COLORADO RIVER RECOVERY PROGRAM Project No.: 161

FY-2010-2011-2012 SCOPE OF WORK for:

Population dynamics modeling of introduced smallmouth bass

Lead Agency: Colorado State University

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Category:
_ Ongoing project
_ Ongoing-revised project
_Requested new project (extension)
_ Unsolicited proposal

Expected Funding Source:
X Annual funds
_ O&M funds
_ Capital funds
_ Other (explain)

I. Title of Proposal: Population dynamics modeling of introduced smallmouth bass, Upper Colorado River Basin

II. Relationship to RIPRAP: General Recovery Program Support Action Plan: *See RIPRAP at* http://www.coloradoriverrecovery.org/documents-publications/foundational-documents/recovery-action-plan.html*]*

III. REDUCE NEGATIVE IMPACTS OF NONNATIVE FISHES AND SPORTFISH MANAGEMENT ACTIVITIES (NONNATIVE AND SPORTFISH MANAGEMENT)

- III.A.2.c. Evaluate the effectiveness (e.g., nonnative and native fish response) and develop and implement an integrated, viable active control program.
- III.A.2.c.3. Level II synthesis: assimilate Level 1 syntheses into a basinwide and population scale analyses of effectiveness of nonnative fish management. (YS G-3)

III. Study Background/Rationale:

Introduction and establishment of non-native fish in western rivers of the USA is a major threat to conservation of native fish assemblages (Minckley and Deacon 1968; Stanford and Ward 1986; Moyle et al. 1986; Carlson and Muth 1989; Minckley and Deacon 1991; Olden et al. 2006). In the upper Colorado River Basin, non-native fish invasions began over 100 years ago, with introduction of channel catfish *Ictalurus punctatus*, common carp *Cyprinus carpio*, and salmonids for sport fishery purposes. In the 1970's, small-bodied species such as red shiner were expanding rapidly (Vanicek et al.1970; Holden and Stalnaker 1975a and 1975b), and potential negative effects of that species and other small-bodied fishes have been documented (Haines and Tyus 1990; Dunsmoor 1993; Ruppert et al. 1993; Muth and Snyder 1995; Bestgen et al. 2006a). More recently, piscivores such as smallmouth bass *Micropterus dolomieu* and northern pike *Esox lucius* have established and are common in the lower Yampa River, the upper and middle Green River basins, and the upper Colorado River (Wick et al. 1985; Anderson 2002, 2005; Bestgen et al. 2006b; Burdick 2008).

The predatory threat of large-bodied piscivorous taxa such as northern pike and smallmouth bass is substantial. For example, based on results of a bioenergetics model, Johnson et al. (2008) ranked smallmouth bass as the most problematic invasive species because of their high abundance, habitat use that overlaps with most native fishes, and capability to consume a wide variety of life stages of native fishes in the Colorado River Basin. Expanded populations of piscivores such as smallmouth bass are a major impediment to conservation actions aimed at recovery efforts for the four endangered fishes in the Upper Colorado River Basin: Colorado pikeminnow *Ptychocheilus lucius*, razorback sucker *Xyrauchen texanus*, humpback chub *Gila cypha*, and bonytail *Gila elegans* (U.S. Fish and Wildlife Service 2002a, b, c, d). In response to the predatory threat posed by non-native smallmouth bass, the Upper Colorado River Recovery

Implementation Program initiated efforts to control such species via mechanical removal in affected stream reaches. Interim goals for removal actions have also been established for the Yampa River and include reduction of smallmouth bass to <30 adult bass/mile in the Yampa River and increasing the composition the small-bodied fish community to 10-30% native fishes. To date, substantial information has been collected on distribution, population abundance, size structure, and movements of smallmouth bass concurrent with removal actions throughout the Upper Colorado River Basin. Removal efforts implemented vary in intensity and effectiveness across stream reaches where invasive piscivores exist, but only a few areas are thought to approach levels of removal needed to enhance survival prospects for native fishes (Badame et al. 2008; Burdick 2008; Hawkins et al. 2009). Further, a clear understanding of population level effects of removal actions limits the ability of managers to understand effectiveness of removal programs and formulate a comprehensive control strategy that will effectively reduce populations of smallmouth bass and enhance prospects for recovery of native fish populations.

A preliminary population dynamics model developed Haines and Modde (2007) showed promise to better understand the levels of removal required to reduce abundance of smallmouth bass in the Yampa River. We propose to expand the scope of a similar population dynamics model using data collected in the system, the summary database of removal information, and our own unpublished information, to develop a comprehensive model to understand factors that affect smallmouth bass population dynamics in the Upper Colorado River Basin. Our basic approach will be to build a population dynamics model with several seasonal and life stage components and parameterize it with existing data. Implementation of the model with different inputs will allow managers to assess the efficacy of present removal efforts to reduce smallmouth bass abundance in the basin, explore means to best achieve long-term reductions via removal efforts, and explore more effective means to achieve recovery of native fishes. Influence of important environmental factors on smallmouth bass abundance dynamics will allow simultaneous assessment of trajectories of bass populations under different levels of removal effort.

IV. Study Goals, Objectives, End Product:

A. Goal: Our goal is to develop a comprehensive age- or size-structured model to understand factors that affect smallmouth bass population dynamics in the Upper Colorado River Basin.

B. Objectives: 1) Assess effectiveness of the Recovery Program's removal efforts to date; and, 2) Predict the Recovery Program's ability to achieve removal targets. **A new sub-objective for FY 2011-2012 is to incorporate into this analysis all 2009 and 2010 smallmouth bass removal data. To accomplish this we request an additional $60,000 for the smallmouth bass synthesis project. This would allow incorporation of the 2010 data, completion of incorporation of the 2009 data, and completion of**

the Elkhead escapement analysis. Addition of the 2010 data will likely be more streamlined than for past data, but all abundance estimation models must be re-run because data are borrowed across all years, which represents additional time expenditure. We have already included portions of the 2009 data, but some of it must yet be added to the database and incorporated into abundance estimation modeling. The unanticipated expansion of time and effort required for the Elkhead Reservoir bass escapement analysis is an additional cost. Finally, we spent much more time than anticipated (nearly six months) getting the original data files into usable form, which was necessary but deteriorated the amount of funding available for the tasks outlined in the original scope of work. Costs for all elements are figured into the expanded budget amount (last page of scope of work).

Our plan would be to revise the abundance estimates first, complete the Elkhead escapement analysis next, in part independently from the abundance estimates task by using Gary White, and then complete the population dynamics portion of the model. However, it is difficult to determine what the timeline impact will be for delivery of the final products because we do not know when we will get the data files needed for this expanded abundance estimate analysis. Thus, we will assume for now that the timeline for some of the final products would be pushed out as much as 9-12 months, understanding that some pieces of the project will be completed well before that. Until those 2010 data are obtained and incorporated, we will continue to work on the population dynamics portion of the project.

Yet another objective for FY 21012, and the subject of a new January 2012 modification, is to enhance analyses described above. Potential tasks include: 1) inclusion of 2011 data in abundance estimates, 2) assess existing non-native fish database for use by biologists in the Recovery Program and enhance capabilities and user-friendliness of that database, 3) provide additional integration of population dynamics modeling aspects by Program participants into the management activities, 4) use structured decision-making to assess removal goal success criteria, and perhaps other items. The priority of these items, how many can be accomplished, and the timeline for such will be discussed and mutually agreed upon by Recovery Program participants and the project Principal Investigators. Deadlines discussed above for products for the first phase of the project remains the same. The priorities for additional tasks should consider the duration of the availability of post-doc Breton, who is applying for other positions at this time.

C. End Products: See item VIII.

V. Study area: Upper Colorado River Basin – excluding the San Juan Sub-basin.

VI. Study Methods/Approach:

We propose to expand the scope of recent population dynamics models using data collected in the system, the comprehensive non-native fish removal database, and our own unpublished information. Our goal is to develop a comprehensive age- or size-structured model to understand factors that affect smallmouth bass population dynamics in the Upper Colorado River Basin. Our model will include density-dependent feedback, and means to assess affects of environmental factors and management actions that can be manipulated independently of each other. We also propose to address uncertainty and variability in the parameters and relationships in the model to address its influence on the outcomes and predictions.

We propose that the actual software used to implement the model should be discussed among the PI's and participants of the Recovery Program before the model is developed. These discussions should focus on the features of a final product that will result in a powerful and flexible, yet easy-to-use model that will be useful to managers and biologists involved in the recovery effort.

VII. Task Description and Schedule

Objective 1: Assess effectiveness of the Recovery Program's removal efforts to date:

Task 1: Age-structured modeling approach and development.

Using the full Recovery Program database, develop an age- or size structured stock assessment model to evaluate past exploitation and future exploitation strategies on the smallmouth bass population.

Response

Model Overview and Approach

We propose to develop an age- or size-structured model for smallmouth bass and a detailed description of the model is below. As requested by the Recovery Program, we will develop a model that describes the influence of exploitation (electrofishing removal) on smallmouth bass population parameters. The basic model will be similar to the model produced by Haines and Modde (2007) based on an earlier model (Peterson and Kwak 1999). Our model will also include the option of density dependent feedback as recommended for population assessment models (White 2000); however, we propose to separate the effects of environment (often density-independent effects) from the equations describing density dependence so they can be independently manipulated. By making each variable a separate component of the model, we can independently assess the influence of environmental variables on population parameters. We also propose to include more life stages to examine the potential effects not included in the earlier models.

Another factor that we propose to address is uncertainty in the parameters and relationships in the model. In general, there are two types of uncertainty in these models; parameter and model uncertainty. Parameter uncertainty is associated variability in population processes, such as demographic and spatial variation, and with the precision and accuracy of sampling (White 2000).

Model uncertainty is associated with uncertainty in the structure of the mathematical expressions used to describe the population (Akcakaya et al. 1999), such as the form of density dependence. We propose to examine variability in the model to address its influence on the outcomes and predictions. We will parameterize the model with estimates derived from analysis of Upper Colorado Recover Program data and will use values from the literature only when necessary.

Equation fitting, survival estimation, and model selection using existing data will be implemented with SAS and program MARK (White and Burnham 1999). Several options exist for programming the population model. One essential element of the final product would be a user interface that would allow users to change life history parameters, environmental relationships, and forms of density dependence. We feel that the modeling options should be discussed among the PI's, the proposed Post-doctoral Research Fellow, and the participants in the Recovery Program before a final approach is implemented, which will ensure a powerful, yet use friendly product. Our general approach to each part of the life history and model variables is explained below.

Basic Summer Model **(Figure 1)**

The first matrix (spring pre-removal or N_t) represents the abundance in each age class in spring (April) just prior to removal efforts that is estimated from sampling data (Figure 1). Initially, the egg and fry stages will be zero until reproduction later in the summer. Removal takes place, which is represented by the second matrix (Numbers Removed or N_r). Subtracting these two matrices gives the abundance in each age class post removal for each month (N_{post}). The post-removal abundances are then multiplied by the appropriate probabilities in the Leslie transition matrix to predict abundances in the next estimation period (N_{t+1}). The simplified calculations are represented in the two equations below, where arrows represent vectors and the brackets represent a matrix. See Figure 1 for the detailed life history and matrices.

$$\vec{N}_t - \vec{N}_r = \vec{N}_{post}$$

$$\vec{N}_{post} \times [L_{summer}] = \vec{N}_{t+1}$$

Basic Winter Model **(Figure 2).**

The winter model takes the abundance is each age class at the end of summer and predicts overwinter survival into the next age class (Figure 2). Winter survival is from October-March (6 months). See Figure 2 for the detailed life history and matrices.

$$\vec{N}_{end\ of\ summer} \times [L_{Winter}] = \vec{N}_{end\ of\ winter}$$

<u>**Life History Parameters and Equations**</u>

Egg Production **(EP in summer transition matrix)**

Smallmouth bass are known to have repeated reproduction, and individual females can produce several cohorts of eggs over a spawning season (Pflieger

1966). Therefore, total fecundity per female is a product of the number of eggs/female (f) and the number of spawning attempts (T) and Egg Production (EP) is the total number of eggs produced in a population by all females;

$$EP = \sum_{i=4}^{K} f \times T$$

where i=age at maturity to maximum age (K) in the population.

Egg production may be density dependent (see model variables below) and we propose to examine the influence of density dependence on reproduction (Figure 3). Individual variation may also be important for reproduction. In some populations of smallmouth bass it appears that many males do not acquire nests and mate and many females also did not reproduce in a given year (Raffetto et al. 1990). Research examining variance in reproductive success has focused on evolutionary implications; however, large proportions of adult non-breeders in a population may influence the effectiveness of mechanical removal to reduce numbers of reproductive fish and reduce population fecundity. In a four year study it was estimated that only 11-75% of males and 16-74% of females reproduced in a given year (Raffetto et al. 1990). We feel it is important to assess the effect of non-breeding adults on population growth rate (λ) and will implement this in the model by varying the proportion of adults allowed to breed.

***Egg, Fry, and Age 0 Survival* (ES, FS, and A0 in the summer matrix, A0 in the winter matrix)**

These parameters in the basic model are survival rates from one time period to the next; however, they can be modified by model variables (potential environmental effects or management actions) such as nest disturbance, discharge, and temperature (see model variables below; Figure 1). Age-0 smallmouth bass can also be mechanically removed (Figure 1). Age-0 bass overwinter survival may also be important and is thought to be dependent on body size (Figure 2, Task 4). Overwinter survival may also be influenced by the severity of winter and related to water temperature and discharge (Figure 2, Task 4).

Age 1, 2, 3, and Adults

These four age classes in the summer model are subject to electrofishing removal (see model variables below; Figure 1). However, they do not move from one age class to the next in the summer period and no juvenile fish (1-3) mature (Figure 1). Overwinter survival of Age 1-3 individuals may also be influenced by winter water temperatures and discharge (Figure 2; see environmental relationships below and Task 4).

Model Variables

Density Dependence

Smallmouth bass have male parental care, and the number of eggs produced is probably also a function of the number of spawning sites available to males (Wiegmann et al. 1992). If spawning locations are limiting, then the number of eggs produced in the population probably has some upper limit. Although the relationship between spawning sites and egg production is probably unknown (see task 3 below), it is conceivable that spawning sites are limited relative to the number of males in the spawning population. If the number of spawning sites places an upper limit on egg production then the relationship between adult density and egg production should have a Beverton-Holt relationship (Figure 3). However, if males actively interfere with each other then the relationship between adult density and egg production may have a Ricker-type relationship with decreased recruitment at higher adult densities (Figure 3). Each of these relationships can be explored with the proposed model (Figure 1).

Although it is not represented in our basic model, density dependence has also been demonstrated in Age-0 smallmouth bass because of cannibalism by older age class juvenile fish (Dong and DeAngelis 1998). Cannibalism alters the density dependence from a Beverton-Holt- type relationship to Ricker-type density dependence (Dong and DeAngelis 1998). Similar relationships could occur between other age classes. For instance, Peterson and Kwak (1999) fit 14 years of data comparing adult stock density to Age-0 recruitment and used this relationship in an age-structured model to assess smallmouth bass population growth. Haines and Modde (2007) used a similar approach in modeling population responses in upper Colorado River smallmouth bass populations. For simplicity and brevity, we have not included these relationships in the figures 1 and 2 of our basic models; however, they will be considered.

Environmental Relationships (Figure 1, Cells 2, 3, and 5 summer and Cell 2 Winter)

Egg production and survival may be influenced by environmental variables such as discharge and temperature (Winemiller and Taylor 1982; Lucas and Orth 1995). For instance, low temperatures or high flows could delay reproduction, thereby reducing the number of spawning attempts during a spawning season (Graham and Orth 1986; Task 4 below). Fry and Age-0 survival are probably dependent on flows and temperature. Growth is also strongly influenced directly by temperature and flow and indirectly by the timing of spawning (Figures 4-7). If water temperature or discharge delay reproduction then Age-0 fish have a shorter growing season and will enter winter at a smaller size (Figure 4). Smaller body size at the beginning of winter probably directly influences overwinter survival of Age-0 fish (Figure 2, Cell 1) and it has been shown that survival of Age 1, 2, and 3 smallmouth bass is negatively related to variation in winter discharge (Sallee et al. 1991).

Effects of Mechanical Removal (Figure 1, Cell #4)

Mechanical removal is represented in the basic summer model (Figure 1). Removals are subtracted from the population at the beginning of each month. Removals affect the overall population size in each age class and the total egg production once adults start reproducing in the summer (See Task 2 below).

Nest Disturbance (Figure 1, Cell #1)

Egg and fry survival are both strongly dependent on male parental care. Disruption of spawning males that are actively guarding nests probably results in decreased egg or fry survival and abandonment of the nest by the male results in complete loss of offspring (Siepker et al. 2006). Seipker et al. (2006) estimated that 41% of largemouth bass that were electrofished from their nests, held for 30 minutes, and returned to the water abandoned their nests. They concluded that routine electrofishing for population assessment could negatively affect recruitment in largemouth bass. Therefore, it seems reasonable to explore effects that targeted electrofishing has on disrupting smallmouth bass spawning and subsequent recruitment in the Upper Colorado River system.

Males might also abandon nests due to other disruptions that might occur, such as variable flow events. Studies of smallmouth bass in lake environments show that nest success was negatively related to the number of storm events (Steinhart et al. 2005). Nest success in smallmouth bass is also related to stream discharge. Reynolds and O'bara (1991) showed that smallmouth bass nest success was 73% in low water years but was reduced to 35% during a year with high and variable discharge. Mason et al. (1991) also showed that the best year smallmouth bass year classes were produced when flow was below normal.

Angling studies provide further evidence that disruption in male nest guarding might cause lower nest success. Nesting smallmouth bass are vulnerable to angling (Suski and Philipp 2004) and when removed from their nest by anglers and returned to the water may abandon their nest (Suski et al. 2003; Steinhart et al. 2005).

Spatial Structure and Metapopulation Dynamics

Spatially explicit age structured models have been developed to describe smallmouth bass population dynamics in a lake and modeling results suggest that the model was most sensitive to Age-0 (YOY) survival (Chu et al. 2006). As a result, they recommend that conservation efforts for smallmouth bass should focus on nesting habitat. We suggest that our proposed model be parameterized for specific areas such as Little Yampa Canyon and Lily Park in the Yampa River to understand the relative contributions specific areas have to the population growth of smallmouth bass (Figure 5). This would allow managers to begin identifying areas that may act as source populations and to further target management efforts. For instance, if population growth rates (λ) are high in some areas (sources, e.g., Little Yampa Canyon)) and low in others (sinks), then management efforts should focus on those areas that are indentified as sources (See objective 2, task 1).

Immigration (I) and emigration (E) can also be incorporated into the model by including age specific vectors for these parameters. The equation below shows N_I and N_E (numbers immigrating and emigrating) modeled after removal, survival, and reproduction have taken place. The equation is one example of how this could be accomplished and I and E could occur before removal or both before and after. If age-specific estimates of I and E are not available, estimates of total migration could be partitioned based on the relative numbers of fish in each age class.

$$\vec{N}_{post} \times [L_{summer}] = \vec{N}_{t+1} + \vec{N}_I - \vec{N}_E$$

Task 2: Did the Recovery Program have a significant population level impact on smallmouth bass?
Determine what effects may have been caused by human exploitation (electrofishing) on this smallmouth bass population. Explore potential impacts to size structure, population numbers, biomass, age/growth relationships, spawning success, recruitment success, or other parameters.

Response: The value of an age- or stage-structured modeling approach lies in estimating the population growth rate (λ) and the relative sensitivity of λ to changes in survival and fecundity in the Leslie Transition Matrix (Caswell 2001). Based on the outcome of various modeling scenarios, management efforts should focus on those life stages that have the most affect on changing the population growth rate. The model will also be useful to explore effects of removal rates that have been implemented to date. By inputting initial abundance levels and size structure information, we can then implement the model with given levels of exploitation to understand the effects on the population over various time periods. In addition to examining population growth rate, we can evaluate changes (reductions) in relative abundance and biomass of specific age-groups of the population, reductions in population fecundity (e.g., spawning success) and recruitment, and changes in size-structure and other population metrics. We can then validate model predictions from year to year by comparing population structure from model output to that estimated by sampling in subsequent years.

Task 3: What important sources of data are lacking?
Determine which data would be helpful in better parameterizing the model and improving model outcomes. Of key concern is the potential impact of

movement and our ability to remove smallmouth bass from all reaches at once.

Response: Modeling exercises, literature sources, and personal experience informs us that additional early life stage information will need to be gathered to better parameterize a population dynamics model. For example, bass nest counts, nest success rates, and survival rates of young smallmouth bass, and their relationships to different levels of environmental disturbances would be useful to incorporate in a population model capable of producing useful predictions. Overwinter mortality rates, especially those that incorporate size dependency of Age-0 smallmouth bass and different levels of environmental disturbance (e.g., duration and harshness of the winter) will be needed to predict important recruitment rates of bass to older life stages. Modeling exercises and particularly, uncertainty analyses will reveal additional information needs. The important impacts of movement and removal strategies that target only some or all reaches, can be explored and estimated explicitly with model output (see section above "Spatial Structure and Metapopulation Dynamics").

Task 4: What has been the impact of environmental factors?
Describe the relative effects of environmental conditions to removal efforts. Using existing data, is it possible to attribute various population level changes to environmental conditions (e.g., high flow events, changes in temperature, turbidity)? If not, what additional work would be required to parse the effects of the exploitation program from environmental conditions?

***Response*:** Environmental factors have the potential to affect smallmouth bass populations in the Upper Colorado River system as much or more than mechanical removal. Understanding effects of environmental factors, which we will call disturbances, will be important to understanding abundance dynamics and effectiveness of control strategies. The placement of disturbance effects is added to the population dynamics model structure (see Figures 1 and 2) so the reader can see where we envision such disturbances may affect smallmouth bass life history in the population dynamics model (Figure 1 and 2). Understanding the effects of disturbances will also guide optimization of mechanical removal efforts. For example, when disturbances hypothesized to affect recruitment of young are anticipated in a given year, is it best to increase efforts to reduce adults as well? Alternatively, should resources be saved for years when recruitment is hypothesized to be high, so that removal efforts could be increased to reduce what might otherwise be a large year-class of young smallmouth bass? An appropriately parameterized population dynamics model with inputs that estimate relevant effects of various disturbance regimes would be useful to guide control strategies. It is our aim to produce such a model, using data and relationships we are developing at this time.

We generally group and describe disturbances as factors that have the potential to influence abundance dynamics of smallmouth bass at any life stage. Such factors may include annual stream flow and temperature regimes. Such factors are known to influence reproductive success and recruitment smallmouth bass in most systems, including the Upper Colorado River (Reynolds and O'bara 1991; Mason et al. 1991; Bestgen et al. 2006b; Burdick 2008; Badame et al. 2008). For example, relatively high and late runoff with cool water temperatures in the Yampa River is known to delay spawning of smallmouth bass. We estimated such a relationship using our unpublished data that depicts a positive relationship between the number of spring runoff period flow days > 6000 and the onset of spawning of smallmouth bass in the Yampa River (Figure 6). High, late, and cool flows such as those observed in 2008 are known to have negative effects on size and abundance of Age-0 smallmouth in autumn in the Yampa and middle Green River systems (Figure 4). These types of relationships will be integrated into the population dynamics model so that realistic modeling scenarios and outcomes can be estimated.

We understand that managers cannot manipulate flow and temperature regimes such as those in the mostly unregulated Yampa River. However, in addition to providing realistic modeling scenarios under conditions expected under unregulated conditions, our population dynamics model will also be useful to understand long-term changes to flows and water temperatures. Most such scenarios that we envision could involve reductions in flows and increases in water temperature, similar to that observed in the recent drought period, the energetic consequences of which were described for the major non-native predator fishes, including smallmouth bass, in the Yampa River (Johnson et al. 2008). Similar to drought conditions, streamflows could be reduced by long-term global climate change or diversion of Yampa River flows to off-channel reservoirs, such as has been proposed for oil shale development in western Colorado. A properly parameterized population dynamics model would be useful to explore such scenarios and determine the duration and conditions under which mechanical removal would need to proceed under expectations for long-term changes in Yampa River (or other system) flows.

In other systems such as the Green River, flow regulation by Flaming Gorge Dam offers the opportunity for managers to directly alter flow regimes, water temperatures, or both, with the potential for disruption of life history of smallmouth bass. For example, we have observed displacement of large numbers of early life stages of smallmouth bass in the Green River in Lodore Canyon during elevated flow events caused by sediment-laden storm runoff, and subsequent reductions in abundance of Age-1 smallmouth bass in downstream reaches of the Green River the following year (Bestgen et al. 2006b). Temperature disturbances are also known to disrupt smallmouth bass spawning, either by delaying reproduction or by causing nest abandonment by males. Such disturbances could be simulated by altering discharge magnitude or reducing temperature of releases from Flaming Gorge Dam. The timing of such activities would be largely governed by the duration and intensity of smallmouth bass spawning, information which is presently being gathered via otolith microincrement analysis of Age-0 bass collected over years of sampling in the Green River.

We also see opportunities to explore effects of various environmental disturbances and conditions on recruitment of smallmouth bass over winter. The overwinter period for smallmouth bass transitioning from Age 0 to Age 1 is thought a critical period for black bass populations and is further thought to be largely governed by size of Age-0 bass entering the winter period. We have abundant information on factors that affect growth and size of smallmouth bass entering winter (Figures 4 and 7), as well as including timing of spawning and absolute growth rates and size of Age-0 bass under different hydrologic and temperature regimes (e.g., Figures 4 and 6), data which are estimated from otolith microincrement analyses or sampling data collected over many sampling years in the Yampa and Green rivers. Additional similar information may also be available soon for the Colorado River (Burdick 2008). Similar to disturbance regimes in summer, effects of winter severity and duration (or flow manipulations) could be parameterized in the population dynamics model using estimates of bass size from field data. This would allow understanding of prevailing environmental conditions on bass recruitment, as well as potential for management actions, including increased removals of small bass, to affect populations in the future.

A properly parameterized population dynamics model would allow simulation of various scenarios, to understand the potential effects of management actions to reduce reproductive success and how such changes cascade through populations. The relative importance and cost:benefit tradeoffs of flow-temperature management activities compared to mechanical removal could also be explored to determine which potential management action(s) may effectively reduce smallmouth bass. Unpublished data and the experience of the investigators should allow us to not only estimate relative effects of environmental factors, but rather, estimate them directly from data we developed to obtain the most realistic population dynamics model output.

We will also make recommendations to obtain information essential to further understanding of smallmouth bass abundance dynamics and better parameterize the population dynamics model. Based on our existing knowledge, and gaps identified in the literature (Peterson and Kwak 1999; Chu et al. 2006), we expect these areas will minimally involve obtaining better information on factors that affect reproductive success of smallmouth bass in variable riverine settings, and a better understanding of factors that affect recruitment of Age-0 bass over the winter period. Current field sampling programs may be modified to allow for some estimates of overwinter survival related to size, with some slight adjustments to sampling gear, such as use smaller size mesh in dip nets to obtain better estimates of small bass abundance in spring.

Objective2: Predict the Recovery Program's ability to achieve removal targets:
Task 1: What exploitation strategy would result in achieving our goals?
Given past experience, is it possible to attain our goals based on observed recruitment and growth rates? Is substantially more exploitation necessary, are goals achievable in a 10-20 year time frame? What is the impact of meta-population structure on our exploitation strategy? Should exploitation be focused on "source" populations or is movement sufficient to require basin-wide exploitation?

***Response*:** The modeling can address the effects of past removal efforts on current recruitment and population growth rates (Haines and Modde 2007). The modeling can also suggest future strategies for reduction of smallmouth bass populations and optimization of removal and management efforts. A critical outcome of the modeling process will be to identify which life history parameters and stages have the largest influence on population growth. Another equally important outcome will be identifying potential management strategies needed to manipulate life stages to achieve population reductions. Finally, it will be important to identify sources of variation in the data and determine the influence of this variability on the model outcomes.
We intend to incorporate immigration or emigration at appropriate rates depending on what movement data is available (see task 1). This aspect will be useful to understand source-sink dynamics of these smallmouth bass populations, which may guide how to allocate removal effort spatially to effect the largest population level reductions. For example, is it more effective to increase reductions in source areas with high abundance of large adults (Figure 5) or is a riverwide removal effort the most effective for achieving target levels of reductions. Exploration of various scenarios such as spatial allocation of removal effort to maximize long-term reductions will be a main feature of the population dynamics model produced in this study.

Incorporation of movement/immigration data will have other corollary uses. For example, it will also be useful to simulate effects of additions of smallmouth bass from Elkhead Reservoir or other generalized sources, to determine effects on removal effectiveness. We have devised a means of using available tag-recapture information to directly estimate escapement rates during Elkhead Reservoir construction activities, as well as the magnitude of escapement, if data are sufficient. Depending on levels of tag recaptures, we may also be able to estimate levels of more recent, chronic levels of escapement, and impacts to removal efforts in the Yampa River or other generalized receiving populations.

Task 2: If goals are not achievable, are intermediate goals beneficial to native fishes?

If it appears that the goals are not achievable, are there other nonnative reduction goals which might benefit native fishes?

***Response*:** The model we propose to develop, when linked with appropriate environmental effects and management actions, will guide whether the present goals of the Recovery Program to reduce smallmouth bass distribution and abundance are achievable. The model will also be able to estimate abundance dynamics under different levels of removal which may be more or less than the present targets. Thus, the results of this research will ultimately inform if there are other intermediate goals which will alter some aspect of smallmouth bass life history and abundance. It may also possible to link model output, such as predicted levels of change in size-structure or biomass of discrete population elements, with bioenergetics modeling (e.g., Johnson et al. 2008). Such an approach would allow estimation of changes in consumption of native fishes, and provide an estimate of the potential benefit to native fishes of non-target changes in smallmouth bass populations. Ultimately, whether the present goals, or some other intermediate goals, benefit native fishes will ultimately be measured by population response of native fishes to reductions in non-native fish predators, research which is ongoing in the Yampa River.

VIII. FY-2009-2012 Work

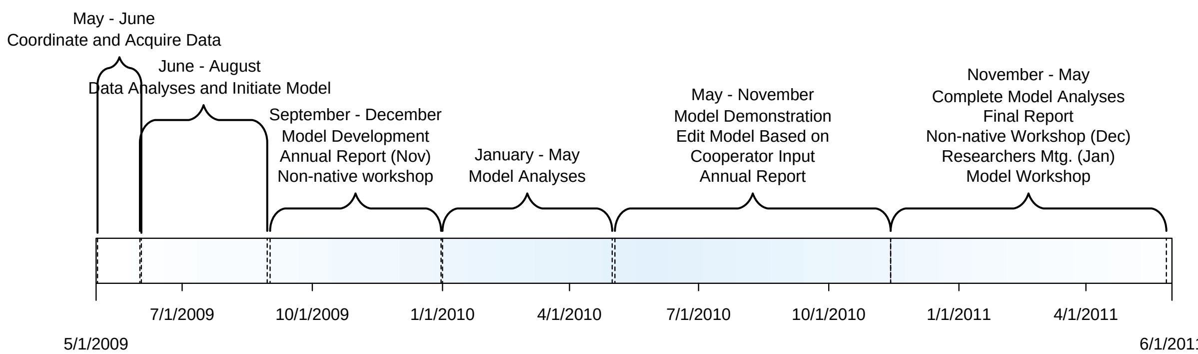
- Deliverables/Due Dates

A draft report, in Recovery Program format, will be available for review according to the schedule provided. The report is expected to contain a synthesis of available information on smallmouth bass ecology and control and management techniques, particularly those revealed by implementation of the population dynamics model. We expect that many of the results presented will be from scenarios developed in collaboration with Recovery Program Participants that are arrived at after consultations. Another product will be a user-friendly population dynamics model and software, which will be presented in an interactive workshop format with interested Program participants. Many of the principal investigators are closely-linked cooperators with the Recovery Program, which will facilitate updating of the population dynamics model with new information and data, which will make this a useful product as needs change well into the future. **We are presently working on revisions of the abundance estimates as well as the Elkhead Reservoir escapement analysis. The population dynamics aspect of this study is also under study but is receiving limited attention so we can focus on the aforementioned abundance estimation and escapement analysis tasks.**

Schedule

The timetable below that extended through 1 June 2011was for the original scope of work, which involved two years of funding. The start date for this project was delayed due to challenges with post-doc hiring until November 2009. Thus, the original 2-year project timetable would have ended in November 2011. Added funding to complete additional data analysis requires a modified timetable for the four main tasks as below:

Task 1. Complete draft of Elkhead Reservoir escapement analysis, 31 May 2011;
Task II. Incorporate 2009-2010 data and revise abundance estimates, 30 November 2011;
Task III. Complete population dynamics analysis, 31 May 2012;
Task IV. Draft final report, 31 August 2012.
Task V. Additional tasks to be identified that may include analysis of 2011 sampling data, database modification to increase utility, population dynamics modeling education, or other mutually agreed upon tasks. Timelines for these potential tasks are unknown but will be discussed and agreed upon but will extend into FY 2013.



IX. Budget Summary – Itemized budget attached at the end of the SOW, pages 25 and 26.

FY 09: $32,424
FY 2010: $60,641
FY 2011: $91,931(31,931, plus 60,000)
Total for FY 2012, $70,000

X. Reviewers:

XI. References

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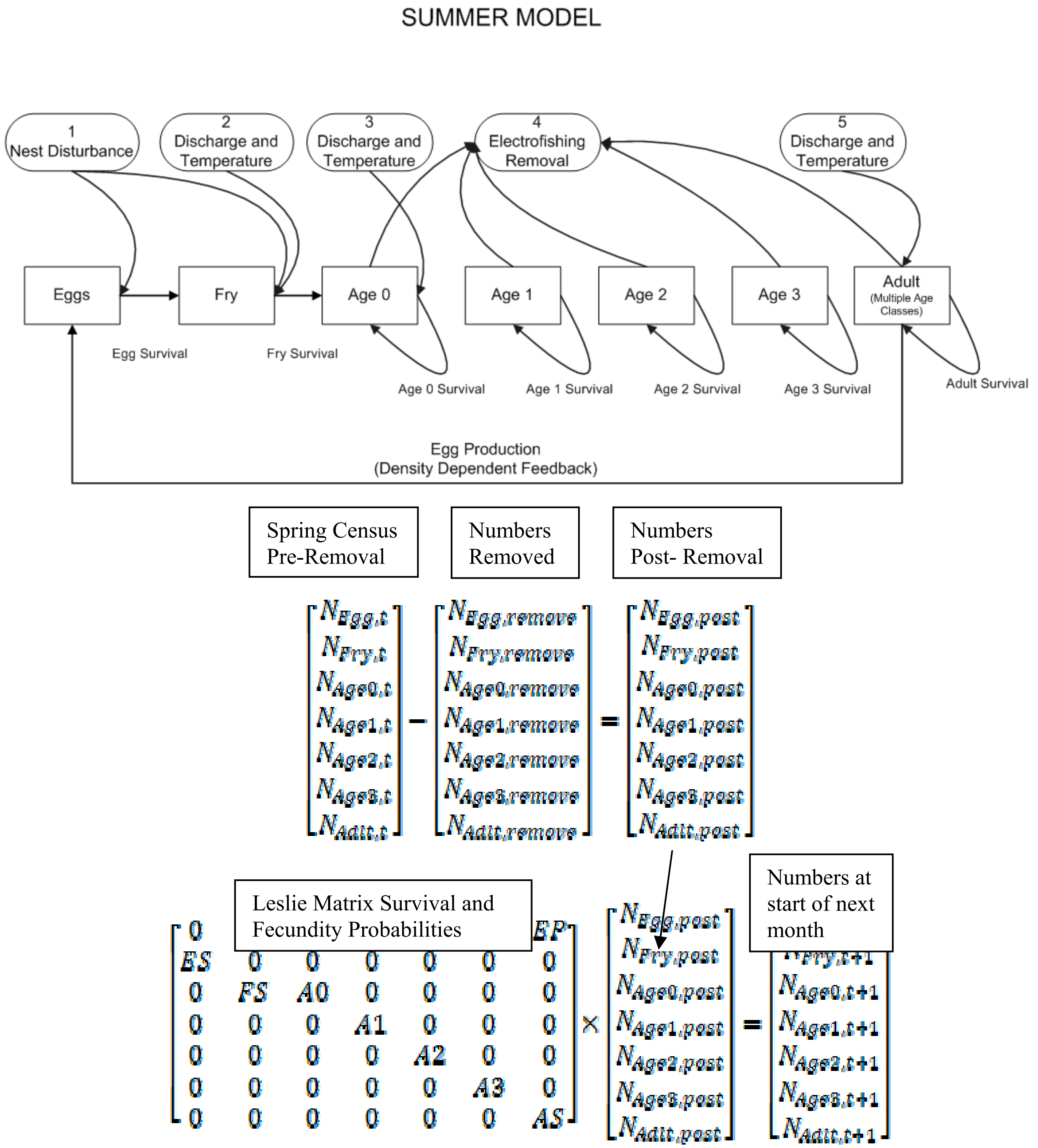
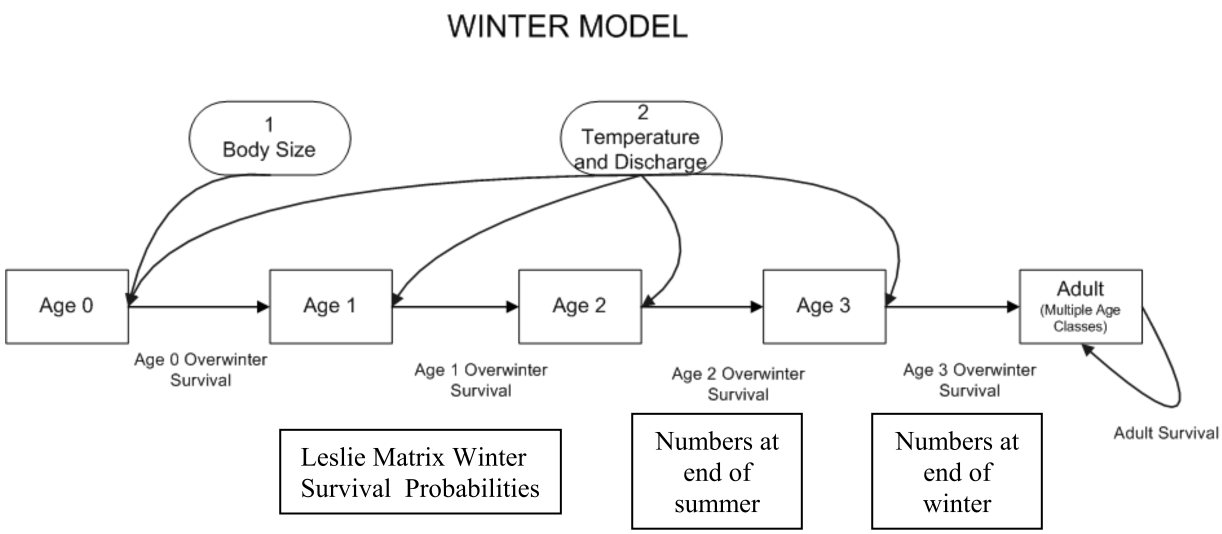


Figure 1. Life history diagram and Leslie matrices for smallmouth bass during the summer (begins in April). The Summer Model assumes that Age-0 through Adult fish remain in their respective stages during the summer (e.g., Age-0 fish don't become juveniles until next spring; no fish mature during the summer). The Summer Model will be updated monthly to account for removals during the spring and summer months. Effects in ovals represent environmentally driven variables or management actions that can be estimated in the model and potentially implemented in field settings to influence abundance and survival of the various life stages.



$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ A0 & 0 & 0 & 0 & 0 \\ 0 & A1 & 0 & 0 & 0 \\ 0 & 0 & A2 & 0 & 0 \\ 0 & 0 & 0 & A3 & AS \end{bmatrix} \times \begin{bmatrix} N_{Age0,t} \\ N_{Age1,t} \\ N_{Age2,t} \\ N_{Age3,t} \\ N_{adl,t} \end{bmatrix} = \begin{bmatrix} N_{Age0,t+1} \\ N_{Age1,t+1} \\ N_{Age2,t+1} \\ N_{Age3,t+1} \\ N_{adl,t+1} \end{bmatrix}$$

Figure 2. Life history diagram and age and Leslie transition matrices for smallmouth bass during the winter (beginning in October). Egg and Fry stages have recruited to Age-0 by the end of summer or died. The Age-0 to Age-3 fish in the winter model that survive the winter period advance one age class by spring. Adult fish Age-4 and older remain in their age class. Effects in ovals represent environmentally driven variables or management actions that can be estimated in the model and potentially implemented in field settings to influence abundance and survival of the various life stages.

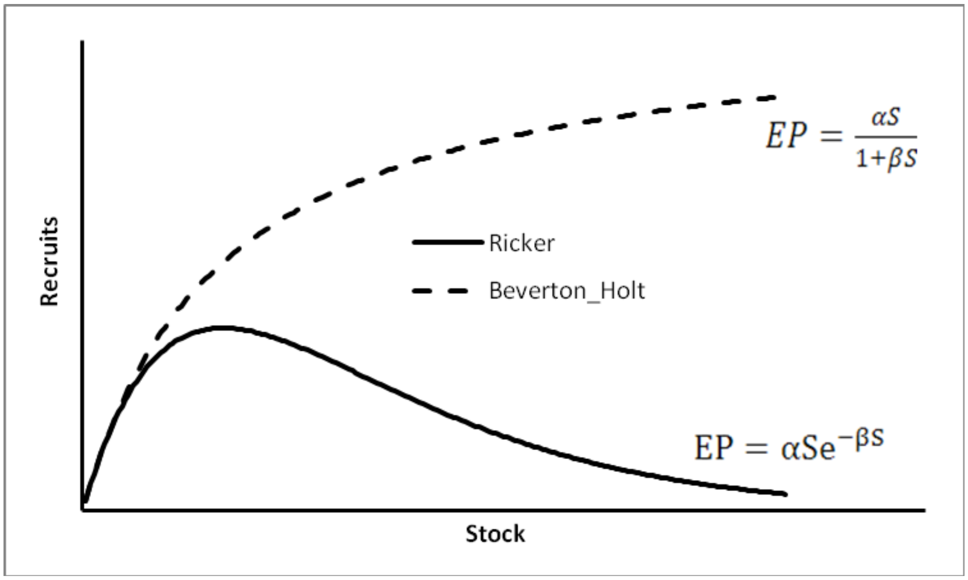


Figure 3. Beverton-Holt and Ricker stock recruitment curves. These curves represent density dependence between the reproducing adult population size (stock or N_t) and subsequent generations (recruits or N_{t+1}). The equations presented represent the relationship between egg production (EP) and adult stock density (S). However, similar density dependence can be included for any other age class in the basic model. For instance, cannibalism on Age-0 individuals by other age classes would probably result in a Ricker or similar type density dependence, such as the one used by Peterson and Kwak (1999).

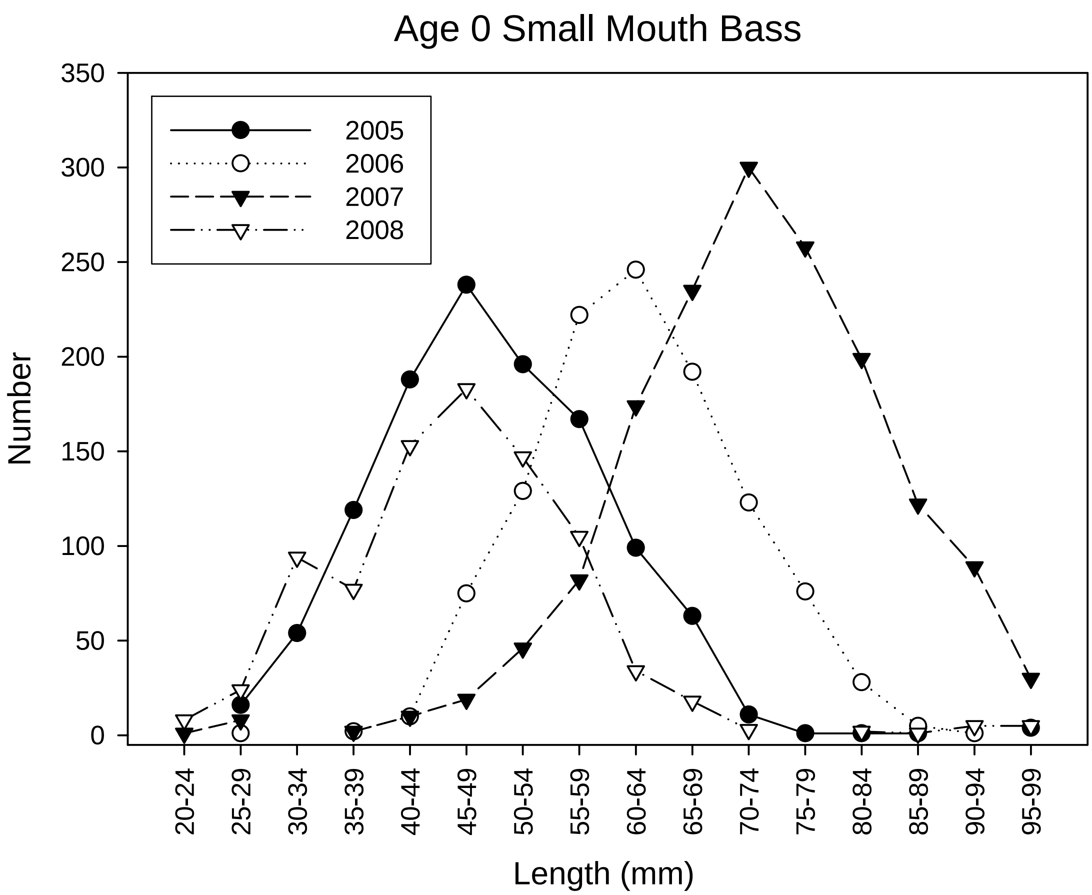


Figure 4. Age-0 smallmouth bass length frequency distributions in August, Little Yampa Canyon, Yampa River, 2005-2008. Years 2005 and 2008 had high spring discharge and relatively cool spring water temperatures; years 2006 and 2007 had low spring discharge and relatively warm summer water temperatures. The differences in mean lengths between high and low flow years were likely due to delayed spawning and slow growth in cool high flow years.

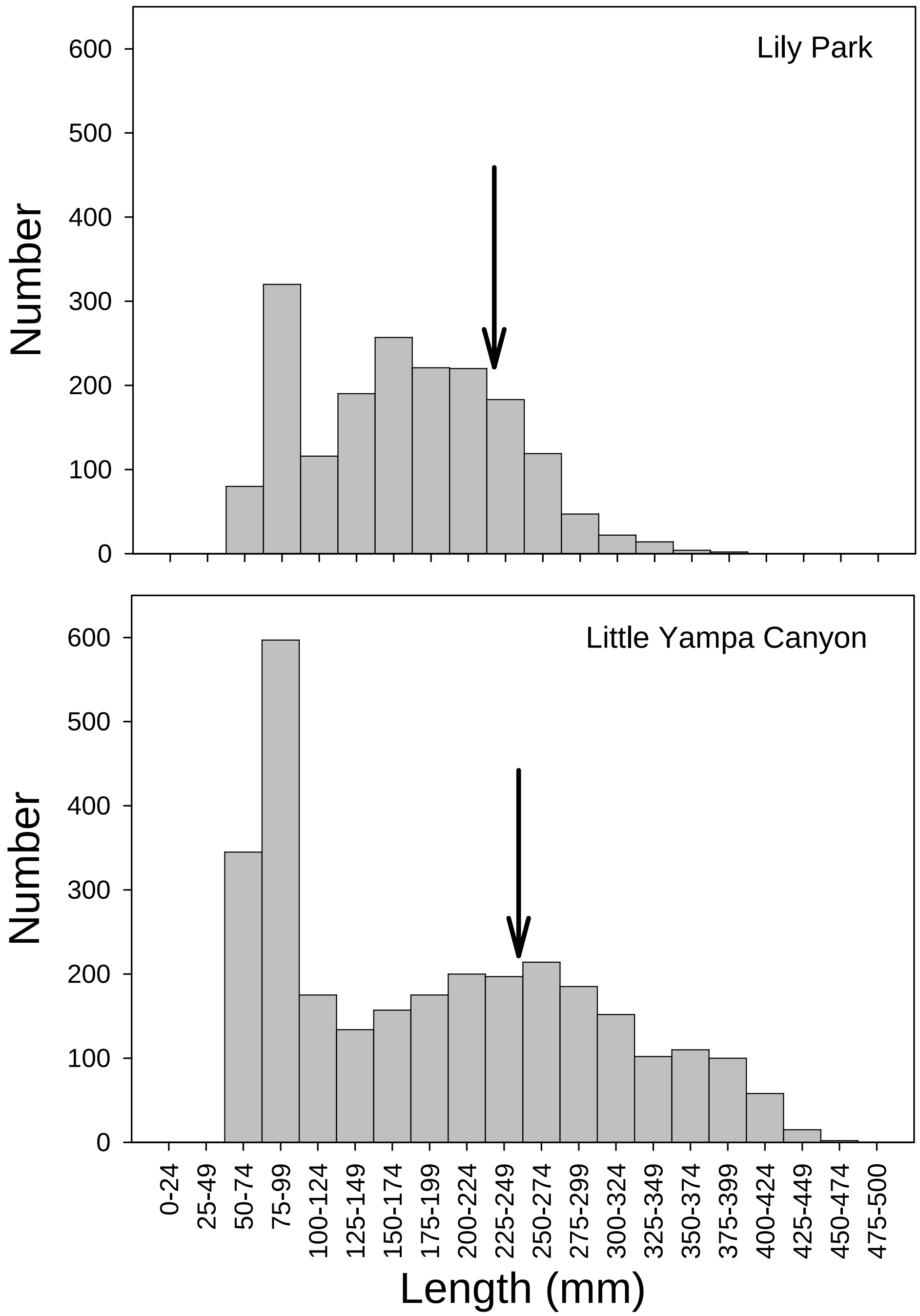


Figure 5. Length frequency distributions (total length) for smallmouth bass in the Lily Park and Little Yampa Canyon reaches of the Yampa River, 2007. The arrow indicates approximate size at maturity.

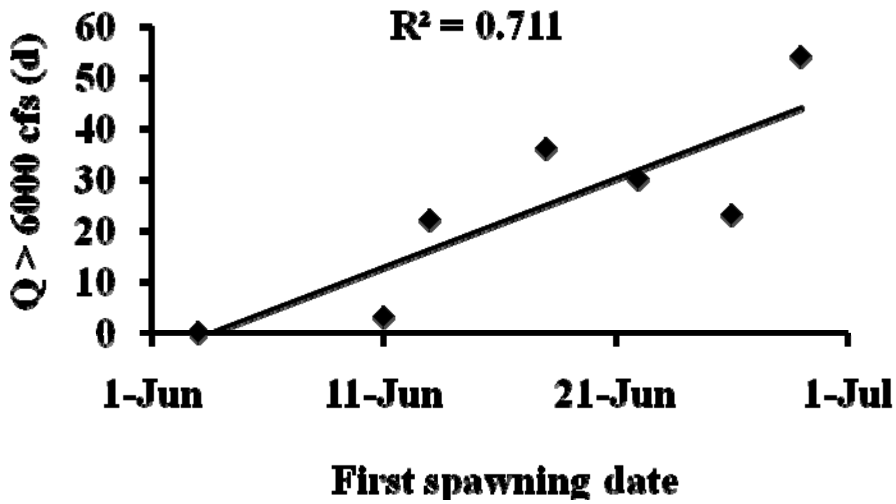


Figure 6. Relationship between estimated initiation of spawning (regular occurrence of water temperatures above 16C) of smallmouth bass as a function of discharge (# days discharge exceeded 6000 cfs in the period 1 April to 30 September) in the Little Yampa Canyon reach, Yampa River, Colorado (2000, 2003-2008).

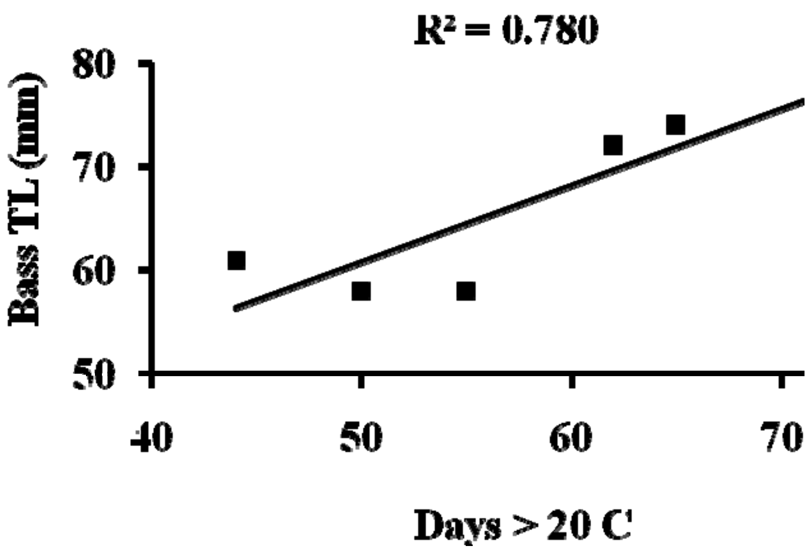


Figure 7. Relationship of smallmouth bass mean total length (TL) in late September as a function of number of days when water temperatures exceeded 20 C (in the period 1 April to 30 September) in the Little Yampa Canyon reach, Yampa River, Colorado (2003-2007).

Scan of the original budget table, FY 2009-2011

Colorado State University
Sponsored Programs
Campus Delivery 2002
Attn: Carmen Morales
Fort Collins, CO 80523-2002

Cooperative Agreement No.
DOI-BOR FON: 09-SF-40-2885

Project Title: Population Dynamics Modeling of Introduced Smallmouth Bass, Upper Colorado River Basin

Proposed Budget

	Year 1	Year 2	Year 3	TOTAL
Salary/Personnel Costs				
Post-Doctorate - (FTE-12 mo.salary @ $3250/mo)	19500	40170	20688	80358
Total Salary/Personnel	19500	40170	20688	80358
Fringe Benefits				
Post Doc @ 25.1-25.8%-26.2%	4895	10364	5412	20670
Total Fringe Benefits	4895	10364	5412	20670
Total Salary/Fringe	24395	50534	26100	101028
Domestic Travel				
Biology Conference Meetings	1000	1000	1000	3000
Total Travel	1000	1000	1000	3000
Materials & Supplies				
Computer	2100			2100
Office/software licenses	100	75	75	250
Total Materials/Supplies	2200	75	75	2350
SUBTOTAL	27595	51609	27175	106378
*****Indirect Costs (17.5%) (Univ)***	4829	9033	4756	18617
TOTAL	32424	60641	31931	124996

*****This budget has been prepared using the CESU indirect cost rate of 17.5%. In the event that the BOR is unable to fund this project under the CESU, Colorado State University will revise the budget to include the indirect cost at our full negotiated rate.***

Detailed budget (additional FY 2011 or 2012 funds, for FY 2012 and 2013 work)

Addition of first $60,000, FY 2011

Post-Doctorate - (FTE-12 mo. salary @ $3250/mo)	**$40,170**
Fringe @ 26.2%	**10,525**
Supplies and materials (computer software)	**369**
Subtotal	**$51,064**
Overhead @17.5%)	**8,936**
	$60,000

Additional $70,000, as discussed by BC on 26 January 2012

FY 2012 (with raise estimated for Breton)

Post-Doctorate - (FTE-12 mo. salary @ $3833/mo)	**$45,000**
Fringe @ 26.6%	**11,970**
Travel	**500**
Supplies and materials (laptop computer, software miscellaneous supplies)	**2,104**
Subtotal	**$59,574**
Overhead @17.5%)	**10,426**
	$70,000