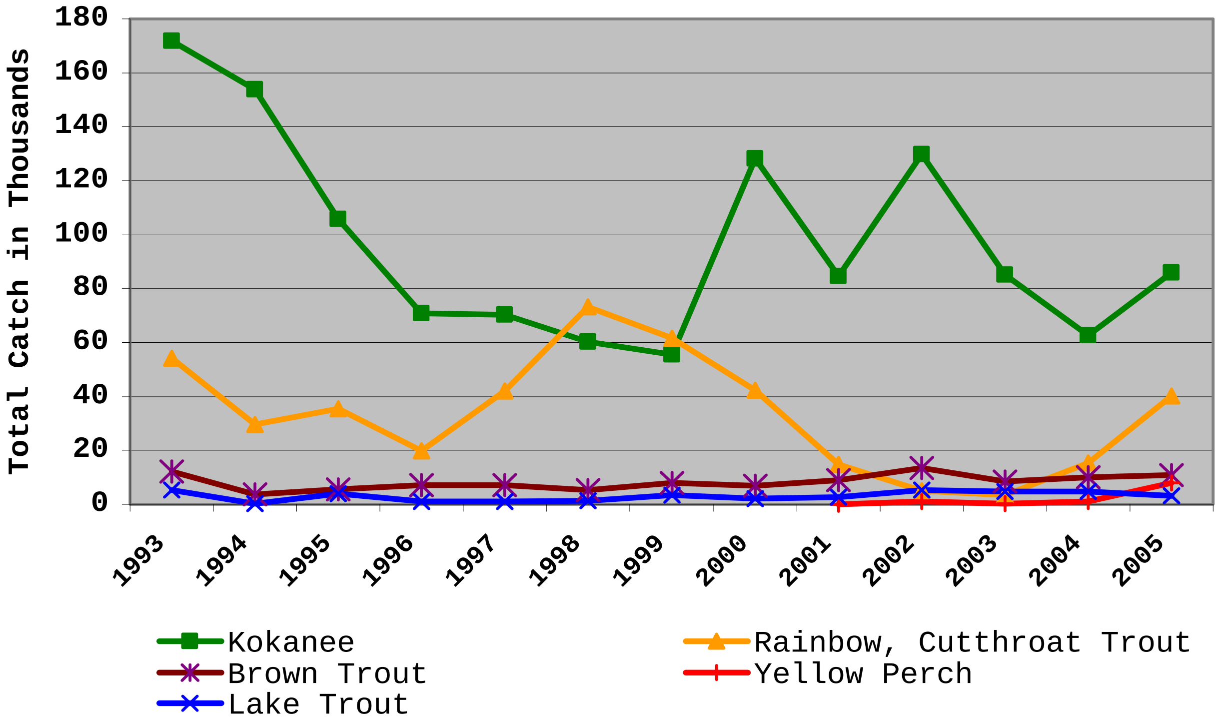

Figure 2.6. Total catch of five sport fishes at Blue Mesa Reservoir, Colorado during May-October, 1993-2005 (Dan Brauch, CDOW, unpublished data).

Eggs taken from Blue Mesa Reservoir's kokanee population are also critical to sustaining kokanee fishing throughout the state. In recent years BMR has provided nearly 90% of the entire state's supply of kokanee eggs. The management objectives at Blue Mesa Reservoir are to maintain kokanee and rainbow trout populations for fishing recreation and to maintain the kokanee population to provide an egg supply for the state's hatchery system.

The fishery at BMR has attracted anglers from 49 states, and although most anglers are Colorado residents about 75% drove more than one hour from home to fish at BMR. Most of the resident anglers come from the Front Range. It appears that fishing effort at BMR is driven partly by the kokanee catch rate anglers enjoy during summer; this phenomenon has been documented in other fisheries (Johnson and Carpenter 1994; Carpenter et al. 1994). The importance of high quality kokanee fishing in BMR is highlighted by the 50% higher fishing effort (~100,000 angler-hours) during years when catch rate was high.

Figure 2.7. Latest state record lake trout caught by Donald Walker at Blue Mesa Reservoir; 50 lbs. 5 oz., May 2007 (photo: J Wenum, CDOW).

Although lake trout were originally stocked into BMR accidentally, the species thrives there (Figure 2.7). Blue Mesa Reservoir has produced several state record lake trout since 1998, and the current state record is 50 lbs 5 oz., caught from BMR in 2007. An in depth analysis of the predator-prey system at BMR (Johnson and Martinez 2000, Johnson et al. 2002, Johnson and Oplinger 2003) showed that lake trout feed primarily on stocked kokanee and rainbow trout here and that lake trout predation is a significant source of mortality for both prey species. Concerns over the sustainability of the predator-prey system and associated fisheries for all three salmonids prompted CDOW to relax harvest regulations on lake trout in the late 1990s. The appearance of yellow perch in the reservoir has increased concern over the ability of the CDOW to maintain excellent kokanee, rainbow and lake trout fisheries in the face of new predatory and competitive threats. However, the lake trout policy remains controversial and some anglers continue to advocate for lake trout harvest restrictions.

3. Suitability of the Environment

"No, I'm simply saying that life, uh... finds a way."
-Dr. Ian Malcolm, Jurassic Park

Introduction

Here we assess the likelihood that walleyes could become established in BMR based on suitability of the physical, chemical and biological habitat in the reservoir.

Methods

Our approach was to examine the condition of each of the essential habitat variables for egg, fry (larval), juvenile and adult life stages that make up the Habitat Suitability Index (HSI) model for walleye (McMahon et al. 1984). The likelihood of establishing a self-sustaining population was assumed to be inversely related to the number of and extent that habitat variables were outside the optimum range for the species.

Blue Mesa Reservoir has been the subject of considerable study for decades, and two recent reviews (Bauch and Malick 2003; Johnson and Koski 2005) provided detailed information on BMR habitat characteristics.

Results and Discussion

Blue Mesa Reservoir's Trophic State Index (TSI) is 42 (Johnson and Koski 2005), indicative of mesotrophic or moderately productive systems (Table 3.1), and this is considered optimal for walleyes (McMahon et al. 1984). The water has a slightly basic pH (8.0) and dissolved oxygen levels exceed 6.0 mg/L, both optimal for all life stages of walleyes. Reproductive conditions are good with ample rubble and gravel substrate, and rising water levels and temperatures during egg incubation. Rate of warming (0.20°C/d) is less than optimal (Table 3.1) but slightly higher than that at which reduced egg survival has been observed (0.18°C; Busch et al. 1975).

Water temperature in BMR is cooler than fry, juvenile or adult life stages prefer (Table 3.1). In some species conditions that reduce first year growth, such as suboptimal temperatures, can result in increased overwinter mortality (Post and Evans 1989; Coleman and Fausch 2007). However, this does not appear to be true for walleye (Pratt and Fox 2002). Growing degree days at BMR have averaged 1,450 since 1967 (WRCC 2008), less than half of that for the top walleye/saugeye reservoirs east of the Divide. BMR is also clearer (mean summer Secchi depth = 4m) than walleyes prefer (1-3 m), and water temperature and clarity may interact to create poorer growth than either factor would alone. Further, because BMR lacks significant cover in the form of macrophytes, manmade structures or woody debris, walleyes may be forced into cooler, deeper water during daytime. Thus, the scope for growth (the maximum a walleye could grow given unlimited food) in BMR will be cold temperature limited. Forage fish density in BMR is far below optimum (Table 3.1), and likely less than on the Front Range where naturally reproducing prey such as gizzard shad can achieve high biomass. Thus, growth rates of walleye in BMR will very likely be slower than growth of walleyes in most waters on the Front Range.

Overall, our evaluation of the walleye's habitat requirements and conditions at BMR suggests that the reservoir is suitable to support a self-sustaining walleye population. There do not appear to be any habitat related bottlenecks at any life stage that would significantly hinder survival or completion of the life cycle. This finding is supported by a model created to predict walleye introduction success (Bennett and McArthur 1990). That work found that walleye introductions were more successful in relatively deep lakes and reservoirs that were larger than 1,000 ac, with pH > 7.5, all of which are true of BMR. However, the walleye population is likely to exhibit modest growth rates and average body condition.

Table 3.1. Physical, chemical and biological habitat requirements and preferences that comprise the Habitat Suitability Index (HSI) Model for walleye in lake and reservoir environments (McMahon et al. 1984), and conditions found in Blue Mesa Reservoir. Conditions outside the optimum range are highlighted in bold. Amount of cover in BMR was not available from published sources and is unknown.

	Requirement by life stage					
Habitat variable	Eggs	BMR	Fry	BMR	Juveniles, adults	BMR
Trophic status	Mesotrophic	Mesotrophic, TSI = 42[2]	Mesotrophic	Mesotrophic, TSI = 42[2]	Mesotrophic	Mesotrophic, TSI = 42[2]
pH	6.0 – 8.5	8.0[1]	6.0 – 8.5	8.0[1]	6.0 – 8.5	8.0[1]
Dissolved oxygen (mg/L)	≥ 6	≥ 6[2]	≥ 5	≥ 6[2]	≥ 4	≥ 6[2]
Temperature (°C)	9 - 15; rising ≥0.28°/day	9-15; **0.2°/day[2]**	22	**18-19**[2]	20 – 24	**18-19**[2]
Substrate	Rubble, gravel	Abundant[2]	--	--	--	--
Water level fluctuation (m)	Stable or rising	+6.1 m[2]	--	--	--	--
Cover	--	--	25-45%	**Unlikely**	25-45%	**Unlikely**
Water clarity (Secchi depth, m)	--	--	--	--	1 – 3	**4**[2]
Forage fish density (mg/m^3)	--	--	≥ 400	**72[3]**	≥ 400	**72[3]**

Sources: [1] Bauch and Malick (2003); [2]Johnson and Koski (2005); [3]Johnson and Martinez (2000)

4. Environmental Impacts

Introduction

Invading organisms often have a wide variety of environmental impacts. Impacts can be manifested as changes in ecological interactions, ecosystem processes, and species composition of ecological communities, which may or may not have direct, quantifiable impacts to humans. Impacts can be considered beneficial or adverse; some adverse impacts will be permanent and unavoidable and others may be mitigable. Our approach to predicting the effects of an illicit introduction of walleye into BMR was to forecast the effects of walleye feeding (trophic impacts) through their direct impacts on their prey (predation) and their indirect effects on other piscivores (competition). We then evaluated possible impacts to adjacent waters by examining the potential for walleyes dispersing out of BMR to other waters on the West Slope and then considered the potential impacts walleyes might have on game and nongame fish populations in those other waters.

We considered potential socioeconomic impacts at regional and statewide scales. First, we evaluated the potential changes to fishing recreation at BMR, and the associated economic impact to Gunnison County. We also accounted for the increased costs to the Division of Wildlife that would be associated with sustaining a rainbow trout fishery in the face of walleye predation. Because kokanee fishing in Colorado is sustained entirely by stocking, and because BMR is the State's primary source of kokanee eggs, loss of this population would jeopardize the statewide kokanee fishery. We present an estimate of the economic impact of such a loss.

Methods

Trophic impacts

We forecasted trophic impacts on the Blue Mesa Reservoir food web by estimating the food consumed by hypothetical walleye population sizes with a commonly used fisheries tool, the Wisconsin Fish Bioenergetics model 3.0 (Hanson et al. 1997). This tool is essentially an energy budget parameterized for walleye that computes how much food fish must eat (consumptive demand) to balance energetic costs and grow a given amount, at a given set of water temperatures.

For this "what if scenario" kind of analysis with the model, we had to determine a reasonable set of simulation inputs for what a BMR walleye population might look like. We chose typical values for growth, body condition, and mortality rate, and we simulated three possible population sizes.

We assumed that walleyes would grow in length according to the von Bertalanffy growth function (Guy and Brown 2007) with parameters equal to the median values in the Fishbase walleye database (Fishbase 2006). These lengths-at-age were converted to weights using the standard weight equation for walleye ≥ 150 mm TL (Murphy et al. (1990)). Energy density (kJ/g wet weight) of adult walleye and various prey organisms found in Blue Mesa Reservoir (Table 4.1) were derived from the literature. Simulations were of 1-year duration, beginning with day 1 = January 1. Initial and final body weights were 1,865 and 2,362 g wet (4.1 and 5.2 lbs wet), respectively. Losses due to spawning were accounted for: fish were assumed to lose 12% of body mass (male+female average; Carlander 1997).

Table 4.1. Approximate energy density (kJ/g wet weight) of walleye and various prey organisms found in Blue Mesa Reservoir, Colorado.

Prey taxon	Energy density	Source
Chironomid larvae and pupae	2.74	Cummins and Wuycheck (1971)
Kokanee (stocked)	5.50	Baldwin et al. (2003)
Rainbow trout (stocked)	5.50	Baldwin et al. (2003)
Walleye (adult)	5.98	Liao et al. (2004)

We computed total consumptive demand for three adult population sizes. The “nominal” scenario (4.8 fish/ha, 1.9 fish/ac) was equivalent to the average density of adult walleyes computed from an abundance:lake area (ha) relationship (density = 27.31*area$^{0.79}$) for 81 North American walleye lakes reported by Baccante and Colby (1996). The “high” scenario (14.8 fish/ha, 6.0 fish/ac) was equivalent to the median abundance in 85 North American walleye lakes (Baccante and Colby 1996). The “boom” scenario (23.9 fish/ha, 9.7 fish/ac) was equivalent to the 75th percentile of 85 North American walleye lakes (Baccante and Colby 1996). This density is similar to the average density of age-3 and older walleyes (29 fish/ha, 11.7 fish/ac) computed from values reported in Colby et al. (1979) for four lakes ≥ 1,200 ha, located in Iowa, New York, and Ohio.

To facilitate simulations with a variety of population sizes, we simulated a single cohort of 1,000 “typical” adult fish (age-5) for both the nominal and high scenarios. For each hypothesized population size we computed a scaling factor, x:

$$x = \frac{\hat{N}_h}{1{,}000} \qquad \text{where } \hat{N}_h = \text{the hypothesized population size.}$$

We then could scale up the simulation consumptive demand C_0 by the factor x to obtain the estimated consumptive demand C_h of the hypothesized population size, as below:

$$C_h = x \cdot C_0$$

A hypothetical value for the total annual probability of death (a = 44%) was assumed for all simulations, and was derived from the average mortality rate of 16 walleye populations reported in Colby et al. (1979). Water temperatures for simulations (Table 4.2) at 2 m (T_2) and 10 m (T_{10}) below the surface at Sapinero and Iola basins were computed by fitting a sine function:

$$T = a + b \cdot \sin(2\pi/365 \cdot DOY + c)$$

to observed temperatures (°C) measured during 1993-2002 (Johnson and Koski 2005), where a, b, and c are fitted constants, and DOY is day of the year. The temperatures used in the nominal run were those from Sapinero basin, at 10 m depth (T_{S10}); the high-impact scenario employed warmer temperatures (T_{I2}).

Table 4.2. Water temperatures used in bioenergetics simulations. Temperatures are for Sapinero basin at 10 m (T_{S10}) and for Iola basin at 2 m (T_{I2}), and for the Gunnison River at Grand Junction (G_{GJ}). Temperatures were computed by fitting a sine function, T = a + b·sin(2π/365·DOY + c), to observed temperatures measured at BMR during 1993-2002 (Johnson and Koski 2005) or in the Gunnison River during1998-2006 (USFWS 2008).

	Water temperature (°C)		
Day of year	T_{S10}	T_{I2}	G_{GJ}
1	4.5	3.3	1.7
31	2.0	1.7	1.1
61	1.4	2.3	3.4
91	2.9	5.1	7.9
121	6.0	9.3	13.5
151	10.0	13.8	18.7
181	13.9	17.4	22.1
211	16.5	19.2	22.9
241	17.3	18.7	20.9
271	16.0	16.1	16.5
301	13.0	12.0	11.0
331	9.0	7.5	5.7
361	5.1	3.7	2.1
365	4.7	3.4	1.8

We assumed that adult walleyes would eat mostly fish (90%) but would also eat some chironomid larvae (10%), a common invertebrate prey found in diets of other fishes at BMR (B.M. Johnson, unpublished data). We do not know what kinds of fish walleyes will eat but we can make an educated guess. Regional literature suggests that when salmonids are available, walleyes will prey upon them heavily (McMillan 1984; McMahon and Bennett 1996; Baldwin et al. 2003). Our nominal run assumed that the fish portion of the walleye diet consisted of rainbow trout and kokanee proportionate to the numbers of each species stocked during 1993-2005 (27% and 73%, respectively).

In the high-impact simulation, we assumed that when walleye ate fish it was exclusively kokanee, which has been observed in another western reservoir (Baldwin et al. 2003).

Our estimates of consumptive demand were compared to the biomass of trout and kokanee stocked (Dan Brauch, CDOW, unpublished data), the biomass harvested (CDOW creel survey), various estimates of prey standing stock and prey production (Johnson et al. 2002) to evaluate the impact that walleye predation might have on these prey populations, and the degree to which walleye might compete with lake trout, which are known to rely heavily on kokanee and trout as prey in Blue Mesa Reservoir (Johnson et al. 2002).

Socioeconomic impacts

Introduction of walleye at BMR could have adverse or beneficial impacts on fishing recreation. We predicted adverse impacts by estimating how reductions in kokanee and rainbow trout abundance could alter fishing effort (E_b, total angler-hours) directed at these species from empirical relationships developed from creel surveys conducted on BMR during 1993-2005. Years 2001-2003 were excluded from the relationship because the region was experiencing extreme drought, the reservoir was drawn down and fishing effort was unusually low during the period. Kokanee fishing effort, K_B (angler-hours/ha), was related to catch rate as:

$$K_B = 95.15 \cdot C_k + 27.26$$

where C_k is kokanee catch per boat angler-hour (r^2=0.87, n = 9). Rainbow trout fishing effort, R_B, assumed to be predominantly a shore-based fishery, and was related to catch rate by shore anglers as:

$$R_B = 2.796 \cdot C_r + 6.860$$

where C_r is rainbow trout catch per shore angler-hour (r^2=0.24, n = 9). The economic impact of the “status quo” fisheries was estimated by computing the 90th percentile of C during 1993-2005 (C_k = 0.48 fish/angler-hour, C_r = 0.19 fish/angler-hour) and estimating fishing effort K_B, R_B as above. Fishing effort was converted to fishing trips T_B using an average trip length computed from all the creel survey data (4.41 h) and was multiplied by the average expenditures per fishing trip E ($66.03; Pickton and Sikorowski 2004). An economic multiplier for Gunnison County (V_G = 1.25, MIG 1997) was applied to account for the additional economic activity stimulated by angler expenditures. Thus, the total economic impact of the kokanee or rainbow fisheries at BMR could be computed as:

$$I_B = T_B \cdot E \cdot V_G$$

A collapse of the BMR kokanee population could also jeopardize the State’s kokanee egg supply, and therefore the entire kokanee management program. We estimated the economic impact of kokanee fishing statewide, I_S, as follows:

$$I_S = A_S \cdot TUA_B \cdot E \cdot V_S$$

where A_S is the total area of kokanee waters in the state, TUA_B is the number of fishing trips per unit area estimated at BMR (mean from 1993-2005, openwater fishery only), E is the average economic expenditure per fishing trip in Colorado (Pickton and Sikorovski 2004), and V_S is the economic multiplier for the state (V_S = 1.79; MIG 1997). All monetary values were adjusted for inflation to 2008 dollars (BLS 2008).

The economic impact to fishery management at BMR was estimated by assuming that the stocked rainbow trout would need to be raised to catchable size to avoid predation by walleye, as has been observed elsewhere (McMillan 1984, McMahon and Bennett 1996). The increase in hatchery costs of raising catchable (TL = 254 mm) vs. subcatchable (TL = 120 mm) rainbow trout was computed by converting fish length L to weight W using the standard weight equation for rainbow trout (Simpkins and Hubert 1996):

$$Log_{10}W = 2.990 \cdot Log_{10}L - 4.898$$

and multiplying by a rearing cost estimate (adjusted for inflation to 2008, $14.06/kg ($6.38/lb), including administrative and support services, and capital replacement costs; Johnson et al. 1995) times the number of fish stocked.

Potential benefits of a walleye introduction were evaluated by considering the likelihood of drawing walleye anglers to BMR to substitute for lost coldwater anglers. We did this in two steps. First we used creel survey information to examine the location of origin of the anglers already visiting BMR. We then computed the human population within various distances from BMR and from alternative walleye fisheries (Carter Lake, Cherry Creek Reservoir, Pueblo Reservoir, Trinidad Reservoir) using a GIS. The magnitude of potential benefits from a walleye introduction depends on the quality of the walleye population that develops, and the willingness of anglers to drive to BMR to fish for walleye. Whether a walleye fishery could substitute for the present coldwater fishery depends on potential benefits relative to the existing fishery, and the characteristics and proximity of alternative walleye fisheries.

Impacts to adjacent waters

The first step to this portion of the analysis was to evaluate the opportunities for walleyes to disperse from BMR and colonize other waters, assuming a self-sustaining population became established in the reservoir. We assumed that walleyes could disperse downstream, over or through the dam. Likelihood that walleyes would move downstream was evaluated by examining dam configuration and historical operational and hydrologic patterns. Walleyes could also swim upstream out of the reservoir and into tributary streams, or they could be transferred by humans to other waters unconnected to BMR. Suitability of the habitat walleyes would encounter outside of BMR was judged using the same suitability criteria employed for the reservoir, for each life stage.

We evaluated potential impacts to other fishes in adjacent waters primarily by examining the nature of the resident fish assemblage, its vulnerability to piscivory, and the potential for walleyes to compete with other fishes in newly invaded habitats. We did not evaluate the possible introduction and transmission of new diseases or parasites by walleyes, nor did we attempt to estimate potential benefits to recreational fishing that might arise from the establishment of new walleye populations outside BMR.

Results and Discussion

Trophic impacts

The present “balance” between lake trout and their salmonid prey has been tenuous, with large annual stocking quotas required to sustain the prey populations.
Even a relatively modest population of walleyes (4.8 fish/ha. 1.9 fish/ac) could upset the balance, and have a significant predatory impact on kokanee and rainbow trout populations in the reservoir. The biomass of these prey consumed by such a walleye population (12.1 kg/ha, 10.8 lbs/ac) would almost double (Figure 4.1) the existing predation pressure exerted by lake trout (Johnson and Oplinger 2003) and together the two predators would consume more than the total August standing biomass estimated by sonar surveys (Johnson and Martinez 2000) as well as a portion of the annual production. The biomass of rainbows and kokanee forecast to be consumed by this minimum walleye population is similar to the average biomass harvested by anglers each year since 1993. This walleye consumption demand is an underestimate since the temperature function we used appeared to underestimate reservoir temperature (higher temperatures would increase consumptive demand). If walleyes were to reproduce more successfully but within the range observed elsewhere, the possibility exists for them to consume a biomass of fish (40.2-64.9 kg/ha, 35.9-57.9 lbs/ac) equivalent to 200-300% of the August biomass of rainbows and kokanee.

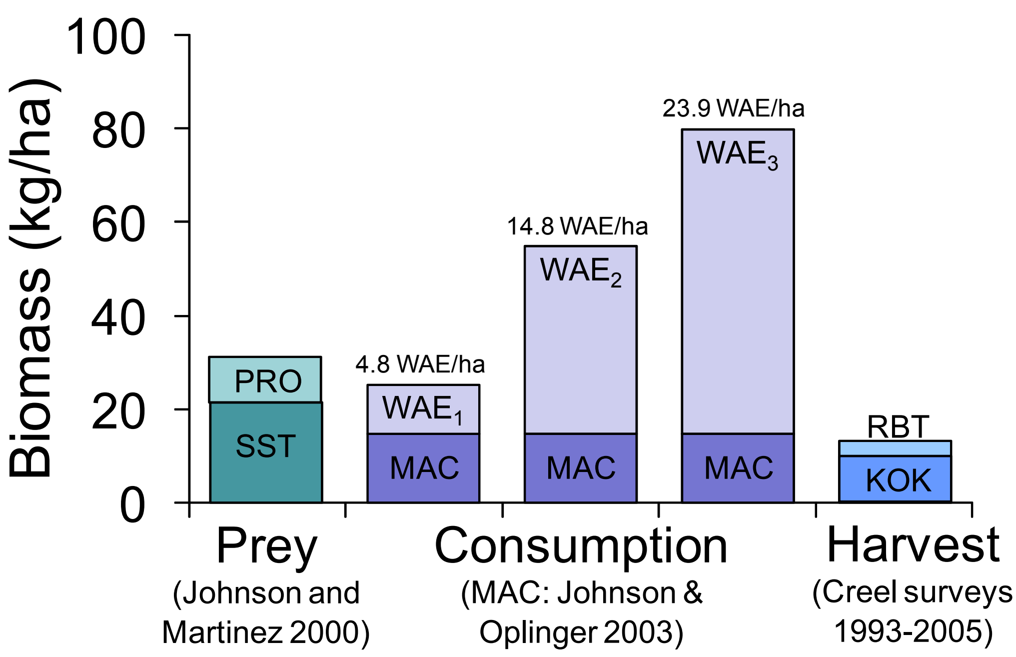

Figure 4.1. Biomass of kokanee and rainbow trout in BMR estimated by sonar (SST), the annual production (PRO) by those two prey populations, annual consumption of the two prey species by lake trout (mackinaw, MAC; estimated by Johnson and Oplinger, 2003) and by three different population sizes of walleye (WAE, shown above bars), and the average annual harvest of kokanee (KOK) and rainbow trout (RBT) by anglers

estimated from creel surveys during 1993-2005 (Dan Brauch, CDOW, unpublished data).

In order for walleyes to consume kokanee and rainbow trout, overlap between the predator and prey in time and space would be required. We believe spatio-temporal overlap among walleyes, kokanee and rainbow trout would be very likely. As noted previously, BMR is clearer than walleyes prefer which would likely force them into deeper water. This would enhance the chances of them encountering kokanee during daytime. At night, when walleyes are no longer light limited, they could move up in the water column where they would be more likely to encounter rainbow trout. In many clear, oligotrophic Canadian lakes walleyes become pelagic predators that prey on coldwater planktivores such as whitefish (McMahon et al. 1984; Colby and Hunter 1989). We believe an analogous pelagic predator-prey system could develop between salmonids and walleye in BMR.

Throughout their native range walleyes are known for their reliance on yellow perch for prey. Clearly the two species have coevolved as a predator-prey system with each exploiting weaknesses in the other that has ensured continued survival of both. With an emerging yellow perch population in BMR people may wonder why walleyes wouldn't be expected to prey on the more familiar yellow perch preferentially over salmonids. Unfortunately few studies exist from waters inhabited by walleye, yellow perch, rainbow trout and kokanee. In one recent study of Carter Lake, Colorado (Murdoch 2007) walleyes consumed exclusively salmonids despite the presence of yellow perch in the lake. Further, walleyes have shown a distinct preference for soft-rayed fishes over yellow perch (Knight and Vondracek 1993). We believe walleye would preferentially feed on salmonids in BMR and switch to yellow perch only after causing severe declines in salmonid abundance.

Reasonable scenarios for invading walleye populations at BMR suggest that rainbow trout and kokanee populations, and the fisheries they support, would be in great jeopardy if walleyes were illegally stocked and became established at BMR. Harm to salmonid prey populations by walleye would also be extremely detrimental to the lake trout population (and fishery) because the fantastic growth rates BMR lake trout exhibit are only possible due to their diet of kokanee and trout (Johnson and Martinez 2000; Johnson et al. 2002). Thus, the introduction of walleye into BMR has the distinct potential to collapse the entire coldwater fishery. In following sections we quantify the socioeconomic costs and potential benefits that may arise from a walleye introduction.

Socioeconomic impacts

If predation by walleyes reduced kokanee abundance such that angler catch rate dropped by half, we estimated that fishing effort would fall off by about 39%, resulting in a $2,026,000 annual loss to Gunnison County. Shore fishing effort was more "inelastic"- if catch rate of rainbow trout dropped by 50% shore fishing effort was predicted to drop only 5%, resulting in a relatively small economic loss ($24,000 per year). A complete collapse of the kokanee boat fishery would forfeit about $5,169,200 per year and the shore based fishery another $523,500 per year for Gunnison County.

The economic impact of the entire State's kokanee fishery was estimated at approximately $29,987,000 per year. Thus, if illegally introduced walleye caused the collapse of the kokanee population at BMR, the local impact would be substantial

($5,169,200) but the loss of the BMR egg supply could cost the State nearly $30M/yr if the kokanee culture program was lost. At present, the USFWS spends approximately $260,800 per year raising subcatchable rainbow trout for stocking in BMR. To raise an equivalent number of catchable rainbow trout, fish large enough to be immune to predation from most walleyes, it would cost an additional $2,194,000 per year in fish rearing expenses. There would also be opportunity costs at other fisheries dependent on stocked fish because the additional hatchery space that would be required to raise larger rainbows for BMR would not be available to raise fish for other destinations.

It is very unlikely that walleyes would substitute for kokanee at BMR. The creel survey shows that most anglers drive from the Front Range or farther to fish for kokanee at BMR. The outstanding kokanee fishery draws on the massive population base of the Front Range for its clientele but these anglers would not be attracted by BMR's walleye population. Based on the habitat at BMR, walleyes would be slower growing and thinner than those on the Front Range. We believe that anglers on the Front Range would be very unlikely to drive 100-300 miles to fish for walleye at BMR when many excellent walleye fisheries exist close to their home. In fact, we found that about 2.5 million people live within 50 miles of one of the top walleye/saugeye lakes in the State. On the other hand, less than 12,000 people live within 50 miles of BMR, and only about 75,000 people live within 100 miles of BMR. Clearly, BMR is a destination kokanee fishery drawing anglers from great distances. We are extremely skeptical that a walleye fishery at BMR would draw comparable numbers of anglers, and in fact we believe that if walleyes replaced kokanee in BMR the sport fishery at the reservoir would be devastated.

Impacts to adjacent waters

The primary tributary to BMR is the Gunnison River (about 46% of the inflow, Boyer and Cutler 2004), which is formed by the confluence of the East and Taylor Rivers about 20 miles upstream of BMR. Taylor Park Dam sits about 40 river miles upstream from BMR, on the Taylor River. The other major tributaries include Lake Fork of the Gunnison River, Cebolla Creek, Soap Creek and West Elk Creek (together about 47% of the inflow, Boyer and Cutler 2004). Minor and ephemeral inputs make up the remainder, including Red, East Elk, Steuben, and South Willow creeks. Beaver and Tomichi creeks enter the Gunnison River just upstream of BMR. There are few barriers to upstream movement of walleyes in the tributaries to BMR, including the dam on the Taylor River, and impassable barriers on the East River (35 miles upstream), Lake Fork of the Gunnison (31 miles upstream), West Elk Creek (11.5 miles upstream) and Beaver Creek (4.9 miles upstream) (D. Brauch, CDOW, pers. comm.). Temporary irrigation diversions may also block upstream movement for short periods during the summer on these and other tributaries.

Generally speaking, habitat in tributaries to BMR is typical of high gradient Rocky Mountain trout streams, with nearly saturated dissolved oxygen levels all year, and low suspended sediment loads and clear water (Gurdak et al. 2002; Bauch and Malick 2003). Water temperatures in nine tributaries, measured near their terminus at BMR, were about 33% colder than BMR surface temperatures in June and August 1999 (Bauch and Malick 2003). Tributary temperatures would be expected to decrease with elevation, upstream from the reservoir. Habitat in tributaries could provide suitable spawning substrate, with abundant gravel and cobble, and incubating eggs would be well oxygenated (Table 4.3). However, extreme fluctuations in flow and stream stage are typical in April-July, which is detrimental to egg survival (McMahon et al. 1984). While tributaries are not inhospitable to juvenile and adult walleyes, summer temperatures and clarity are far from optima. We do not know what forage fish density is in tributaries but we assume, given the low nutrient loading throughout the upper watershed (Gurdak et al. 2002), that it is lower than in BMR. Overall, habitat conditions appear to be much more suitable within the reservoir. We expect that walleyes would make forays out of the reservoir, particularly in spring and fall, but they would not occupy upstream tributaries for extended periods of time.

Movement of walleyes downstream from reservoirs can be significant, often in late winter and early spring, and among juvenile fish especially (Groen and Schroeder 1978; Jernejcic 1986), though fry losses can be substantial as well (Willis and Stephen 1987;Colby and Hunter 1989). Walleyes moving downstream from BMR can do so by swimming over the dam in years when the spillway is operated or they can pass through the penstocks and out the outlet in any year. Little data on walleye exist but survival of fish passing over the spillway would presumably be greater than that of fish moving through the penstocks. Dam operators generally prefer not to use spillways so they can maximize hydropower generation. During the past 39 years of record, BMR has only spilled in 12 years, when inflow was very high. If this frequency continues then walleyes inhabiting BMR could pass over the dam roughly every 3.25 years.

The likelihood that walleyes would pass through the penstocks at BMR may be higher in low water years because of the depth of the penstock openings (164 ft below surface at full pool). However, the reservoir's surface has never dropped to within less than 72 ft of the penstocks. We believe entrainment of walleyes in releases through the penstocks could be greatest during early spring. Walleyes tend to be sedentary in summer and are most migratory during spring and fall (Becker 1983). During March and April the reservoir is usually as low as it will be, but releases are increasing in anticipation of spring runoff. The installation of a temperature control device (TCD) has been proposed for BMR (Boyer and Cutler 2004). Such a device would draw water from layers closer to the surface than the present dam configuration and this would likely increase the chances of entraining walleyes in the outflow.

Walleyes passing over or through the BMR dam would need to pass through two more hydropower dams (Morrow Point, Crystal) before they could reach the free flowing Gunnison River. Walleyes would probably not linger in the "gold medal" section of the Gunnison River below Crystal Dam, where water temperature peaks at 12-16 °C (USFWS 2008). Below the gold medal section and above Delta, water temperatures are 17-20 °C (USFWS 2008), similar to surface temperatures in BMR. We believe that walleyes would continue to move downstream in summer, seeking warmer water, although they would probably move throughout the Gunnison River between Redlands and Crystal Dam at other times of the year. The goal of a TCD at BMR is to increase Gunnison River temperatures, which would increase the thermal suitability of much of the river for walleye, and increase their predatory impact on their prey.

The section of the Gunnison between Delta and Grand Junction currently appears to provide the most suitable habitat for walleyes (Table 4.4). Although reproduction in the mainstem may be precluded by slow warming and rapid stage fluctuations, conditions for other life stages appear to be excellent. Summer water temperatures are nearly optimal, clarity is reduced, and soft-rayed fishes are abundant. This reach of the Gunnison is classified as critical habitat for razorback sucker and Colorado pikeminnow, and other native species such as bluehead sucker, flannelmouth sucker and roundtail chub are abundant (Anderson 2005). Walleyes would have no nonnative piscivores to compete with for fish prey because other such species have been excluded by the Redlands diversion/fish passage (Anderson 2005). The per capita consumption demand of an adult walleye in this reach of the Gunnison (4.69 kg/year, 10.3 lbs/year) would be about 22% higher than the nominal consumption in BMR (4.16 kg/year, 9.2 lbs/year), at the growth rate assumed for BMR simulations. Walleyes in the lower Gunnison would probably grow faster and therefore they would consume more than in BMR since foraging conditions are more favorable in the lower Gunnison.

The prospect of walleyes colonizing the lower Gunnison River is a concern because this reach has developed as a de facto native fish refuge. The Redlands fish passage has successfully excluded nonnative predators from this reach from below and cold water has limited their access from above, and native fishes are thriving. If walleye establish a reproducing population upstream in the Gunnison Basin this would provide a continuous supply of piscivores ideally adapted to preying upon native fishes in this lower Gunnison “refuge” and would nullify much of the benefit from the multi-million dollar selective fish passage at Redlands.

Our predictions of walleye movement upstream and downstream through the Gunnison Basin are uncertain. Particularly with respect to downstream movement, we do not know what the passage rate will be of walleye through the three dams of the Aspinall Unit (BMR, Morrow Point, and Crystal), nor do we know what their survival rate will be in passing over or through each of the dams. Likewise, it is difficult to know how many walleyes will move upstream out of the reservoir. However, the high connectivity of reservoirs suggests that once a species becomes established in a reservoir it becomes a stepping stone, facilitating further invasions on the landscape (Havel et al. 2005). Further, a successful illegal stocking of walleye into BMR serves as an example and a source population for future illegal introductions throughout the basin and beyond.

Table 4.3. Physical, chemical and biological habitat requirements and preferences that comprise the Habitat Suitability Index (HSI) Model for walleye in rivers (McMahon et al. 1984), and conditions found in tributaries to Blue Mesa Reservoir. Conditions outside the optimum range are highlighted in bold. Current is not a component of the HSI model but is considered an important habitat variable for all life stages of walleye (Houde 1969; Jones et al. 1974; McMahon et al. 1984). Amount of cover in tributaries was not available from published sources and is unknown.

	Requirement by life stage					
Habitat variable	Eggs	Upstream tributaries	Fry	Upstream tributaries	Juveniles, adults	Upstream tributaries
pH	6.0 – 8.5	7.8[1]	6.0 – 8.5	7.8[1]	6.0 – 8.5	7.8[1]
Dissolved oxygen (mg/L)	≥ 6	≥ 7[1]	≥ 5	≥ 7[1]	≥ 4	≥ 7[1]
Temperature (°C)	9 - 15; rising ≥0.28°/day	**9-13; 0.01°/day**	22	**13**[1]	20 – 24	**13**[1]
Substrate	Rubble, gravel	Abundant[2]	--	--	--	--
Water level fluctuation (m)	Stable or rising	**Rising then falling**	--	--	--	--
Cover	--	--	25-45%	?	25-45%	?
Water clarity (Secchi depth, m)	--	--	--	--	1 – 3	**>> 3**
Forage fish density (mg/m^3)	--	--	≥ 400	**< BMR**	≥ 400	**< BMR**
Current (cm/sec)	> 0	Available	Slight	**“high gradient”**[2]	Low	**“high gradient”**[2]

Sources: [1]Bauch and Malick (2003); [2]Gurdak et al. (2002);

Table 4.4. Physical, chemical and biological habitat requirements and preferences that comprise the Habitat Suitability Index (HSI) Model for walleye in rivers (McMahon et al. 1984), and conditions found in the Lower Gunnison River, between Delta and Grand Junction. Conditions outside the optimum range are highlighted in bold. Current is not a component of the HSI model but is considered an important habitat variable for all life stages of walleye (Houde 1969; Jones et al. 1974; McMahon et al. 1984). Amount of cover and forage fish density in the Lower Gunnison River were not available from published sources and are unknown.

	Requirement by life stage					
Habitat variable	Eggs	Lower Gunnison	Fry	Lower Gunnison	Juveniles, adults	Lower Gunnison
pH	6.0 – 8.5	8.3[3]	6.0 – 8.5	8.3[3]	6.0 – 8.5	8.3[3]
Dissolved oxygen (mg/L)	≥ 6	≥ 8[3]	≥ 5	≥ 8[3]	≥ 4	≥ 8[3]
Temperature (°C)	9 - 15; rising ≥0.28°/day	9 – 15; **0.09°/d**[1]	22	20-24[1]	20 – 24	20-24[1]
Substrate	Rubble, gravel	available	--	--	--	--
Water level fluctuation (m)	Stable or rising	**Rising then falling**[2]	--	--	--	--
Cover	--	--	25-45%	?	25-45%	?
Water clarity (Secchi depth, m)	--	--	--	--	1 – 3	< 3
Forage fish density (mg/m^3)	--	--	≥ 400	?	≥ 400	?
Current (cm/sec)	> 0	Available	Slight	**unlikely**	Low	available

Sources: [1]USFWS (2008);[2]USGS (2008); [3]Butler et al. (1991) and Butler and Osmundson (1999)

5. Remediation and Mitigation

If walleyes establish a self-sustaining population in BMR managers may require knowledge of means to remediate or mitigate the situation. We examined some of the options that are available to achieve three levels of control over walleyes in this system, and we evaluated the feasibility of accomplishing each.

Desired level of control:

1. *Eliminate walleyes from BMR*

   Experience has shown that once a nonnative fish becomes established in a system it is rarely possible to eliminate it. The only proven method to eliminate a fish population from a large, natural system is by chemical removal. To treat BMR with rotenone to kill walleyes (which would kill all other fishes too), approximately 5-10 lbs of 5% rotenone powder at $2.11/lb would be required per ac-ft of water (A.M. Martinez, CDOW personal communication, January 2007). If BMR were drawn down to 600,000 ac-ft about $9,495,000 would be required to purchase rotenone. An additional $9,675,000 would be needed for 2,250 tons of $KMnO_4$ (potassium permanganate) to detoxify the water after the treatment. Personnel and logistical costs for a rotenone operation of this magnitude would be enormous as well. The total cost of a single chemical treatment of BMR would easily exceed $20,000,000 and it is unlikely that the first treatment would be successful because some fish could easily move upstream into tributaries to avoid the toxicant. Follow-up treatments would probably be needed, requiring an equivalent amount of supplies, labor and other resources as the initial treatment.

   Unfeasible: Cost ≥ $20M, complete kill virtually impossible.

2. *Suppress the population*

   a. *Drawdown*

      Drawdown of the reservoir after walleyes have spawned but before eggs have hatched (i.e., during the egg incubation period) dewaters the eggs resulting in complete year class failure. Egg incubation period in BMR would most likely occur during May and early June. Drawdown of the reservoir at this time would probably be impossible as runoff and inflow are increasing. Historically May has been the month with the most rapid increase in reservoir elevation. Adjustments to reservoir operations would require consideration of impacts to hydropower generation, irrigation supply and other downstream water rights, as well as flows required for native fishes.

      Unfeasible: May-June drawdown conflicts with other water uses

   b. *Physical removal*

      Alternatively, the walleye population could be suppressed by physical removal of juvenile and adult fish. This could be accomplished by targeted sampling, such as with trap nets during the walleye spawning season or with gill nets set at times and locations that minimized bycatch of desirable species. Regardless of the number of walleyes targeted for capture, physical removal would likely be prohibitively labor-intensive because of the enormous surface area (~10,000 ac) and shoreline length (>95 miles) of BMR.

Recommended but likely unfeasible: physical removal may be impractical in such a large water body.

c. *Mandatory kill regulation*
A mandatory kill regulation, such as in place for illegally stocked walleyes in Utah and Wyoming, would require anglers to dispatch any walleyes they catch. Such a regulation is beneficial because it minimizes fishery returns to those that stock illegally and it enlists the assistance of the angling community in mitigation efforts. However, it is unlikely that sport fishing exploitation alone would be high enough or be sustained long enough to suppress the population.

Recommended, but not sufficient

d. *Genetic biocontrol*
Genetic biocontrol is an emerging technology being evaluated for possible application in Australia and the United States. Genetic biocontrol involves the release of genetically modified fish designed to disrupt the survival or reproduction of a targeted invasive species (Kapuscinski and Patronski 2005). Although promising as a means to control undesirable target fish species, this technology has a host of technical, regulatory, and societal hurdles to overcome before it would be ready for use as a management option.

Unfeasible at this time.

3. *Contain walleyes within BMR*
Given the difficulty in eliminating a walleye population from BMR managers may wish to attempt to restrict the population to BMR, and prevent walleyes from spreading to other waters. Preventing the downstream movement of walleye should be a priority because habitat downstream is more suitable than that found upstream of BMR.

a. *Fish screens*
Fish screens that prevent any life stage of walleye from passing through spillways and penstocks are available. Miller and Laiho (1997), Martinez (2000) and Ayres Associates (2001) provide evaluations of some of the materials, and practical and technical considerations necessary for deploying fish barriers at dams in the Upper Colorado River Basin. Based on experience at much smaller reservoirs in Colorado (Highline, Elkhead) the total cost to purchase, install and maintain an industry-standard fish screen at one of the Aspinall dams could easily exceed $1,000,000. It may be that fish screens could not be constructed or installed to meet BOR specifications or that dam configuration or maximum discharge are prohibitive.

Investigate cost and feasibility

b. *Weirs*

Weirs could be constructed downstream of Crystal Dam to capture walleyes that survived passage through the Aspinall Unit. However, flows in the Gunnison River below Crystal can exceed 10,000 cfs, which would likely either destroy or render weirs unfishable.

Unfeasible: Gunnison flow up to 10,000 cfs.

c. *Close BMR to fishing*

Even if it were feasible to prevent walleye from moving out of BMR by their own means, a reproducing population at BMR would provide a perpetual source of transplants for illegal stocking at other waters. Some jurisdictions (e.g., British Columbia) have closed small water bodies to fishing and other access when illegally stocked fish are discovered. Such an action would prevent BMR from becoming a source population for future transplants. However, the Curecanti National Recreation Area where BMR is located owes much of its 1,000,000 annual visitation to BMR fishing. Closing the reservoir to fishing would have profound impacts on Park visitation and the local economy.

Unfeasible: Curecanti visitation approximately 1,000,000/year

6. Conclusions

- In general, we found that the habitat in BMR is cooler and clearer than optimal for walleyes but there are no habitat-related bottlenecks preventing the species from completing its life cycle and establishing a self-sustaining population.

- BMR is substantially higher in elevation, colder, deeper and larger than the top 15 walleye/saugeye lakes in the State. It is likely that walleye growth and size structure in BMR would be inferior to most of the State's popular walleye fisheries.

- The baseline simulation suggested that a modest walleye population in BMR could consume as much kokanee and rainbow trout biomass as the current lake trout population. An abundant walleye population would consume 4 times as much as the lake trout do now or about 300% of the August biomass of kokanee and trout.

- A reproducing walleye population in BMR would eliminate the kokanee population from the reservoir.

- Lake trout growth rates would decline from competition with walleyes for fish prey and BMR would no longer produce remarkably large lake trout.

- Stocked rainbow trout within the gape limit of lake trout and walleye would have a low probability of survival. Agencies would have to stock catchable sized fish to sustain a rainbow trout fishery, at an added cost of $2 million per year.

- Loss of the kokanee fishery at BMR would result in about $5.2 million per year in forgone revenue in the Gunnison County economy.

- Loss of the BMR kokanee fishery would also jeopardize the State's kokanee egg supply and hence all of its kokanee fisheries, which we valued at more than $29 million per year.

- Walleye fishing is unlikely to compensate for lost kokanee and trout fishing at BMR, given the reservoir's characteristics and distance from population centers. Because of suboptimal conditions and moderate productivity relative to Front Range walleye reservoirs, the walleye fishery in BMR is not likely to produce the numbers or sizes of fish that attract levels of angler effort seen at the State's premier fisheries.

- If a walleye population became established in BMR dispersal beyond the reservoir is likely. Walleyes are known to travel >60 miles in rivers and can survive passage through hydropower dams.

- Likelihood of downstream escapement would be greatest in early spring when surface elevation is minimal and discharge is high, or during periods when spillways are used.

- Downstream from BMR, temperature and turbidity of the Gunnison River below Delta appear to be nearly optimal for walleye growth and feeding. In this reach nonnative piscivores are rare and walleyes represent a potentially novel predatory threat to the currently robust populations of native fishes, some of which are endangered.

- While tributaries above BMR support outstanding trout fisheries, and some populations of rare Colorado River cutthroat trout, these waters are high gradient, clear and cold, and thus, are inhospitable to walleye.

- Predictions of emigration from BMR are highly uncertain but a reproducing population in the reservoir will likely serve as a source or “stepping stone” facilitating further illegal transfers of the species throughout the region.

- Mitigation options include: water level manipulation during egg incubation, mechanical removal by netting or other means, chemical reclamation with piscicides, and containment to prevent dispersal from BMR, which might include closing the reservoir to fishing.

- Because of the size of BMR, all available options to eliminate, suppress or contain walleye would be extremely expensive, impractical or minimally effective.

7. Recommendations

Given the severity of potential adverse impacts and lack of practical and effective mitigation options we recommend vigorous prevention efforts as the most prudent course of action. In considering the costs of prevention efforts, agencies would be wise to keep in mind that successful prevention would be cost effective even if very expensive, when compared to the predicted economic impacts of walleyes becoming established at BMR.

We offer the following suggestions to assist agencies in mounting an effort to prevent walleye introduction in BMR and to stem the tide of illegal fish introductions throughout the region.

1. **Inform stakeholders in the region**
   Publicizing the expected adverse effects of walleyes on fish populations and fisheries in BMR and surrounding waters may dissuade some individuals from illegally stocking walleyes. Public awareness of the economic losses that Gunnison County would suffer could create tremendous peer pressure against individuals contemplating stocking walleyes in BMR. We recommend that the findings of this report be made widely available to agencies, Wildlife Commissioners, anglers' groups, fishing-related businesses, environmental groups, and the public at large.

2. **Adopt policies that discourage illegal stocking**
   Agency policies that discourage illegal stocking in general will help prevent walleye introduction at BMR. Suggestions include:
   a. Enact "must kill" regulations in advance
   b. Do not reward illicit introductions with management (no harvest protections on illegally stocked fish; discontinue stocking of prey/sport fish where predators have been stocked illegally)
   c. Do not reward or recognize anglers for catching illegally stocked fish (e.g. Master Angler Award)
   d. Do not condone illicit introductions with a passive response
   e. Do not stock problematic species regionally
   f. Close waters to fishing if stocked illicitly
   g. Pursue a test case of the forensic approach and techniques described in Johnson et al. (2007).

3. **Inform the general public**
   Agencies need to engage in better information and education efforts around illegal stocking in general. Increased public awareness of the impacts that illegal stocking can have will be helpful in curbing individual inclination to stock and creating peer pressure against others, and will provide more opportunity to witness and capture perpetrators. Within agencies and the legal system there does not appear to be sufficient appreciation of the magnitude of the illegal stocking issue, nor the resolve to take sufficient action to stem the problem. Thus, internal education efforts are needed as well.

4. **Increase rewards for information about violators**
   Enforcement of stocking regulations is challenging because of the cryptic nature of the crime and vast area over which it can occur with few enforcement personnel to cover it. Increasing the rewards offered for information about violators would encourage peers to provide much needed witness information. Substantial rewards would also serve to notify all that the crime is serious and that agencies are serious about prosecuting violators. This would have some deterrent value regardless of whether any rewards were paid out. As Johnson et al. (in review) suggest states and Canadian provinces and territories could form a consortium to pool their reward funds. Together they could offer enormous rewards for witness information with the economy of scale that comes with a continental level cooperative.

5. **Substantially increase penalties for illegal stocking**
   Given that the damage to sport fisheries from a single illegal stocking event can exceed $30,000,000, the mitigation costs may be $20,000,000 or more, and the ecological harm to native species (threatened, endangered and otherwise of special concern) may be incalculable, the current penalties for illegal fish stocking seem ludicrous ($68 in Colorado, on average about $2,800 in the western U.S., Johnson et al. In review). Such fines do not convey the seriousness of the crime, either to prospective violators, or to the enforcement or legal system. If we are to demonstrate the severity of impacts to the resource and fisheries-related economies that illegal stocking is imposing, and if we wish to deter potential violators, it is essential that management agencies act swiftly to dramatically increase the penalties for illegal stocking. Information such as that contained within this report and in a forthcoming article (Johnson et al. in review) should prove useful in demonstrating to Commissioners, stakeholders, and the legal system the necessity of enacting severe penalties for illegal stocking.

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