Proposal for Adaptive Management to Conserve Biotic Integrity in a Regulated Segment of the Tallapoosa River, Alabama, U.S.A.

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Abstract: *Conserving river biota will require innovative approaches that foster and utilize scientific understanding of ecosystem responses to alternative river-management scenarios. We describe ecological and societal issues involved in flow management of a section of the Tallapoosa River (Alabama, U.S.A.) in which a species-rich native fauna is adversely affected by flow alteration by an upstream hydropower dam. We hypothesize that depleted low flows, flow instability, and thermal alteration resulting from pulsed flow releases at the hydropower dam are most responsible for changes in the Tallapoosa River biota. However, existing data are insufficient to prescribe with certainty minimum flow levels or the frequency and duration of stable flow periods that would be necessary or sufficient to protect riverine biotic integrity. Rather than negotiate a specific change in the flow regime, we propose that stakeholders—including management agencies, the power utility, and river advocates—engage in a process of adaptive-flow management. This process would require that stakeholders (1) develop and agree to management objectives; (2) model hypothesized relations between dam operations and management objectives; (3) implement a change in dam operations; and (4) evaluate biological responses and other stakeholder benefits through an externally reviewed monitoring program. Models would be updated with monitoring data and stakeholders would agree to further modify flow regimes as necessary to achieve management objectives. A primary obstacle to adaptive management will be a perceived uncertainty of future costs for the power utility and other stakeholders. However, an adaptive, iterative approach offers the best opportunity for improving flow regimes for native biota while gaining information critical to guiding management decisions in other flow-regulated rivers.*

Una Propuesta de Manejo Adaptivo para Conservar la Integridad Biótica en un Segmento Regulado del Río Tallapoosa, Alabama (E.U.A.)

Resumen: *La conservación de la biota de río requerirá de aproximaciones innovadoras que promuevan y utilicen el entendimiento científico de las respuestas del ecosistema a escenarios alternativos de manejo de ríos. Describimos temas ecológicos y sociales involucrados en el manejo de flujo de una sección del Río Tallapoosa (Alabama, E.U.A.) en el que la fauna nativa rica en especies es adversamente afectada por alteración del flujo por una presa hidroeléctrica río arriba. Nuestra hipótesis es que los flujos bajos agotados, la inestabilidad de flujo y la alteración térmica resultantes de descargas pulsadas de la presa hidroeléctrica son los responsables principales de los cambios en la biota del Río Tallapoosa. Sin embargo, los datos existentes son insuficientes para prescribir con certeza los niveles de flujo mínimos o la frecuencia y duración de los períodos de flujo estable necesarios o suficientes para proteger la integridad biótica del río. Proponemos que, en lugar de negociar un cambio específico en el régimen del flujo, los actores (incluyendo agencias de manejo, la compañía eléctrica y los defensores del río) se involucren en un proceso de manejo adaptivo del flujo. Este proceso requeriría que los actores (1) desarrollen y aprueben los objetivos de manejo; (2) modelen relaciones hipotéticas entre operaciones de la presa y los objetivos de manejo; (3) implementen cambios en las operaciones de la presa y (4) evalúen las respuestas biológicas y otros beneficios por medio de un pro-*

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grama de monitoreo revisado externamente. Los modelos serían actualizados con datos del monitoreo y los actores estarían de acuerdo en modificar los regímenes de flujo necesarios para cumplir los objetivos de manejo. Un obstáculo primario para el manejo adaptivo será una percepción de incertidumbre de los costos futuros para la compañía eléctrica y otros actores. Sin embargo, una aproximación adaptiva, iterativa, ofrece la mejor oportunidad para mejorar los regímenes de flujo para la biota nativa mientras se obtiene información crítica para guiar las decisiones de manejo en otros ríos con flujos regulados.

Introduction

Conserving the biotic integrity of river systems will require creative management approaches that accommodate human uses of surface water while increasing protection of native biota and ecosystem function. The need for innovative management is evident in global decline of aquatic species (Moyle & Leidy 1992; Folkerts 1997), coupled with continuing dam construction, increasing human demands for water supply, and societal conflicts over river-management objectives (McCully 1996; Postel 1996). These patterns are manifest in the southeastern United States, where rivers support among the most species-rich assemblages known from temperate streams and rivers (Bogan et al. 1995; Lydeard & Mayden 1995; Walsh et al. 1995; Neves et al. 1997). During the past 100 years, southeastern rivers have been extensively dammed to provide hydroelectric generation, transportation, flood control, reservoir-related recreation, and water supply. As in other regions, dams have strongly affected faunal diversity, species distributions and fisheries in southeastern U.S. rivers (Neves & Angermeier 1990; Lydeard & Mayden 1995; Neves et al. 1997). Faunal assemblages native to larger rivers now persist mostly in river fragments affected by upstream dams and reservoirs. Therefore, comprehensive strategies for conserving imperiled riverine fauna must explicitly address management options for improving biological function in flow-altered river reaches downstream from dams.

Adaptive management is an approach that incorporates uncertainty, such as that due to environmental variation and to incomplete understanding, and knowledge gained through the scientific process to prescribe flexible scenarios for the conservation and management of resources (Walters 1986). The adaptive-management approach explicitly recognizes the uncertainty underlying ecological relations to environmental variation (Walters 1986; Hilborn 1987). The approach aims to reduce uncertainty by monitoring biotic responses to management actions and by comparing responses to predictions generated by alternative hypotheses. Based on what is learned, management strategies are then adjusted and biotic responses are again monitored and compared with predictions in an iterative process. Stakeholder involvement is key to the success of adaptive management (McLain & Lee 1996); stakeholders must agree on management objectives and support a monitoring program and a process for assessing the effects of management on natural resources (Williams & Johnson 1995).

Our purpose is to present a conceptual model for adaptive-flow management in a regulated river of the southeastern United States. Others have advocated the wider use of adaptive management to improve the process of setting instream flow standards (Castleberry et al. 1996; Van Winkle et al. 1997; Walters 1997; Johnson 1999). Flow settlements in some cases in the western United States have stipulated additional scientific studies to address uncertainties and to support future adjustments to flow requirements (Castleberry et al. 1996; Van Winkle et al. 1997). Walters (1997) points out, however, that most attempts to manage adaptively have not moved beyond planning phases. Walters cites several reasons for lack of success: difficulty in moving from model development to experimentation; perceptions that experimental management is too expensive or ecologically risky; perceived threats to the self-interests of research and management agencies; and conflicts among environmental and other management goals. In addition, the institutional framework for making flow-management decisions involves agencies and development interests that generally see themselves at cross purposes, and it lacks a basis for engaging stakeholders in a cooperative management process.

Despite potential obstacles, an adaptive management approach holds substantial promise for improving management of regulated rivers by providing an objective, scientific process through which managers and scientists can address the uncertainty inherent in predicting how river fauna will respond to flow-regime alterations. We describe some of the ecological and social issues involved in flow-management decisions for a regulated segment in the Tallapoosa River in Alabama (U.S.A.), and outline a process for applying adaptive-flow management to this system. We address some of the barriers to the process and identify potential conservation benefits of adaptively managing regulated rivers in the Southeast.

Study System and Management Issues

This study addresses a strongly flow-regulated reach of the Tallapoosa River, Alabama (Fig. 1). For management purposes, the reach is defined as beginning at Harris

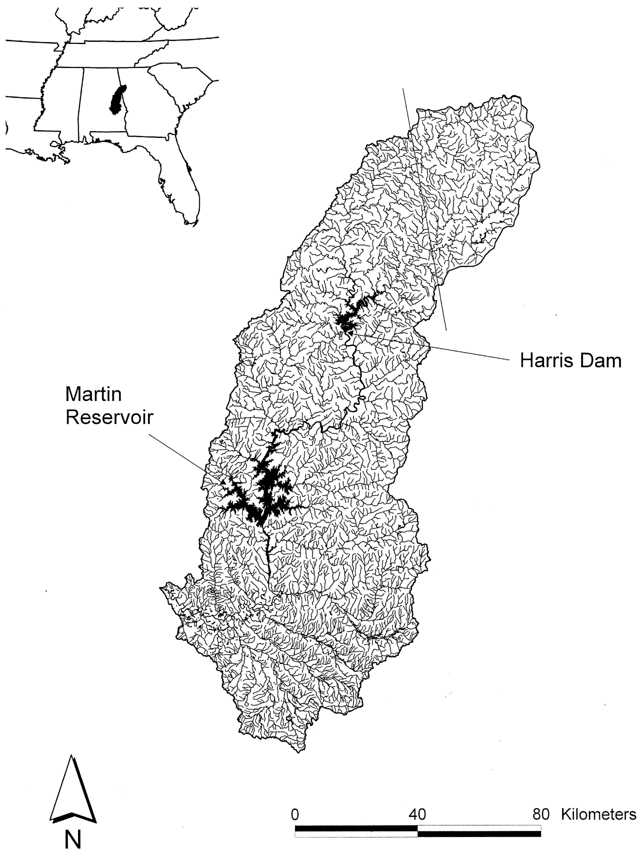

Figure 1. Tallapoosa River system, Alabama and Georgia. The flow-regulated reach we studied between Harris Dam and Martin Reservoir is indicated in bold black.

Dam and terminating 78 km downstream in the headwaters of Martin Reservoir. Harris Dam was completed in 1982 and was constructed primarily for hydropower production. Other potential benefits of the dam include flood control, recreation, and increased real-estate values associated with the reservoir created by the dam.

The generating capacity of the project (135 MW) accounts for about 10% of the total capacity of the 11 privately owned hydropower dams in the eastern Mobile River drainage. Harris Dam is normally operated in a hydropeaking mode, in which water is released in pulses—typically for 4-6 hours—through one or two turbines, each with the capacity to pass 226 m^3/second. Power is typically generated once or twice daily, 5 days a week. During nongeneration periods, the U.S. Federal Energy Regulatory Commission (FERC) license for Harris Dam requires that flow at a gauge 22 km downstream from the dam not be permitted to fall below the pre-dam, historic-record low flow (1.27 m^3/s). As a result of the hydropeaking operation, the flow regime through the study reach typically fluctuates between extreme low flows and high flows corresponding to patterns in power generation (Fig. 2). Altering the peaking operation could threaten the power utility's flexibility to provide and sell electricity on demand during periods of peak consumption. Changes in dam operation could also affect water levels and thus values for users in the reservoirs, particularly in Harris Reservoir.

At issue is the effect of the hydropower operation at Harris Dam on values associated with the general health of the Tallapoosa River ecosystem and with recreation on the river. The primary conservation concerns are that the regulated flow regime threatens to extirpate native biota. The river reach downstream from Harris Dam represents one of the longest and highest-quality segments of Piedmont river habitat remaining in the Mobile River drainage, one of the most biologically diverse river drainages in North America (Lydeard & Mayden 1995; Mettee et al. 1996; Neves et al. 1997). The native fish assemblage of the upper Tallapoosa includes at least 57 species (Mettee et al. 1996), including at least 5 species

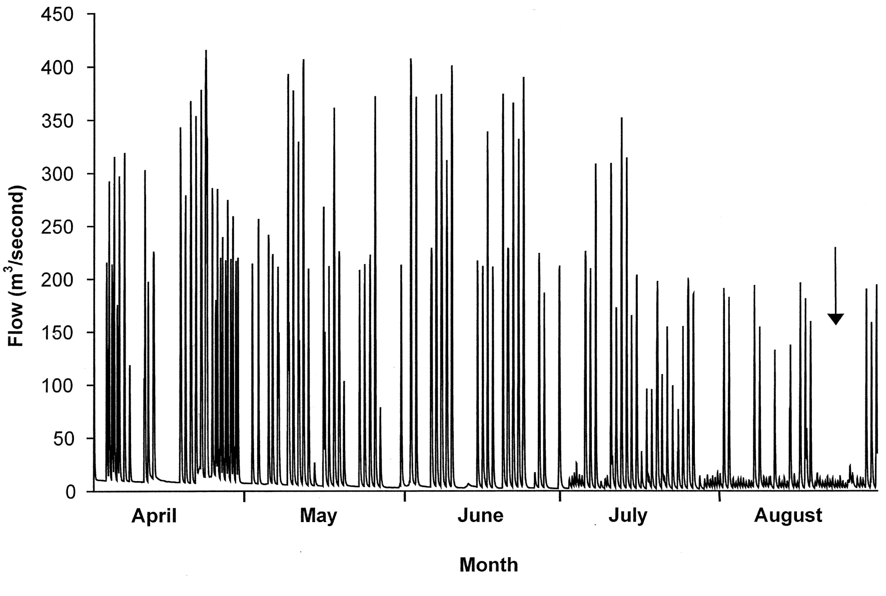

Figure 2. Hourly flows recorded from 1 April to 31 August 1995 at U.S. Geological Service gauge 02414500 located 22 km below Harris Dam on the Tallapoosa River. Arrow indicates a 10-day period of nongeneration at the dam.

endemic to the Tallapoosa River system. The invertebrate fauna is less well known, but the fine-lined pocketbook (*Lampsilis altilis*), which is listed as threatened under the U.S. Endangered Species Act, and at least two endemic species of crayfishes occur in the upper Tallapoosa system (Hobbs 1981; Johnson 1997). The river reach between Harris Dam and Martin Reservoir contains extensive shoals, river habitat features that characteristically support high faunal diversity and that have been replaced by impoundments through much of the southeastern United States. Shoals in the downstream portion of the study reach support populations of shoal lily (*Hymenocalis coronaria*), a river species that has been eliminated from portions of its native range by impoundment. The entire fauna and flora native to this portion of the Tallapoosa system are potentially affected by how Harris Dam is operated.

Recreational boaters and anglers express concern that the extreme flow fluctuations caused by hydropeaking limit their access to the river and may be detrimental to fish populations. Prior to construction of Harris Dam, the study reach supported productive sport fisheries for black basses (*Micropterus* spp.) and catfishes, primarily channel catfish (*Ictalurus punctatus*) and flathead catfish (*Pylodictis olivaris*) (D. Catchings, personal communication). River fisheries have been valued at more than $426 million/year in Alabama (U.S. Fish and Wildlife Service & U.S. Bureau of the Census 1998). A decline in sport-fish populations and loss of access to the river because of inhospitable flow regimes has been a major concern since construction of Harris Dam (U.S. Fish and Wildlife Service 1987).

Therefore, the operation of Harris Dam is a management issue for a diverse group of stakeholders. Potential management objectives include (1) conserving native aquatic assemblages, (2) maintaining viable river sport fisheries, (3) supporting boating and other river recreation, (4) providing for economically viable power generation, (5) maintaining values for reservoir users on both ends of the reach, and (6) avoiding damage to archeological and historical features on lands adjacent to the river. The last objective applies primarily to land owned by the U.S. National Park Service (i.e., Horseshoe Bend National Military Park) located in the lower portion of the regulated reach. Stakeholders supporting the other five objectives include state and federal natural-resource agencies (objectives 1, 2, 3, and 5), the power utility that owns Harris Dam (objective 4), environmental and river-advocacy groups (i.e., nongovernmental organizations, objectives 1, 2, and 3), reservoir homeowners and users (objective 5), and the general public (potentially supporting all objectives). Reaching agreement among stakeholders on actions to maximize conservation potential downstream from Harris Dam will require, at minimum, clear evidence of the effects of the present and of alternative regulated-flow regimes on river biota.

Effects of Present Management Regime on River Biota

Dam operations affect at least two biologically important physical characteristics of the Tallapoosa River: instream

Table 1. Changes in annual flow characteristics for the Tallapoosa River (U.S. Geological Survey gauge 02414500), comparing flows before construction of Harris Dam (1924–1980) with those after (1984–1996).[a]

Flow characteristic	*1924–1980*	*1984–1996*	*Change (%)*
November average daily flow (m^3/second)	30.5	51.9	70
April average daily flow (m^3/second)	119.8	70.0	−42
Low-flow extremes (m^3/second)			
1-day minimum	9.3	3.1	−67
3-day minimum	9.8	4.3	−56
7-day minimum	10.8	6.0	−44
Base flow (7-day low/average annual flow)	0.13	0.09	−31
Date of minimum flow	23 September	30 August	−9
High-flow extremes (m^3/s)			
1-day maximum	762	481	−37
3-day maximum	606	434	−28
Low-pulse frequency (no./year)	8	41	412
Low-pulse duration (days)	9.4	2.7	−72
High-pulse frequency (no./year)	13	28	115
High-pulse duration (days)	5.5	3.3	−40
Daily fall rate (m^3/second)[b]	−16.4	−26.1	59
Flow reversals (no./year)	101	184	82

[a] *Median values are shown for flow parameters that exhibited statistically significant differences ($p < 0.05$) between pre-dam and post-dam regimes (Wilcoxon two-sample test). Values were calculated with Indicators of Hydrologic Alteration software, with pulses defined as above seventy-fifth (high-pulses) and below twenty-fifth (low-pulses) percentile flows calculated for the pre-dam period (Richter et al. 1996).*

[b] *Average rate of decline in daily flow.*

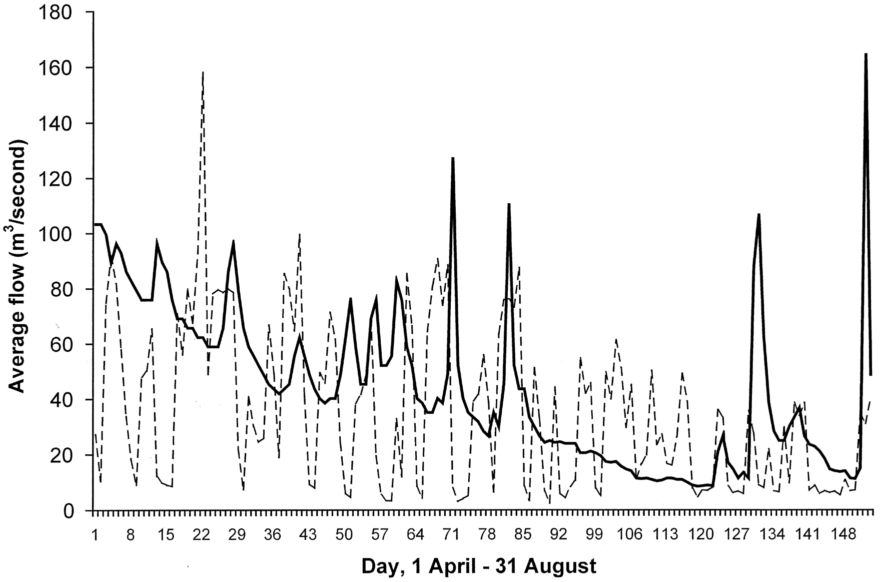

Figure 3. Daily flow patterns in pre-dam (1952, solid line) and post-dam (1995, broken line) conditions. Daily flows are plotted for 1 April to 31 August in each year. Average flows were similar between 1952 and 1995 (72.6 and 70.7 m^3/second, respectively) and approximated the average annual flow for the post-dam period (72.6 m^3/second).

flow and water temperature patterns. Analysis of pre-dam and post-dam daily flow records demonstrates strong effects of the dam on the Tallapoosa River flow regime (Table 1). In particular, low flows are lower and more frequent, and flow conditions are less stable (Table 1, Figure 3). Post-dam average daily low flows are as much as 67% lower (1-day minimum) than during the pre-dam period. The post-dam frequency of low-flow pulses is over 400% greater than in the pre-dam period (Table 1). High-flow pulses also occur more frequently in the post-dam regime, and average durations of low- and high-flow pulses are significantly shorter than during the pre-dam period (Table 1). Thus, although average annual discharge has changed <3% between pre- and post-dam periods, timing and variability in discharge has been altered considerably.

Flows are less stable, whether measured at hourly or daily time steps. Hourly data illustrate fluctuations from pulsed hydropower releases (Fig. 2). Daily data smooth hourly fluctuations but elucidate the loss of prolonged periods of stable or gradually changing flow (Fig. 3). Decreased flow stability reduces the temporal stability of biologically critical habitats, generally to <35% of habitat stability in an unregulated segment of the river (Freeman et al. 2001). Under present dam operations, the only periods of prolonged habitat stability occur during extended periods of nongeneration at the dam and are coincident with flows as low as the pre-dam annual minimum lows. An example occurred in August 1995 (Fig. 2), when hydropeaking was curtailed for as long as 10 days. Under the pre-dam regime, in comparison, stable, low-flow pulses exceeding 20 days duration occurred in 52% of years. Under the post-dam regime, extended periods of nongeneration occur most frequently during summer months in years with low rainfall.

Water temperatures measured approximately 22 km downstream from Harris Dam show an effect of flow regulation on thermal patterns during spring and summer. We used a submersible data logger (Onset Corporation, Bourne, Massachusetts), placed near the bank at a depth of 1.5 m during low flow, to collect hourly temperature data. Records for 115 days from May to September in 1998 showed that water temperature dropped by as much as 10° C when water was released at the dam for power generation (Fig. 4). The result was a pattern of lower temperatures (minimum, maximum and average) and higher diel fluctuations on days with power generation than on days with no generation (generally weekends). In 1998 the differences between generation and nongeneration days were greatest in May (average daily temperature = 21.4° and 24.4° C, respectively) and least in August (25.6° and 26.3° C). Reduced generation effects on temperature in late summer may have resulted from warmer reservoir temperatures or withdrawal at the dam from higher water strata relative to the thermocline. However, the drop in temperature resulting from power generation following 1 or more days of nongeneration remained large (5–9° C) through September.

Studies conducted over various portions of a 15-year period (1983–1998) have documented a number of probable faunal responses to flow alteration in the regulated reach below Harris Dam in the Tallapoosa River. Fish species diversity is diminished near the dam (Pierson et al. 1986), where low, nongeneration flows desiccate portions of the channel. Although native fishes persist in the regulated reach, fish abundances are depressed at locations throughout the regulated reach compared with unregulated reaches upstream (Travnichek & Maceina 1994; Costley 1998; Nash 1999; Freeman et al. 2001). Fishes with lower abundances in the regulated reach include riverine suckers (*Moxostoma* spp. and *Hypentelium etowanum*; Travnichek & Maceina 1994; Costley

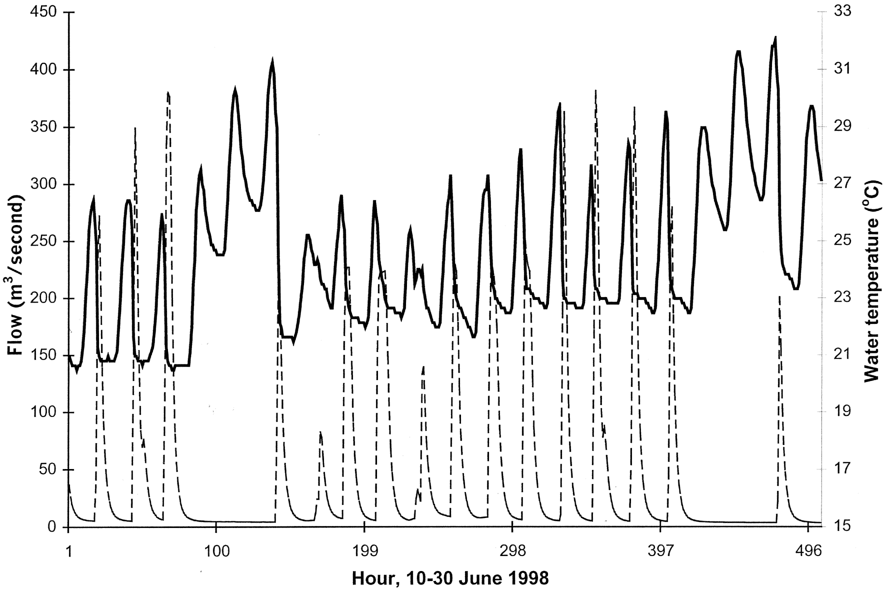

Figure 4. Water temperature (solid line) in relation to flow variation (broken line) at a study site located 22 km below Harris Dam on the Tallapoosa River. Data are 504 hourly values recorded for a representative 20-day period. Temperature data show diel variation and effects of pulsed-flow increases, except during two 2.5-day periods lacking power generation at the dam.

1998; Freeman et al. 2001), black basses (E. Irwin, unpublished data), and at least seven minnow (Cyprinidae) and darter (Percidae) species (Freeman et al. 2001). Mussel species richness also appears low in the regulated reach: Johnson (1997) collected only a single native mussel species at one location in the mainstem downstream of Harris Dam, whereas at least four other species persisted in the upper Tallapoosa system (Johnson 1997). Populations of shoal lilies appear to have been negatively affected by the extreme water fluctuations associated with the dam operation (Davenport 1996).

We hypothesize that (1) depleted low flows, (2) flow instability, and (3) thermal-regime alteration resulting from pulsed hypolimnetic releases at Harris Dam are the features most responsible for faunal changes in the regulated reach. With respect to low flows, we hypothesize that extreme low flow during nongeneration periods limits habitat suitability for riverine biota. During nongeneration periods, channel areas near the dam become exposed, which limits habitat suitability for organisms unable to migrate to refugia between water releases. Channel storage and tributaries augment flow in the channel farther downstream, maintaining flow in shallow areas in the lower half of the reach except at the lowest flows experienced. Pool habitats become essentially lentic throughout the regulated reach during prolonged low flow periods, which limits habitat suitability for filter-feeding insects and drift-dependent fishes. Depressed productivity and food-web alteration, resulting from periods of channel desiccation and low current through pools, likely contributes to reductions in fish growth (e.g., in catfishes; Nash 1999), especially fishes that typically forage in pool habitats.

Flow instability caused by daily peaking operations likely affects the reproductive success and recruitment of many fishes. We have measured increased juvenile fish abundances when the spring-summer season included prolonged periods of stable, nongeneration flows (Freeman et al. 2001), and we hypothesize that flow fluctuations caused by typical peaking operations limit the reproductive success of a variety of fishes in the regulated reach.

We hypothesize that lowered temperatures resulting from pulsed hypolimnetic releases likely delay spawning periods, impede hatching success, and decrease rates of larval development. During extended nongeneration periods, as sometimes occur during summer, elevated water temperatures may actually decrease larval development periods for species able to spawn during these occasional stable flow intervals. Finally, with respect to effects on river fisheries, we hypothesize that fluctuating water levels and low population sizes of target species limit angler access and catch rates.

Management Options and Uncertainty

These hypothesized links between hydrologic and thermal alteration and effects on biota suggest at least two management changes likely to benefit Tallapoosa River fishes. First, increasing the flow level during nongeneration periods should have positive effects on the abundance, diversity, and growth of fishes (and likely on other flow-dependent biota), as has been observed when minimum flows were increased in other regulated rivers (Weisberg et al. 1990; Weisberg & Burton 1993; Travnichek et al. 1995). Secondly, providing periods of stable flow without pulsed intervals of power generation should increase opportunities for fish to spawn and larvae to develop successfully. These actions could return some of the most altered aspects of the flow regime—minimum flows, low-pulse duration (Table 1)—nearer to pre-dam conditions.

The difficult management questions concern how much water should be released during nongeneration periods and how long stable-flow intervals should last (and at what flow levels and frequency) to benefit the riverine ecosystem. The answers depend on the underlying relations between biological processes and flow conditions. For example, one management goal is to maintain or enhance the diversity of native fishes. However, relations between flow regime and the diversity of native fishes downstream from the dam are not well defined. Fish diversity may increase asymptotically with increased base flows or only after minimum continuous flows exceed a threshold (e.g., that provides a minimum required level of instream habitat). Increasing base flows may have negligible benefits for biotic integrity if other features of the altered flow regime strongly limit habitat suitability. It is also conceivable that fish diversity could decline coincident with increased nongeneration flows. For example, the positive effect of increased instream habitat with higher base flows could be negated for some native, warm-water fishes by the effects of lower water temperature (caused by water release from the reservoir hypolimnion).

Similar questions apply to length of stable-flow periods. The negative effects of fluctuating flows on river fauna have been widely documented (Cushman 1985; Bain et al. 1988; Kinsolving & Bain 1993; Bowen et al. 1998*b*). We do not know, however, what duration, frequency, or interannual variability in periods of stable flow are necessary to sustain diverse faunal assemblages in regulated systems. Furthermore, we do not know the relative importance of flow stability and seasonality. For example, would a period of low, stable flows typical of pre-dam summer conditions benefit spring-spawning fishes, or does faunal restoration also require restoration of seasonal high-flow pulses?

The power company and regulators face at least three options for future flow management of the Tallapoosa River below Harris Dam. All parties may elect to impose no change in present operations, which is unlikely to be a long-term solution. State and federal resource agencies, angler groups, and nongovernmental organizations have expressed dissatisfaction with present low flows during nongeneration periods. Resource agencies could negotiate with the power company to provide a nongeneration release and/or periods of stable flow to facilitate fish reproduction. Negotiations would be based necessarily on uncertain relations between fauna and flow characteristics and could result in an agreement that fails to accomplish management goals. A third option would be for stakeholders to agree to a process of adaptive management.

Case for Adaptive-Flow Management

Decoupling relations among biological responses and specific components of the hydrologic regime requires manipulation of certain flow features and rigorous monitoring and hypothesis testing. Only by varying manageable-flow features and quantifying biotic responses can we gain understanding of how best to balance biological conservation with human uses such as hydropower production. The alternative approach of negotiating fixed changes, such as an increased continuous base flow, eliminates the opportunity for gaining knowledge that could generally improve the management of regulated rivers.

Implementing an adaptive approach to managing the flow regime of the Tallapoosa River downstream from Harris Dam could improve conditions for native biota, allow evaluation of alternative hypothesized links between flow regimes and biota, and thereby provide knowledge to guide flow management elsewhere. An adaptive approach could also facilitate inclusion of diverse stakeholders, such as boaters, anglers, reservoir users, and conservationists, in a broader consideration of the potential effects of alternate management strategies. Stakeholders would have to come to agreement on management objectives, including river conservation objectives, before continuing the adaptive process. The approach would also require that stakeholders agree to initial changes in current operations, support assessment of effects on biota, and implement iterative management changes based on what is learned by testing hypotheses that explain how the system works. Based on our interpretation of the biological data, we propose the following steps as part of an adaptive-flow management approach for the Tallapoosa River.

(1) Stakeholders Develop and Agree to Management Objectives

Examples of natural-resource objectives include (1) restoration of native fish species richness in the regulated segment to 90% of pre-dam richness, when assessed over a specified period; (2) attainment of biotic integrity scores (i.e., as assessed through a multimetric index such as the index of biotic integrity) of at least "good" in most years (Bowen et al. 1998*a*); (3) increase abundance of imperiled native species, such as the shoal lily, to a specified level; (4) increase angler catch rates of sport fishes to a level approximating pre-dam catch rates. Power-production objectives likely would include limits on acceptable losses in generation capacity or flexibility, and reservoir users may seek to limit the detrimental effects of dam operations on reservoir recreation and property values. It would be critically important at this step for stakeholders to come to agreement on the legitimacy of a set of management objectives. Therefore, power interests and reservoir users must agree to the value of restoring some level of ecological function to the river, and river conservationists must agree that some level of power production and reservoir recreation also represent legitimate uses of the altered Tallapoosa River system.

(2) Develop Models Relating Dam Operation to Management Objectives

Use existing data—such as relating instream habitat to flow levels (Bowen et al 1998*b*), and juvenile fish abundance (Freeman et al. 2001) to length of stable flow periods—to construct alternative hypotheses of faunal dependence on those flow-regime features that can be altered by changing dam operations. The most prominent features are base flow and magnitude, frequency, and duration of low-flow pulses. Hypotheses are used to predict faunal responses to alternative flow manipulations and will be quantitatively evaluated with data obtained through monitoring. Hypothesized responses of biota to flow changes, along with dam-operation effects on other management objectives (e.g., power production, reservoir levels, riverine recreation), may be incorporated into simulation models, such as probabilistic networks (Lee & Rieman 1997). Stakeholders would use these models to examine predicted outcomes and the associated degree of uncertainty of alternative management actions with respect to agreed-upon management objectives.

(3) Implement a Change in Dam Operations

The most obvious change is providing a continuous water release (i.e., base flow) at the dam. The initial base-flow level will likely be based on engineering constraints, but should be sufficient to maintain flowing water conditions in pools and riffles throughout the regulated reach. The initial level could be based on an analysis of instream habitat availability (or, for example, recreational value) in relation to flow, an approach widely used in instream flow negotiations (Stalnaker et al. 1995). Stakeholders could agree to implement a seasonally variable base flow, or a base flow that varies with changes in inflow to the reservoir (and thus with rainfall), to evaluate hypotheses addressing faunal tolerance for periods of reduced base flows. Discovering that infrequent or seasonally specific periods of reduced base flows have negligible effects of riverine fauna could allow the power company greater flexibility in operating the dam to meet power-generation needs and to provide higher base flows in other periods.

A second, obvious flow manipulation is to provide periods with continuous flows uninterrupted by hydropeaking during spring and summer. The initial duration of stable flow windows could be based on median larval development time for dominant native fishes. Spring and summer stable-flow windows should be provided together in the same year and in different years to allow evaluation of species responses to stable-flow seasonality.

(4) Use Externally Reviewed Study Design to Address Hypotheses

Biological variables and flow and temperature regimes should be monitored along with other measures of management objectives. In the case of the Tallapoosa River, baseline data for fish species richness and abundances in the regulated reach and in an unregulated site upstream from Harris Dam (Freeman et al. 2001) would allow for a before-after-control-impact (Underwood 1992) design to assess statistically significant faunal changes in response to flow manipulation. Temperature should also be monitored in relation to flow regime. It may be necessary to mitigate low temperatures at the dam—for example, if a continuous base flow holds downstream water temperatures below levels required to initiate spawning by native fishes. All stakeholders should participate in the monitoring program at minimum by understanding the study design, data collection, and implications of alternative outcomes.

(5) Evaluate Biological Responses and Costs and Benefits to the Stakeholders

Biological hypotheses should be modified based on data collected during a 3- to 5-year period of experimental flows, and revised models should be used to predict outcomes of future flow manipulations. Flow regimes should be modified as needed based on attainment of management objectives during the evaluation period. If all objectives are attained, future flow adjustments may become necessary to mitigate the effects of other watershed changes that affect flow regimes, such as land-use changes that affect runoff, construction of additional dams in the watershed, prolonged drought, or climate change.

Discussion

The use of adaptive management to conserve native biota and meet other stakeholder objectives for the Tallapoosa River would represent a substantially new path for management of flow-regulated rivers in the southeastern United States. Management agencies and other stakeholders would shift their focus from flow amounts to resource-oriented objectives, accepting the possibility that a return to pre-dam flow averages may not be the only way or even an effective way to restore biological resources in a highly altered flow regime. Utilities and water developers would, in turn, forgo multidecade certainty in downstream flow requirements to participate in a more meaningfully balanced approach to achieving multiple uses in managed river systems. This shift would be driven by recognition of the uncertainty in responses of the river ecosystem to alternative management actions.

An adaptive approach to flow management offers a framework for improving conditions for river biota, including imperiled species and fishery resources, that could advance conservation beyond the current state of negotiated flow settlements. In adaptive-flow management, developers, regulators, and other interest groups would establish management objectives and then negotiate a starting point rather than a final flow solution designed to meet all parties' needs. From a conservation perspective, the problem with the latter approach is that biologists cannot confidently prescribe flow parameters for altered systems that will sustain native communities. Consequently, natural-resource managers negotiate for and accept flow conditions that provide minimal safeguards for biota. Required minimum flows below dams are prime examples of minimal safeguards. Even though the ecological importance of natural levels of flow variability is well established (Sparks 1995; Poff et al. 1997; Richter et al. 1997), the scientific community lacks the data to prescribe a level of similarity to the natural condition sufficient to protect biota. The best alternative left to resource managers often is a low-flow requirement that prevents streambed desiccation but cannot provide the spatial or temporal variability in habitat theorized as essential for sustaining natural assemblages (Sparks 1995; Poff et al. 1997). To advance conservation in managed river systems, we require data on the responses of biota and ecological processes (e.g., productivity) to incremental changes in natural flow regimes (Poff et al. 1997). An adaptive approach allows managers and scientists to acquire data on the biological consequences of different levels of flow alteration while keeping open the possibilities for continually improving river management for biota.

Adaptive management is unlikely to appear advantageous to the power industry (or other water-resource developers) unless they can be assured of limits to their costs, including the uncertainty of future yield. Countering the cost of uncertainty, natural-resource proponents could offer to accept a more altered flow condition as a starting point for adaptive management than they would accept under a negotiated flow settlement. The risk to natural-resource managers is that the starting conditions may not be sufficient to support the native river biota. In the context of improving conditions in an already altered system, this risk is relatively small. A flow regime that proves insufficient contributes to our knowledge of biological processes in altered systems and can be incrementally improved in the adaptive-flow management process.

The Tallapoosa River is not unique in its potential to benefit from an adaptive-flow management framework. Like the Tallapoosa River, many river systems have strongly altered flow regimes but still harbor remnants of native biotic assemblages. Hydropower relicensing procedures (e.g., required for 25 dams by 2009 in Alabama and Georgia alone) and reevaluation of priorities for operation of federal dam projects (e.g., U.S. Army Corps of Engineers 1998) provide opportunities to improve management beyond simply increasing minimum flow requirements. Efforts to restore striped bass (*Morone saxatilis*) in the Roanoke River, Virginia, provide an example of the potential efficacy of an adaptive approach (Rulifson & Manooch 1990). In this case, biologists used long-term data on juvenile abundance in conjunction with flow data to hypothesize how dam operations were limiting recruitment of striped bass. Alternative-flow regimes designed to lessen effects on striped bass were implemented along with continued monitoring to evaluate the hypothesized relations between juvenile recruitment and flows.

The U.S. Federal Energy Regulatory Commission has begun to encourage an alternative dam-licensing process (U.S. Federal Energy Regulatory Commission 1997) that involves all stakeholders from the beginning of the process in a collaborative effort. Stakeholders and the license applicant work together to identify resource goals, concerns, and agency statutory responsibilities with respect to the effects of proposed and alternative actions. This process, while not necessitating an adaptive management approach, may provide such an opportunity where substantial uncertainty exists about the effects on key resources of alternative dam operations. One of the first implementations of the alternative licensing process resulted in license provisions aimed at protecting an imperiled redhorse sucker (*Moxostoma robustum*) below a hydropower dam on the Oconee River, Georgia. These provisions included alteration of hydrogeneration schedules during the spring spawning season for the sucker and monitoring of population responses and juvenile recruitment (FERC project 1951–037). A flow-advisory team that includes agency, academic, and power utility representatives reviews results and may recommend additional changes in dam operation as necessary to insure conservation of this species.

The most viable alternative to adaptive management for the Tallapoosa River below Harris Dam is probably a negotiated (or FERC–mandated) flow settlement between the agencies and the power utility. In this case, the best outcome would be for post-implementation studies to show benefits of the new flow regime to native fauna (e.g., study in the lower Tallapoosa River; Travnichek et al. 1995). Although a positive outcome, this approach eliminates the possibility of gaining information on underlying relations between biota and flow alteration. In the case reported by Travnichek et al. (1995), for example, providing a minimum-flow equivalent to approximately 25% of average annual flow resulted in increased fish abundance and diversity at one of two study sites downstream from a dam on the lower

Tallapoosa River. Whether the same benefits could be gained by a lower minimum flow or how additional flow adjustments could benefit other fauna including fishes at the second, more downstream site are unknown. Although this case represents an important improvement in flow management, the information offers only limited guidance for managing other systems.

An adaptive management framework is the best option for improving flow regimes for native biota while gaining information critical to guiding management decisions in other flow-regulated rivers. The greatest challenge to implementing adaptive-flow management in this case and elsewhere likely involves building the necessary communication, trust, and vision among the stakeholders to allow an adaptive, iterative decision process that both addresses and entails uncertainty in future conditions.

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