A Population Viability Analysis for the Rio Grande Silvery Minnow (*Hybognathus amarus*)

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Introduction

The Rio Grande silvery minnow (*Hybognathus amarus*) historically occupied approximately 3,862 river km (2,400 mi) in New Mexico and Texas. It was found in the Rio Grande from Española, New Mexico, down through Texas to the Gulf of Mexico (Bestgen and Platania 1991). It was also found in the Pecos River, a major tributary of the Rio Grande, from Santa Rosa, New Mexico, downstream to its confluence with the Rio Grande in Texas. Currently, the Rio Grande silvery minnow is believed to occur in only one reach of the Rio Grande in New Mexico, a 280 km (174 mi) stretch of river that runs from Cochiti Dam to the headwaters of Elephant Butte Reservoir. Its current habitat is limited to about 7 percent of its former range. The species was listed as federally endangered in 1994 (59 FR 36988 36995).

Increasing demands for available water in this area – particularly in and around Albuquerque – have altered the normal hydrologic and ecological processes in the Rio Grande river. Ongoing drought in this area of the United States has exacerbated these problems still further. As a result, the long-term persistence of endangered species such as the Rio Grande silvery minnow will likely be compromised to a greater degree.

Population viability analysis, or PVA, can be an extremely useful tool for investigating current and future risk of Rio Grande silvery minnow population decline or extinction. The need for and consequences of alternative management strategies can be modeled to suggest which practices may be the most effective in managing silvery minnow populations in its wild habitat. *RAMAS METAPOP*, a simulation software package written for population viability analysis, was used here as a vehicle to study the interaction of a number of silvery minnow life history and population parameters, to explore which demographic parameters may be the most sensitive to alternative management practices, and to begin testing the effects of selected management scenarios.

The *RAMAS* package is a simulation of the effects of a number of different natural and human-mediated forces – some, by definition, acting unpredictably from year to year – on the health and integrity of wildlife populations. *RAMAS* models population dynamics as discrete sequential events (e.g., births, deaths, sex ratios among offspring, catastrophes, etc.) that occur according to defined probabilities. The probabilities of events are modeled as constants or random variables that follow specified distributions. The package simulates a population by recreating the essential series of events that describe the typical life cycles of sexually reproducing organisms.

PVA methodologies are not intended to give absolute and accurate "answers" for what the future will bring for a given wildlife species or population. This limitation arises simply from two fundamental facts about the natural world: it is inherently unpredictable in its detailed behavior; and we will never fully understand its precise mechanics. Consequently, many researchers have cautioned against the exclusive

use of absolute results from a PVA in order to promote specific management actions for threatened populations (e.g., Ludwig 1999; Beissinger and McCullough 2002; Reed et al. 2002; Ellner et al. 2002; Lotts et al. 2004). Instead, the true value of an analysis of this type lies in the assembly and critical analysis of the available information on the species and its ecology, and in the ability to compare the quantitative metrics of population performance that emerge from a suite of simulations, with each simulation representing a specific scenario and its inherent assumptions about the available data and a proposed method of population and/or landscape management. Interpretation of this type of output depends strongly upon our knowledge of Rio Grande silvery minnow in its habitat, the environmental conditions affecting the species, and possible future changes in these conditions.

The *RAMAS* system for conducting population viability analysis is a flexible and accessible tool that can be adapted to a wide variety of species types and life histories as the situation warrants. This makes it a trusted method for assisting in the definition of practical wildlife management methodologies. For a more detailed explanation of the program and its use in population viability analysis, refer to Akçakaya (2005).

Specifically, we were interested in using this preliminary analysis to address the following questions:
- Can we build a series of simulation models with sufficient detail and precision that describe the dynamics of Rio Grande silvery minnow (RGSM) with reasonable accuracy?
- What are the primary demographic factors that drive growth of RGSM populations?
- What are the predicted impacts of severe drying on RGSM populations?
- What are the predicted impacts of a water quality event on RGSM populations?
- How vulnerable to extinction are small, fragmented RGSM populations under current management conditions? How small must a population become to increase its risk of extinction to an unacceptable level under conditions of minimally acceptable population growth?
- What is the impact of dispersal on the viability of source and recipient reaches?
- How effective can augmentation of RGSM individuals be as a long-term population management strategy?
- How effective can salvage of RGSM individuals be as a long term population management strategy?
- Which water management strategies work best towards the goal of increased viability of RGSM populations?

Baseline Input Parameters for Stochastic Population Viability Simulations

The biological information used to develop demographic input for these PVA models comes from a variety of published and unpublished sources. Of greatest relevance to this process is the series of meetings involving members of the Rio Grande Silvery Minnow Biology Working Group and associated invited guests. This group was composed of representatives from a number of diverse agencies and other interested parties, including:

- US Fish & Wildlife Service
- US Army Corps of Engineers
- Interstate Stream Commission
- New Mexico Department of Game & Fish
- The Offices of Senators Jeff Bingaman and Pete Domenici
- City of Albuquerque
- Bureau of Reclamation
- American Southwest Ithyological Researchers
- Bureau of Indian Affairs
- Santa Ana Pueblo SWCA Environmental Consultants
- University of New Mexico

Through five days of discussions spread across three meetings, and dozens of electronic messages distributed in the intervening periods, this group provided and evaluated data and information in an open and productive process. As a result, while some differences of opinion remain concerning the interpretation of selected elements of the data, and while significant gaps in our definitive knowledge of the species' biology remain, the information discussed below represents an effective consensus regarding our collective understanding to date of Rio Grande silvery minnow demography and population ecology.

Structure of Demographic Information Used in PVA

The analysis discussed here employs an age-structured matrix model of silvery minnow demography, with input data on age-specific fecundity and survival rates based on an assumed pre-breeding census methodology. The matrix that describes these demographic rates, knows as a Leslie Matrix, is algebraically combined with a description of this year's population to project the size of that population in the next year. Specifically, if we assume that a species lives until just beyond two years of age, we can describe one year's change in population size algebraically by:

$$\begin{bmatrix} N_0(t+1) \\ N_1(t+1) \end{bmatrix} = \begin{bmatrix} F_0 & F_1 \\ S_1 & 0 \end{bmatrix} \begin{bmatrix} N_0(t) \\ N_1(t) \end{bmatrix}$$

where $N_0(t+1)$ and $N_0(t)$ are the numbers of individuals in age class 0 (here, $0 - 12$ months) at time $(t+1)$ and (t), respectively; F_0 is the fecundity of age 0 individuals (defined here as the average number of offspring that are censused at the next time step produced by individuals in age class 0); and S_1 is the survival rate of individuals in age class 1 (i.e., the proportion of individuals that survive from 12 months to 24 months of age). Note that the Leslie matrix value in the lower-right corner is automatically set to 0 because, in this case, we assume that individuals do not live to see their third birthday. Therefore, survival rates beyond 24 months of age are 0.0.

The process of developing input data for the PVA revolves largely around the estimation of the fecundity and survival rates that define the Leslie matrix. Moreover, it is important to remember that we are assuming that these age-specific demographic rates are not static in time, but instead fluctuate randomly from one year to the next in response to changes in the external environment within which the minnow lives. Consequently, in addition to estimating mean rates of birth and survival we must also try to assess the degree to which these rates fluctuate through time.

We have decided to construct a matrix model for the Rio Grande silvery minnow that includes only females. This is a rather common approach in the matrix-based analysis of wildlife populations in which there are few if any measurable differences in demographic behavior between males and females. With this formulation, we are interested only in the number of female offspring produced by a given adult female, and only in the survival rates of female fish in each age class. This approach simplifies the overall computational structure and also reduces the number of required variables and, more importantly, their measurement uncertainty.

Finally, we assume here that only two age classes are required to adequately describe the demographics of the Rio Grande silvery minnow. Specifically, we define Age 0 fish as those that are produced immediately after the preceding census and live to the next census when they are counted as 12 months old. Additionally, we define Age 1 fish as those that are 12 months old in the current census and survive to be counted again in the next census as 24 months old. We further assume that both Age 0 and Age 1 fish produce offspring, with the Age 1 fish dying soon after their second annual spawn and, therefore, failing to reach the next census as 36 months old. With this simplification, we acknowledge the potential

for some silvery minnows to live beyond 36 months of age. However, given our survival estimates for younger fish (see below) we conclude that the total number who would reach this age are so few in number as to be of little to no demographic value. Early matrix analyses (which are not presented here but can be obtained from the lead author of this report) confirms this expectation.

Age-specific fecundity rates
Based on how fecundity is defined in our matrix approach – namely, the average number of offspring that survive to the next census period that are produced by an individual female of a given age class – our definition of this parameter is slightly more complicated than what might be apparent at first glance. In particular, we must account for those individuals that are "born" to a given female during the reproductive event that occurs just **after** the current pre-breeding census – this is referred to as *maternity* – as well as the survival of those newborns until the next census, just under one year from the present. In other words, our definition of age-specific fecundity is

$$F_0 = m_0 S_0$$
$$F_1 = m_1 S_0$$

where m_0 and m_1 are the maternity values (specifically, the number of female eggs) for Age 0 and Age 1 fish, respectively, and S_0 is the survival rate of those newborns to one year of age (i.e., the next census). We assume here that the survival of newborns to one year of age is independent of their mother's age. In the calculations that follow, we assume that very close to 100% of all reproductively capable females do in fact spawn.

Data from experiments conducted by R. Dudley and S. Platania (American Southwest Icthyological Researchers) in May – June 1994 were used to estimate maternities. In these experiments, gravid females were collected and treated with hormones and then introduced to males. The number of spawning events and the total number of eggs was counted, with up to 30 females used in each trial. The length of each adult female was measured and, using established length – age relationships, each fish was assigned to one of the two age classes. The total number of eggs from each female is tabulated below.

Age Class (x)	Mean # eggs (SD)	Females produced (m_x)
0	1316 (582)	658
1	2961 (826)	1480.5

Note the larger maternity for larger (older) females, as is expected. Since we assume no skewed sex ratios among clutch of eggs, we can simply halve the total number of eggs in order to estimate the number of female newborns produced per adult female.

J. Remshardt (US Fish & Wildlife Service) attempted to estimate survival of Age 0 fish to 12 months of age. Specifically, data were collected from Angostura Reach on a monthly basis from June 2004 to the following May 2005. His observations led to an estimated survival rate of newborns across this period of 0.00832 or 0.8%. However, this accounts for only a part of the full 12-month period; the first app. 45 days of life from spawning to the beginning of Remshardt's observation period are not included in this numerical estimate. Unfortunately, the small size of the individuals in this very early period and the difficulties associated with studying them in detail makes it very difficult to make a confident estimate of this parameter. Discussions among Biology Working Group members led to the acceptance of a 10% mean survival rate for this early period. Taken together, we therefore estimate the total survival rate for silvery minnows through their first year as 0.00083. The fecundity values then become $(658)(0.00083) = 0.547$ for Age 0 fish, and $(1480.5)(0.00083) = 1.229$ for Age 1 fish.

Survival from Age 0 to Age 1 classes

To calculate matrix parameter S_1, we relied primarily on field data collected by J. Remshardt in a mark-recapture study of stocked fish conducted in 2004 – 2005. A monthly survival estimate of 0.662 was calculated through the period of study, which was not a full year in the field. From this observation, and assuming a constant rate of monthly survival throughout the year, we estimate the survival of individuals (females) age 12 months to age 24 months as

$$S_1 = (0.662)^{12} = 0.007.$$

In addition to this estimate, we discussed the technique employed by M. Hatch (SWCA Environmental Consultants) using observations of salvaged fish. Hatch estimated the age class distribution of fish collected in salvage operations and, using these frequency data, was able to calculate an expected survival rate that would most likely give rise to the observed distribution of individuals in the two different age classes. This estimate was equal to 0.09. While both methodologies are reasonable approaches to estimating survival rates, the meeting participants reached consensus that, due in large part to the likely complexities of relying on salvaged fish (that may be significantly different in their overall characteristics compared to the larger pool of individuals within a given age class) for this type of analysis, the mark-recapture data derived using a more representative sample of the entire age class would likely provide a more reliable estimate of Age 1 survival rate. It may very well be reasonable to expect the value derived by Hatch to be more of an upper bound on survival.

Sources of variability in demographic rates

Annual environmental variation (EV) in demographic rates is modeled in *RAMAS* by specifying a standard deviation (SD) that is applied each year to the base rates in order to simulate fluctuations due to extrinsic factors (both natural and anthropogenic) in the environment within and near the Middle Rio Grande. Specifically, we used a lognormal distribution of demographic rates over the period of the simulation, using the specific extent of environmental variation as the standard deviation of the distribution. The lognormal distribution is often a more accurate reflection of random variability in demographic rates, and often reduces truncation bias when describing rates bounded by 0 and 1.0.

Unfortunately, the methods to arrive at mean estimates of Rio Grande silvery minnow fecundity and survival described in the preceding section are effectively only "snapshots" of data within a short time period – often over a single year (spawning season). While there may be abundant data on, for example, the *spatial* nature of variance in demographic rates, there is no way to estimate the *temporal* variation in these same rates from just one year of data. Instead of trying to accurately assign a particular level of environmental variability to fecundity and survival rates in the absence of appropriate data, we took a more exploratory approach to this facet of silvery minnow population biology. More precisely, we used a sensitivity analysis methodology to investigate the impact of systematic changes in EV on overall model performance. To accomplish this, a range of plausible values for EV in both fecundity and survival rates were calculated by computing coefficients of variation (CV, defined as standard deviation divided by mean value) for each rate that varied from 10% to 50%. For example, if we assume CV = 10% our two estimates of EV in fecundity (given mean values for Age 0 and Age 1 fish of 0.547 and 1.229, respectively) would be 0.0547 and 0.1229 for Age 0 and Age 1 fish, respectively. The same degree of variability would be calculated for the survival parameter S_1. Furthermore, we assume in all our models that EV for fecundity and survival will be correlated within a year; in this way, the model draws only a single random normal deviate for a population and applies that same deviate to each demographic rate.

In addition to environmental variability, our simulations include demographic stochasticity. This factor describes the uncertainty within a given year that arises when applying birth and death rates to a population that must be described in whole numbers (e.g., you cannot have 1.2 offspring per female, but only 1 or 2 offspring). This source of uncertainty is most important when populations become quite small,

when such uncertainty can have major impacts on rates of fecundity or survival. To simulate demographic stochasticity in *RAMAS*, the number of survivors for the ith age class is drawn from a binomial distribution with parameters S_i (survival rate) and $N_i(t)$ (as sample size). The number of young produced by the ith age class is then drawn from a Poisson distribution with mean $F_i(t)N_i(t)$.

Initial population size

In order to construct a meaningful PVA model, we must derive even a crude estimate of population size so that we can evaluate the impact of predicted growth dynamics that emerge from our Leslie matrix analysis. We must therefore assess the appropriate information available to us and decide on a productive course of action.

The best data we have at our disposal to begin estimating the Rio Grande silvery minnow population size is the data on catch per unit effort, or CPUE, that has been collected since the early 1990s by S. Platania and R. Dudley. There are some concerns with using data like these for the purpose of estimating total population size – both within the silvery minnow management group and in the broader population biology community (see, for example, Maunder et al. 2006). We can acknowledge these concerns and use this preliminary analysis to stimulate further discussion towards a more robust evaluation of the size of the silvery minnow populations and an estimate of the recent trend in numbers.

We started by using the October 2006 point estimate for silvery minnow CPUE in the Middle Rio Grande, namely 1.4 individuals / $100m^2$. In order to transform these data to an estimate of population size for each reach of the river, we had to make the following assumptions:

1. The sex ratio among those individuals captured as part of the CPUE effort is 50:50.
2. The habitat for silvery minnows is uniformly distributed throughout the length and breadth of each reach. In effect, we are assuming for this initial estimate that the morphology of the Middle Rio Grande is akin to a channel with constant width and depth from north to south.
3. Silvery minnows are evenly distributed throughout this channel-like habitat.

With these assumptions in hand, we simply estimate reach-specific population size by multiplying the CPUE (effectively, a density) by the measured length and average width of each reach, remembering to divide by 100 given the units used to measure CPUE. Finally, we must reduce this size estimate by 50% as we are modeling only females. The results of this analysis are presented in the table below.

Reach	Length (m)	Average Width (m)	N_{Total}	$N_{♀♀}$
Angostura	65,000	182	165,600	82,800
Isleta	85,500	161	192,700	96,350
San Acacia	92,000	182	234,400	117,200

Additional efforts will be directed towards improving our understanding of habitat heterogeneity within each reach in order to come up with a more accurate estimate of total population size.

Density dependence and habitat carrying capacity

The regulation of one or more demographic rates by density is a nearly universal phenomenon among wildlife populations. Birth and/or survival rates can be reduced when density increases to a point where competition for space or resources becomes critical; at the other extreme, very low population densities can lead to a reduction in breeding rates simply because individuals of the opposite sex have difficulties in finding each other to mate (known as the Allee effect). Therefore, a proper PVA must include at least some form of density-dependent regulation of vital rates.

At the present time, no studies exist that explicitly investigate density dependence in vital rates. We must therefore rely on information from other species and expert opinion to derive some form of relationship. We assume that Allee effects are not present, and we will also assume that processes operating at high densities are most easily explained by a more simple ceiling model of density dependence. Under the ceiling type of density dependence, the population grows exponentially until it reaches the ceiling, also known as the carrying capacity K (e.g., until all available habitat is occupied), and then remains at that level. For large population sizes, the population size at $t+1$ is a constant function of the population size at t. A population that reaches the ceiling remains at that level until a population decline (e.g., a random fluctuation or an emigration) takes it below the ceiling.

After numerous discussions among Working Group members on this issue, spanning multiple meetings, a consensus was reached on a process for simulating carrying capacity throughout the Middle Rio Grande with an acceptable degree of accuracy. Over the past 15 years of observation, the maximum density calculated from CPUE data is approximately 40 fish / 100m^2. It is possible that this density may be even higher in a single year, although the likelihood of achieving such high densities is relatively small. More reasonably, we might expect the long-term maximum to be on the order to 30 fish / 100m^2, with some degree of variability around this value to simulate changes in local environmental conditions such as water availability, predator or competitor densities, etc. Using this logic, we set the average maximum density at 30 fish / 100m^2 with annual variability expressed in terms of a standard deviation in this density equal to 10 fish / 100m^2. Using this range of densities, and applying them to the reach-specific morphology data given above, we arrive at the following estimates for reach-specific carrying capacity:

Angostura: 1,775,000 ± 394,000
Isleta: 2,065,000 ± 459,000
San Acacia: 2,512,000 ± 558,000

The variability around reach-specific carrying capacity is described by a normal distribution with mean K and the standard deviation specified above.

Simulating External Impacts on Silvery Minnow Population Demography

Severe drying event
The Working Group identified severe drying as an event that could be labeled as a "catastrophe": an event with comparatively low probability of occurrence but with the potential for significant demographic impact in any given year. Because we want to be able to look at the long-term dynamics of each reach separately, in addition to analyzing the composite Middle Rio Grande, we discussed development of reach-specific multiplicative factors that describe the impacts of such an event of silvery minnow fecundity and/or survival.

We have defined a severe drying event to be one with characteristics similar to that which occurred in 2003, where a total of 70 miles of river between Isleta Dam and Elephant Butte Reservoir (64% of the 110 total miles) dried. We assume that every mile of river that dries results in a 1% decline in silvery minnow abundance throughout the reach of interest. Therefore, we assigned a 64% decline in silvery minnow abundance in the Isleta and San Acacia reaches during the severe drying event. For the Angostura reach, we assume that drying would occur but at a lower severity as the river would remain connected. We do not have specific data to apply to a precise estimate of the amount of drying. Expert opinion based on experience and qualitative observation resulted in an estimated 20% decline in abundance in the Angostura reach during a severe drying event. Finally, we assumed that such an event would be expected to occur approximately once every ten years. We have observed the 2003-type event once in a six-year period, but are unwilling to consider this to be representative of a long-term estimate of

probability of occurrence. A long-term expected probability of 10% for each reach was considered to be more realistic. The severe event was expected to be classified as regional, i.e., each reach would experience the severe event in the same year.

Water quality event
This event was defined as, most likely, a release of petrochemical toxins that would lead to significant loss of fish immediately after the release of the toxin into the river. We focused our attention on the release of chlorine from the industrial areas around Albuquerque, as some data are available on the frequency and impact of such an event and it seems to be representative of the type of event intended to be investigated using this process. With this in mind, and because of the highly localized nature of these events, we assume that the impacts of a water quality event will be restricted to the Angostura reach.

Analysis by Working Group members of recent significant chlorine releases into the Rio Grande near Albuquerque indicate a rough average periodicity of about five years between releases. Using this information, we assumed an average probability of occurrence of 20% in a given year. With regards to the severity of such an event, Working Group members consider an event of this type would lead to local extermination (i.e., 100% mortality) of fish within close proximity of the event. However, members also assumed that the impact would dissipate quickly away from the point source of the event. Taken together, we assume that an event akin to a chemical spill would lead to a 33% reduction in abundance across the entire length of the Angostura reach.

The Middle Rio Grande as a metapopulation: Dispersal rates between reaches
Although the three reaches of the Middle Rio Grande are separated by diversion dams, there will inevitably be some small level of movement of individuals from one reach to another. More specifically, because of the morphology and dynamics of the river itself, we expect all movement of relevance to this PVA to be downstream and to occur largely between neighboring reaches.

In a 2002 study of silvery minnow movement conducted by S. Platania, nearly 12,000 VIE tagged fish were released into the San Acacia reach in early January. He was later able to collect a total of 66 fish in the period February – May and found that a small number of these fish traveled as far as 25km, while the majority of them stayed with 1 – 5km of the release site. While this study suffered from a few unavoidable complexities, including a major drought in 2001 – 2002 that made conditions in the river more problematic for the purposes of the study, that led to extremely low recapture rates of marked fish, the information obtained sheds some light on the issue of dispersal capability in Rio Grande silvery minnow.

We assume that there is some level of downstream dispersal, although the Platania study above is not adequately designed to accurately determine rates of dispersal among nearby reaches. Given this data deficit, we devised a basic range of plausible (and perhaps upper-end) dispersal rates that ranged from 0.5% to 1.5% between neighboring reaches. These percentages refer to the average proportion of the population that is expected to disperse from one reach to the neighboring downstream reach in a given year. In addition, we assumed that dispersal between the Angostura and San Acacia reaches was only 33% that of the rate between neighboring reaches. For example, if the rate between neighboring reaches is set at 1.0%, then the rate between Angostura reach and San Acacia reach is 0.33%. We did not include any source of environmental variability in annual dispersal rates.

A Brief Summary of Initial Baseline Model Analysis

Based on the above discussion of input data used in constructing our first PVA models for the silvery minnow, we can construct the following basic Leslie age-specific transition matrix for the Rio Grande silvery minnow:

$$\begin{bmatrix} 0.547 & 1.229 \\ 0.007 & 0.000 \end{bmatrix}$$

The above matrix is used when we assume a lower bound on S_1, the survival of fish from 12 to 24 months. When we assume the upper bound survival for this parameter, our matrix changes to:

$$\begin{bmatrix} 0.547 & 1.229 \\ 0.090 & 0.000 \end{bmatrix}$$

We can conduct a deterministic analysis of this matrix – assuming no random variability in demographic rates or density dependence – in order to calculate the annual rate of growth of the population, often designated as λ. The estimate of growth rate of a population is a useful metric to assess the consequence of the various matrix elements and their interactions (although, because of the deterministic nature of the analysis, λ is an inadequate and often misleading metric when applied to the assessing of risk of population decline or extinction in the presence of demographic variability in the long term).

Using this analysis, the population growth rate λ is estimated to be 0.561 when the lower S_1 value is used. This means that, on average, the population is expected to decline deterministically by more than 40% annually. This is, of course, a rapid rate of population decline and is entirely unsustainable. When the larger value of S_1 is used, the growth rate increases to $\lambda = 0.703$ – but the overall trend remains highly negative with a nearly 30% rate of population decline expected annually.

While it is important to remember that these growth rate estimates must be interpreted with great caution, it is also worth noting that the inclusion of stochastic elements into the model, such as environmental variability and density dependence through carrying capacity, will only serve to decrease mean λ in the long term. With this in mind, it is instructive to reflect on the meaning of these initial results in the context of what one predicts from larger-scale observations of trends in population size on the Middle Rio Grande. In other words, do these growth rate estimates seem to accurately reflect what we think is happening on the river itself? If not, then we must revisit either our gross observations of long-term population trends, or our estimates of baseline demographic rates calculated from field data. Nevertheless, it is perhaps most critical to remember that, despite the exact numerical results one can obtain from any single modeling scenario, the true value of PVA methods lies in its ability to facilitate comparative analysis of alternative scenarios in order to make more informed decisions about how to manage wildlife populations in the face of oftentimes considerable uncertainty.

The following analysis is a first attempt at estimating the size of silvery minnow populations in the Middle Rio Grande and, more importantly, the trend in population estimates over time. Such an analysis is an important component in providing a kind of "reality check" to the estimates of population dynamics that emerge from a PVA. Taken together, these analyses will help to guide our interpretation of results from existing models, and to assist us to create more realistic and informative scenarios for more detailed analysis using updated models.

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The Silvery Minnow in the Middle Rio Grande: A Preliminary Attempt at Inferring Population Trends from CPUE Data

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Introduction

In the course of preparing a population viability analysis (PVA) for the Rio Grande silvery minnow, members of the Biology Working Group and other experts agreed that it would be valuable to make an attempt at using the population monitoring data collected in earnest since 1993 to infer a trend in the total size of the minnow population in the river, and to use this trend analysis to derive a crude estimate of the population growth rate, λ. Such an estimate can provide a more accurate starting point for the PVA in the context of understanding what types of management strategies should be employed to minimize the risk of additional population decline, and the intensity with which those strategies should be pursued (given the assumption that a specific biologically-based management strategy is designed to increase λ).

It should be noted up front that the use of these population monitoring data, often presented in the form of catch per unit effort or CPUE, for the purposes of estimating population size is controversial (e.g., see Maunder 2006). While there may be difficulties involved in the interpretation of CPUE data, the intention here is to present a starting point for discussion of the means by which these data can be interpreted more effectively and, therefore, can be made more valuable for conservation management planning.

Methodology

CPUE data were obtained from silvery minnow population monitoring reports prepared by Steven Platania and Robert Dudley. Graphical depiction of annual October CPUE data from 1993 to 2007 were used to derive numerical estimates of minnow density (number of fish / $100m^2$) across the areas sampled.

In order to transform these density data to crude estimates of total population size, annual CPUE values were multiplied by the total stretch of the Middle Rio Grande reach, defined as the sum of the distances defining the Angostura, Isleta, and San Acacia reaches (65.0 km + 85.5 km + 92.1 km = 242.6 km), as well as by a (very) crude estimate of the average width of the Middle Rio Grande, defined here as 150m. It is important to remember here that precise estimates for the length and width of the Middle Rio Grande are not important from the standpoint of evaluating the relative change in total census number from one year to the next -- as long as the same transformation is used for each datapoint in the time period of interest. This allows for some greater flexibility in the use of CPUE data for estimating population growth parameters. The raw and transformed data are presented in Table 1. below.

Table 1. Census estimates for silvery minnow in the Middle Rio Grande based on catch-per-unit-effort (CPUE) reports. Raw CPUE data transformed to total census estimate through multiplying by total Middle Rio Grande reach length = 242.6 km and average river width = 150m.

Year	CPUE (fish / 100m2)	Census estimate
1993	14.452	5,259,083
1994	15.285	5,562,212
1995	26.078	9,489,784
1996	1.400	509,460
1997	13.916	5,064,032
1998		
1999	6.289	2,288,567
2000	0.208	75,691
2001	0.814	296,215
2002	0.080	29,112
2003	0.025	9,098
2004	0.858	312,226
2005	36.990	13,460,661
2006	1.378	501,454
2007	10.847	3,947,223

These data were then plotted, and non-linear regression was used to fit an exponential growth curve of the form

$$N_t = N_0 \lambda^t$$

where N_t = population size estimate at time t, N_0 = population size estimate at time $t = 0$, λ = annual rate of population growth, and t is time in years. In our regression, N_t is the dependent variable and t is the independent variable.

Statistical analysis of the full dataset suggests a long-term rate of significant population decline (Figure 1). Through the 14 years that make up this analysis, the growth rate λ is estimated to be 0.927. This equates to, on average, a 7% decline in population census each year through the period of study. Of course, there is considerable variability in this rate of growth from year to year. This is not surprising for an "r-selected" species such as the silvery minnow. Despite the high levels of variability, in particular the apparent large increase in population size detected in the past couple of years, the overall trend in population size appears to be largely negative for most of the period of observation.

Perhaps it is more instructive to tease apart the population growth dynamics for this species into two relatively distinct time periods: a first period from 1993 – 2000, during which time population size was declining sharply; and a discrete second period from 2000 – 2007, where the census population began to show signs of increase. Similar statistical analyses were conducted separately on these two datasets, with the early period showing highly negative population growth ($\lambda = 0.837$) and the second period showing considerable positive growth ($\lambda = 1.285$). The specific causes of the apparent decline and subsequent rebound are beyond the scope of this particular document, but could be the source of additional discussion as the silvery minnow PVA continues to evolve.

Figure 1.
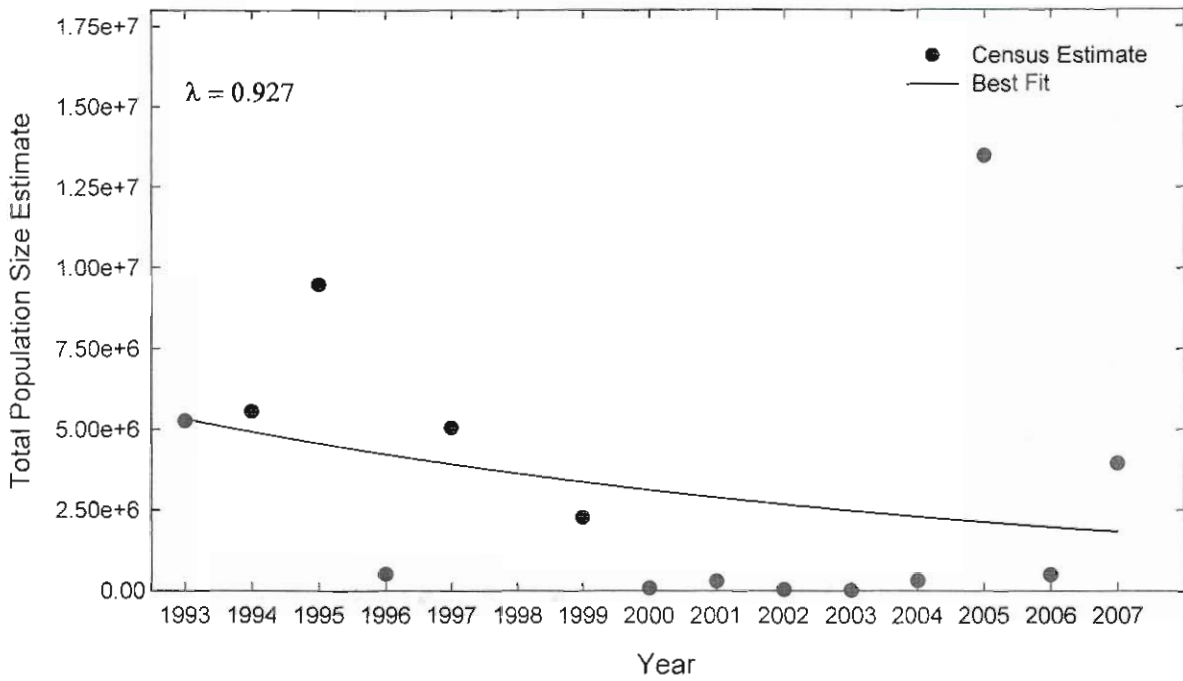

Estimated Population Trajectory: 1993 - 2007

Figure 2.
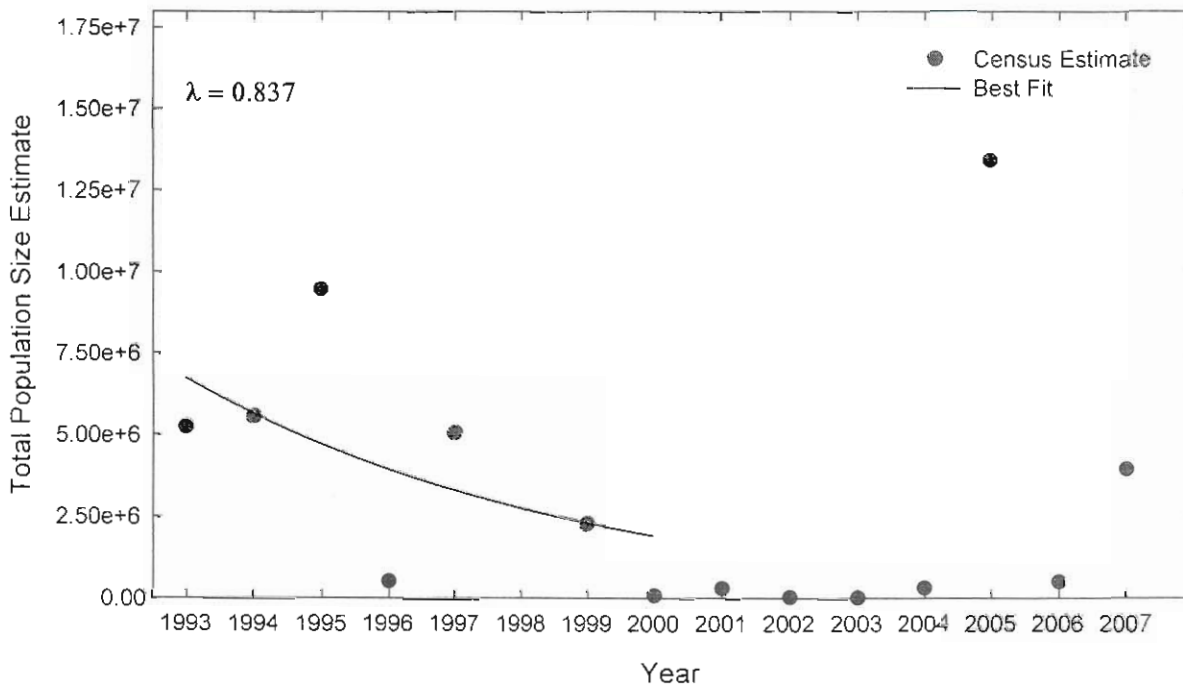

Estimated Population Trajectory: 1993 - 2000
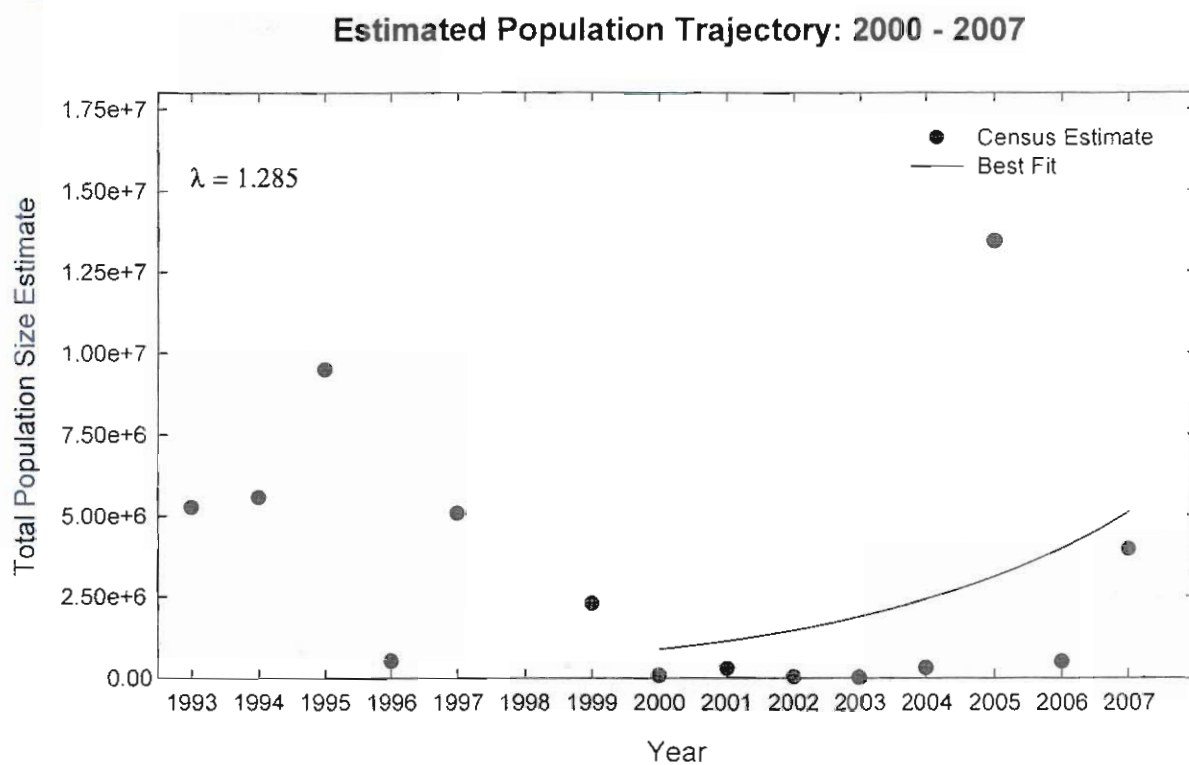
Figure 3.

Estimated Population Trajectory: 2000 - 2007

Reference

Maunder, M.N., J.R. Sibert, A. Fonteneau, J. Hampton, P. Kleiber, and S.J. Harley. 2006. Interpreting catch per unit effort data to assess the status of individuals stocks and communities. *ICES Journal of Marine Science* 63:1373-1385.