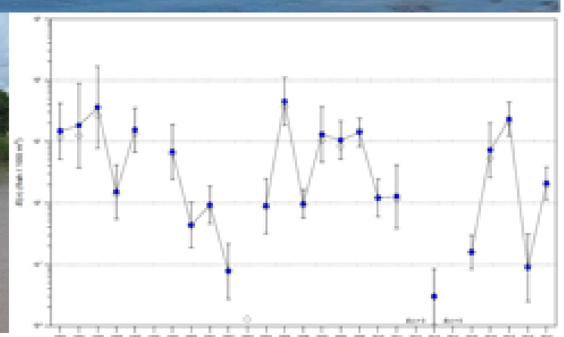
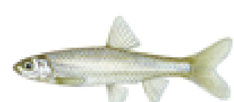
Review of the Middle Rio Grande Fish Monitoring Program



Status Report of:

The Population Monitoring Workgroup



Rio Grande Silvery Minnow

Prepared for:

The Middle Rio Grande Endangered Species Collaborative Program

In memory of Rick Billings, our beloved friend and colleague whose vision gave rise to many positive aspects of the Middle Rio Grande Program, including The Population Monitoring Workgroup

Review of the Middle Rio Grande Fish Monitoring Program

Status Report of

The Population Monitoring Workgroup
Richard A. Valdez, Ph.D.
Workgroup Chair (2019-2020)

Prepared for

The Executive Committee of
The Middle Rio Grande Endangered Species Collaborative Program
Albuquerque, New Mexico

Final

July 20, 2021

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Preface

The Population Monitoring Workgroup (PMWG) was formed in 2012 by the Executive Committee (EC) of the Middle Rio Grande Endangered Species Collaborative Program (MRGESCP) to evaluate the fish monitoring program for the Middle Rio Grande, with a focus on the Rio Grande silvery minnow. Of the three tasks assigned by the EC, Task 1 (science workshop) was completed in 2016, and Task 2 (review the fish monitoring plan) was completed in 2020. For Task 3 (updates to the fish monitoring plan), recommendations from the science workshop were incorporated into the monitoring plan in 2017, but additional recommendations were not developed before the PMWG was dissolved in December 2020.

The workgroup consisted of 15 to 20 technical and species experts from MRGESCP signatory organizations or contractors. The workgroup held 29 meetings over eight years, including seven virtual meetings starting in March 2020 because of the COVID-19 Pandemic. The proceedings of each meeting were documented, with presentations and other pertinent materials distributed as read-aheads and archived on the Program Portal. The meetings consisted of discussions and technical presentations that addressed the workgroup tasks and objectives, including topics related to the findings and recommendations of the Hubert et al. (2016) and Noon et al. (2017) science panels.

The information presented in this status report reflects a wide range of discussions and materials related to the monitoring program, as compiled and synthesized by the workgroup chair and author of this report. This report provides findings and recommendations pertaining to the monitoring plan for the Science and Adaptive Management Committee (SAMC) and the EC, who will make their own final recommendations. The report strives to provide an objective summary of the PMWG's activities over its eight-year span, and findings and recommendations are based on the best available scientific information.

Richard A. Valdez, Ph.D., Chair (2019-2020)
Population Monitoring Workgroup
July 20, 2021

Acknowledgments

Many individuals attended the population monitoring workgroup meetings and contributed to the information and materials presented in this report. Those individuals are too numerous to name, and the following is a list of the core members of the workgroup that attended meetings on a regular basis, and contributed substantially to the workgroup proceedings:

Member	Organization
Thomas Archdeacon	U.S. Fish and Wildlife Service
Rick Billings	Albuquerque Bernalillo County Water Utility Authority (ABCWUA)
Andy Dean	U.S. Fish and Wildlife Service
Kim Eichhorst	Bosque Ecosystem Monitoring Program, University of New Mexico
Lynette Giesen	U.S. Army Corps of Engineers
Eric Gonzales	U.S. Bureau of Reclamation
Grace Haggerty	New Mexico Interstate Stream Commission (NMISC)
Mo Hobbs	Albuquerque Bernalillo County Water Utility Authority
Joel Lusk	U.S. Bureau of Reclamation
Mike Marcus	Assessment Payers Association, Middle Rio Grande Conservancy District
Anne Marken	Middle Rio Grande Conservancy District
Mickey Porter	U.S. Army Corps of Engineers
Rich Valdez	SWCA, contracted by NMISC
Ara Winter	Bosque Ecosystem Monitoring Program, University of New Mexico
Matt Wunder	New Mexico Department of Game and Fish
Charles Yackulic	U.S. Geological Survey, contracted by NMISC and ABCWUA

Members of the WEST Program Support Team were instrumental in coordinating workgroup meetings and providing support and review of workgroup activities and of this report.

Preparation of this report was supported and funded by the New Mexico Interstate Stream Commission. Thanks to Thomas Archdeacon, Steve Carothers, Grace Haggerty, Mo Hobbs, Joel Lusk, Mike Marcus, Catherine Murphy, and Dave Wegner for their reviews and comments on parts or all of this report.

Cover photographs were provided by Mike Marcus.

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Executive Summary

A reliable and effective fish monitoring program is essential to support the goals of the Middle Rio Grande Endangered Species Collaborative Program (MRGESCP) and its signatories. A monitoring program with a well-designed sampling plan that systematically collects data and information is needed for a timely and accurate assessment of the year-to-year trends in abundance and up-to-date status of target species. These assessments are important aspects of an active adaptive management program in order to evaluate the effects of water management on the fish community of the Middle Rio Grande (MRG), particularly the endangered Rio Grande silvery minnow (*Hybognathus amarus*, RGSM).

Fishes of the MRG have been monitored annually since 1993. Sampling is conducted monthly from April to November at 20 sites in 151 miles from the Angostura Diversion Dam to the inflow of Elephant Butte Reservoir. Fish are captured with beach seines, and a mean catch-per-unit-effort (CPUE as number of fish per 100 m^2) is computed from an aggregate of the 20 sites for October and reported as an annual CPUE index of RGSM population abundance. This CPUE index is assumed to represent the overall density of RGSM in the MRG, and to incorporate and reflect the effects of natural flow and flow management in the MRG on the overall RGSM population.

This CPUE index is also used for various aspects of RGSM conservation, including criteria for the species recovery plan, surrogate measures of incidental take for the 2016 Biological Opinion (BiOp) for water operations in the MRG, to gage stocking of RGSM, and together with monthly data, to inform parameters in hydrology and population models. Data for other fish species, and for habitat and water quality are also collected as part of the monitoring plan and appended annually to a long-term database.

The Executive Committee (EC) of the MRGESCP formed the Population Monitoring Workgroup (PMWG) in 2012 with the goal *"…to evaluate and update the fish monitoring plan for the Middle Rio Grande…"* with *"…the focus…on the endangered Rio Grande silvery minnow, along with the identification and development of population demographic parameters…"*. The workgroup was formed in response to a letter from the U.S. Fish and Wildlife Service to the U.S. Bureau of Reclamation (Reclamation), recommending that the EC host a facilitated science workshop to resolve issues surrounding monitoring of RGSM that had been raised by a Science Review Panel and by the EC signatories.

Three tasks were identified by the EC, including Task 1 (a facilitated science workshop held in December 2015 with a science panel report [Hubert et al., 2016]); Task 2 (an evaluation of the sampling design, methods, protocols, and analyses for the current monitoring plan, as described in this report); and Task 3 (a revision and refinement of the monitoring plan to be implemented at the completion of Task 2). Initial recommendations from the science workshop were provided by the PMWG in 2017 to Reclamation and incorporated into the scope of work for fish monitoring. Additional recommendations were not reached before the PMWG was dissolved by the EC in December 2020 as part of the transition to a new Program structure.

Findings

This review found the following with respect to the goal and tasks assigned by the EC:

1. **The MRG fish monitoring plan provides systematic sampling that tracks year-to-year trends in relative abundance of the RGSM, but lacks the spatial and temporal resolution to evaluate species response to specific management actions.**

2. **The plan provides monthly data for estimating population demographic parameters of the RGSM, including age structure and vital rates (e.g., growth, survival, recruitment), that help to better understand the species' life history.**

3. **The hydrologic and geomorphic variabilities of the MRG, combined with the stochasticity of the RGSM population, limit the level of precision for the CPUE index, and may limit the efficacy of any practical sampling design to measure, with a high level of precision, the true status of the RGSM and its response to specific management actions.**

4. **A complete redesign of the fish monitoring plan is not currently warranted, but refinements could improve the precision of the CPUE, provide a better estimate of species status, and better represent the density of RGSM with CPUE, while providing cost-effective, consistent, and ongoing indices of trends in RGSM and monthly data for demographic parameters.**

The following are recommendations for the fish monitoring plan that are further detailed in the body of this report, and linked to basic questions and uncertainties in Table 3.

Recommendations (order does not reflect priority)

1. **Continue to implement the MRG fish monitoring plan, as conducted during 2017-2020 that includes the recommendations of the Hubert et al. (2016) science panel.** The plan should continue to track the long-term population trend of the RGSM, and continue to collect monthly data for population demographic parameters, including age structure and vital rates (growth, survival, recruitment), pending refinements that may be made under other recommendations.
2. **Evaluate the use of other fish sampling gear types, in addition to beach seines, as a discrete study of catchability to inform and possibly supplement the current monitoring plan.** A number of gear types are used to sample the RGSM in the MRG; these gears should be evaluated to determine if species and sizes of RGSM captured can inform the monitoring plan.
3. **Re-evaluate the relationship of CPUE to total abundance of RGSM, as a discrete study to derive independent estimates of the total numbers of RGSM in the MRG simultaneous to estimates of CPUE.** This relationship was developed for data collected in 2008-2011, but may change over time or with different RGSM abundance levels.
4. **Characterize the physical parameters of the principal mesohabitat types sampled as part of the fish monitoring plan to inform fish population models and hydraulic habitat models.** Measurements from representative mesohabitat types should include at least: depth, velocity, substrate, and cover.
5. **Refine the current monitoring plan to optimize precision and representation of the October CPUE, and continue to provide monthly data for estimating population demographic parameters, at acceptable program costs.** The refinement should use empirical data to develop a plan that continues to provide a consistent and reliable October CPUE for RGSM and monthly data for demographic parameters. The refinement should consider, but not be limited to: numbers and locations of sampling sites, random vs nonrandom sites, months sampled, use of other gear types, and additional measurements.
6. **Evaluate and compare other analytical methods against the mixture model and determine if other methods are more suitable for computing RGSM CPUE.** The mixture model addresses the zero-inflated CPUE data and the negative binomial distribution, but can be difficult to deploy and understand, and other models may be as effective and more easily applied.

7. **Develop and regularly evaluate integrated population models to help identify and reconcile complex environmental and resource influences on monitoring and RGSM CPUE, and determine if these models can be used to help evaluate RGSM response to management actions in the MRG.** Influences may include effects of habitat and river discharge on capture probability, prior year class strength, capture frequencies for small- and large-bodied RGSM, and salvage and stocking of RGSM.
8. **Draft a clear and concise MRG Fish Monitoring Plan for review and approval by the SAMC and the EC.** A stand-alone fish monitoring plan should be developed to archive the sampling design and methodologies used to monitor the RGSM. The plan should include an updated detailed description of fish sampling methodology; data analytical methods, including all variables and covariates of the model(s) used to compute CPUE; the rationales for site selection and apportionment of mesohabitat types sampled; and the intended result and use of the monitoring data.

1.0 Introduction

1.1 Genesis of the Population Monitoring Workgroup

The Population Monitoring Workgroup (PMWG) was formed by the Executive Committee (EC) of the Middle Rio Grande Endangered Species Collaborative Program (MRGESCP) in response to a March 23, 2012 letter from the U.S. Fish and Wildlife Service (USFWS, 2012) to the U.S. Bureau of Reclamation (Reclamation), recommending that the EC host a facilitated science workshop to resolve issues surrounding monitoring of the endangered Rio Grande silvery minnow (*Hybognathus amarus*; RGSM). As the MRGESCP proceeded with development of a Recovery Implementation Program, resolution was critical for issues surrounding population estimation and population monitoring of the RGSM, as previously raised by the Science Review Panel (Atkins, 2012) and by the EC signatories. Refinement of accurate demographic criteria through appropriate metrics and sampling methodologies was also important to the development of a reliable monitoring plan as part of an evolving adaptive management program. The Rio Grande silvery minnow is an indigenous species of the Middle Rio Grande (MRG) that was listed as endangered in 1994 under the Endangered Species Act.

The PMWG was formed July 13, 2012 with the goal of evaluating and updating the fish monitoring plan. The EC assigned the PMWG with three tasks, starting with the planning and conduct of the science workshop, in coordination with Reclamation. In addition to the workshop, the PMWG was asked to review and update the fish monitoring plan for the MRG. A workgroup chair was named by the EC, and each of the 17 program signatories was invited to send representatives as members of the PMWG. The PMWG was not chartered and was active for eight years until it was dissolved at the December 17, 2020 EC meeting, following a decision to adopt a new Science and Adaptive Management Plan (WEST, 2020).

1.2 Goal and Tasks of the PMWG

The primary goal of the PMWG was to *"…evaluate and update the fish monitoring plan for the Middle Rio Grande…"* with *"…the focus…on the endangered Rio Grande silvery minnow, along with the identification and development of population demographic parameters…"* (PMWG, 2012). This evaluation was intended to determine the efficacy of the current monitoring plan and to resolve how the plan can provide more reliable, precise, and accurate measures of the status and trend of the RGSM.

The following are the three tasks assigned by the EC:

1. Conduct a workshop on catch-per-unit-effort (CPUE) methodology used by the current RGSM population monitoring plan;
2. Review the MRG fish monitoring plan; and
3. Update the MRG fish monitoring plan.

Task 1 was completed with a CPUE Workshop in December 2015 and a report in 2016 (Hubert et al., 2016[1]). Task 2 was initiated in 2016 and the information contained in this report is an assimilation of the work by the PMWG. Task 3 was to be implemented at the completion of Task 2. Recommendations from the science workshop were provided to Reclamation by the PMWG in 2017 and incorporated into the scope of work for fish monitoring. Additional recommendations were not reached before the PMWG was dissolved by the EC in December 2020 as part of the transition to a new Program structure.

[1] The Expert Panelists for the CPUE Workshop included: Dr. Wayne A. Hubert, Professor Zoology and Physiology at the Univ. of Wyoming; Dr. Mary C. Fabrizio, Professor, Department of Fisheries Science, Virginia Institute of Marine Science; and Dr. Robert Hughes, Associate Professor, Department of Fisheries and Wildlife, Oregon State Univ.

1.3 Purpose and Use of This Report

The purpose of this report is to archive the work of the PMWG and to provide findings and recommendations for fish monitoring to the EC and the Science and Adaptive Management Committee (SAMC). This report assimilates the information gathered and evaluated by the PMWG as part of an objective and independent scientific review of the monitoring plan, and it provides findings and technical recommendations based on the workgroup deliberations and proceedings. This report offers recommendations for refining the plan, but it does not offer an update of the plan or alternative designs or costs that were part of Task 3. This report is the first step in evaluating the fish monitoring plan, and any refinements to the plan should be done in conjunction with the SAMC.

1.4 PMWG Process, Timeline, and Accomplishments

The process used by the PMWG to achieve the tasks assigned by the EC is outlined in Figure 1, and a timeline of meetings, actions, and reports of the PMWG is provided in Figure 2. Task 1 began with a survey of the EC members to determine the importance and need for monitoring (see section 3.1), and to help frame the questions for the CPUE workshop (see section 3.2). The workshop and the associated science panel report (Hubert et al., 2016) helped provide the foundation for transitioning to Task 2. Selected recommendations from the Hubert et al. (2016) panel were transmitted by the PMWG to Reclamation for implementation into the 2017 scope of work (SOW; see section 4.1), and the workgroup began to evaluate the remaining recommendations from the Hubert et al. (2016) and Noon et al. (2017)[2] science panels. A consolidated review of the panels was produced (Valdez and Marcus, 2020) that helped provide the foundation for this report. In 2020, the PMWG began work with a research scientist from the U.S. Geological Survey (USGS) under contract with the Albuquerque Bernalillo County Water Utility Authority (ABCWUA) and the New Mexico Interstate Stream Commission (NMISC) to develop an integrated RGSM population model (Yackulic, 2018). The model was developed to better understand the complexities of monitoring and the relationships of environmental correlates to the RGSM.

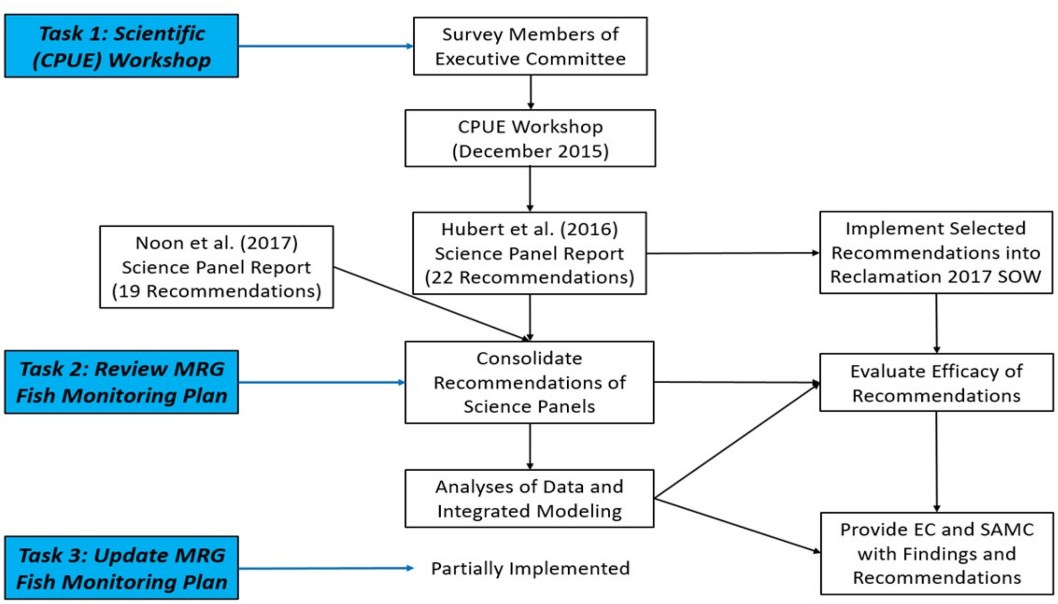


Figure 1. Population Monitoring Workgroup process for achieving the tasks assigned by the EC.

[2] The Noon science panel was convened as a group of subject matter experts to address scientific uncertainty for the RGSM as part of developing an adaptive management framework for the MRG (Caplan et al., 2017). The panel was convened independent of the PMWG, but its recommendations were considered relevant by the PMWG to the fish monitoring plan.

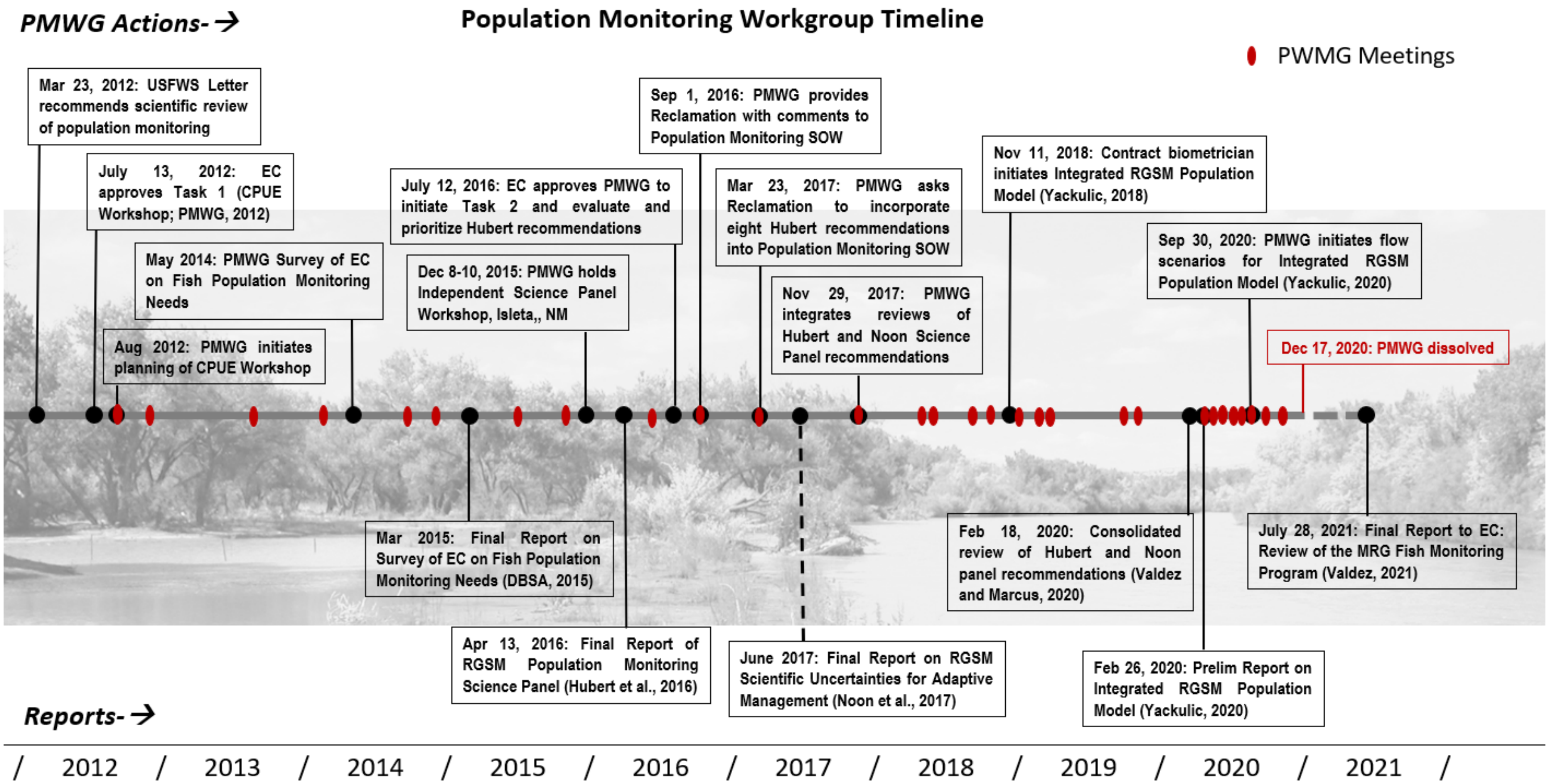


Figure 2. Timeline for Population Monitoring Workgroup (PMWG) actions and reports, 2012-2021. Actions are above the date line and reports are below.

Altogether, 29 PMWG meetings were held from July 2012 to December 2020 (Fig. 2) that focused on conducting the CPUE workshop and evaluating and implementing the recommendations of the two science panels. Planning for the CPUE workshop, selection and confirmation of science panelists, and setting up contracts and meeting logistics took over three years, during which time members of the PMWG conducted independent analyses of the monitoring data as part of evaluating population demographic parameters for the RGSM (see section 5.6). Results of those analyses as presentations and reports were provided as read-aheads to the PMWG and are archived on the Program Portal at: webapps.usgs.gov/mrgescp/. The reports and presentations by members of the PMWG are identified in the Literature Cited section of this report.

The following is a list of the more significant accomplishments of the PMWG:

1. Coordinated and completed CPUE Workshop and Report (Hubert et al. 2016).
2. Implemented Hubert recommendations into Reclamation's 2017 SOW for fish monitoring.
3. Consolidated Hubert (2016) and Noon (2017) science panel recommendations.
4. Analyzed monitoring data for demographic parameters (age, growth, survival).
5. Coordinated and helped develop the RGSM integrated population model (Yackulic, 2020).
6. Reviewed the fish monitoring program for EC.
7. Provided findings and recommendations to SAMC and EC.

1.5 Evaluation of Fish Monitoring Prior to the PMWG

The importance of a fish monitoring program for the MRG was recognized with formation of the MRGESCP in 2002. In 2004, the MRGESCP convened the Rio Grande Silvery Minnow Program Advisory Panel (PAP, 2005) and asked the panel *"…to assess the present situation in the MRG, to review past and present research and monitoring activities for the RGSM that are now under the umbrella of the Program..."* The PAP was asked five questions, including *"Are current research/restoration and monitoring activities adequate to: determine with statistical confidence RGSM population estimates, develop measurable recovery goals for the RGSM in the MRG, attain recovery of the RGSM in the MRG, and to measure success of recovery implementation actions?"* The answer was "no" and the PAP offered several recommendations for fish monitoring, many of which were addressed by the Hubert et al. (2016) and Noon et al. (2017) science panels, and some were incorporated into the current monitoring plan.

A second science panel, the Science Review Panel (Atkins, 2012), found that "*…the monitoring and estimation programs are producing high quality, reasonably accurate, and useful data in a timely, accessible, and understandable fashion,*" and recommended further evaluation, including "*…comparing monitoring and estimation results on a site basis rather than on an annual range wide basis.*" The issues raised by this science panel led to the USFWS's request for a facilitated science workshop.

In 2007, the EC established under charter, the "PVA Biology ad hoc Work Group." This workgroup helped to develop population viability analysis (PVA) models used by Reclamation and the U.S. Army Corps of Engineers (ACOE) in a biological assessment (BA) as part of a biological opinion (BiOp) for the 2010 irrigation season. The workgroup satisfied the needs of the BA and continued to meet regularly, helping to develop two PVA models that used the fish monitoring data as parameters. A RAMAS frequentist model was developed by Miller (2012), and a FORTRAN Bayesian model was partly developed by Goodman (2010). The output from these models was used to develop recovery criteria for the revised Rio Grande Silvery Minnow Recovery Plan (USFWS, 2010). The PVA Work Group ended in 2012, and some members transitioned to the PMWG, providing a continuity of understanding for fish monitoring.

2.0 Overview of the Fish Monitoring Plan

2.1 Basic Sampling Design

Fishes of the MRG have been monitored since 1993, with a focus on the RGSM. The basic sampling design is described here to provide a foundation for understanding the way that fish are currently sampled in the MRG and how the CPUE index of RGSM abundance is computed. A discrete and formal fish monitoring plan is not available, but the sampling design is described by Dudley et al. (2020).

- Twenty fixed (nonrandom) sites, each about 200 m long, are sampled in 151 miles of the MRG from the Angostura Diversion Dam (RM 209.9) to just upstream of Elephant Butte Reservoir (RM 58.5), including five sites in the Angostura reach, six in the Isleta reach, and nine in the San Acacia reach (Fig. 3). Sampling includes most of the MRG occupied by the RGSM (~160 mi).
- Sites are currently sampled annually during April through November (Table 1). Each site is sampled with 20 seine hauls apportioned by mesohabitat type, as available: runs and shoreline pools (4 each); backwaters, pools, and riffles (2 each), and the remaining samples are taken in shoreline runs (~6) (Fig. 4). Mesohabitats were first recorded by seine haul in 2002.
- CPUE is computed by site as the total number of fish caught with the 20 seine hauls divided by the total area seined, and is expressed as fish per 100 m^2. Arithmetic mean CPUE for October is computed as the average of the 20 site CPUEs. The variability of the annual October CPUE, as 95% CI, is computed with a mixture model and is displayed in Figure 4.

The following are observed characteristics about the sampling design:

- The number of sampling sites by month has remained approximately consistent at 20 sites for April to October starting in 2002, with few exceptions (Table 1).
- The number of seine hauls per site has remained nearly consistent at 20 hauls, such that a total of 400 seine hauls are taken in each month sampled (i.e., 20 seine hauls x 20 sites = 400 seine hauls).
- Ten sites were added each to April and October starting in 2017, as recommended by the Hubert science panel and requested by the PMWG to evaluate the effect of site numbers on CPUE and variance (see section 4.1).
- Replacement sites were added to replace dry sites when encountered, as recommended by the Hubert science panel and requested by the PMWG. Replacement sites were selected randomly using a generalized random tessellation stratified design (GRTS; Stevens and Olsen, 2004). Dry sites were encountered in October during 1994 (2), 2010 (1), 2012 (5), and 2015 (1) (see section 4.1).
- The arithmetic mean CPUE is reported monthly in the monitoring reports, and the mixture model mean is reported for October in the annual reports. The mixture model mean CPUE is a little different from the arithmetic mean CPUE because the mixture model accounts for the statistical nuances of the CPUE data (Fig. 4; see section 5.4).

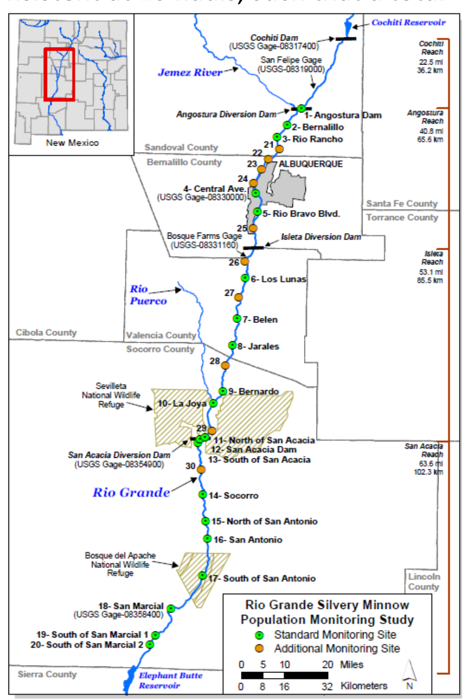


Figure 3. The MRG with 20 standard and 10 additional sites for fish population monitoring. Figure 1 from Dudley et al. (2020).

Data by Seine Haul (Site #10, RM 127)

Mesohabitat	Seine Haul	Area Seined (m²)	No. RGSM
MCPO	1	20	2
	2	18	1
	3	16	3
MCRU	4	29	0
	5	33	0
	6	37	0
	7	29	0
MCSHPO	8	18	1
	9	1	4
MCSHRU	10	29	0
	11	29	0
	12	29	1
	13	31	0
	14	32	0
	15	32	0
	16	31	1
	17	24	0
SCPO	18	16	0
	19	21	2
	20	1	8
Site Totals =		**474**	**23**

20 seine hauls x 20 sites = 400 seine hauls per month

Data by Site (October, 2017)

Site Number	Site (RM)	Area Seined (m²)	No. RGSM	Site CPUE
1	209.7	332	0	0.0
2	203.8	609	79	13.0
3	200	472	48	10.2
4	183.4	542	16	3.0
5	178.3	494	252	51.0
6	161.4	560	59	10.5
7	151.5	517	61	11.8
8	143.2	581	185	31.8
9	130.6	534	30	5.6
11	116.8	559	260	46.6
12	116.2	531	9	1.7
13	114.6	476	134	28.2
14	99.5	502	38	7.6
15	91.7	493	212	43.0
16	87.1	570	51	8.9
17	79.1	484	36	7.4
18	68.6	487	300	61.6
19	60.5	467	114	24.4
20	58.8	480	285	59.3
10	**127**	**474**	**23**	**4.9**
Arithmetic Monthly Mean (Oct 2017) =				**21.56**
Mixture Model Monthly Mean (Oct 2017) =				**23.17**
Mixture Model 95% CI =				**12.41 - 43.26**

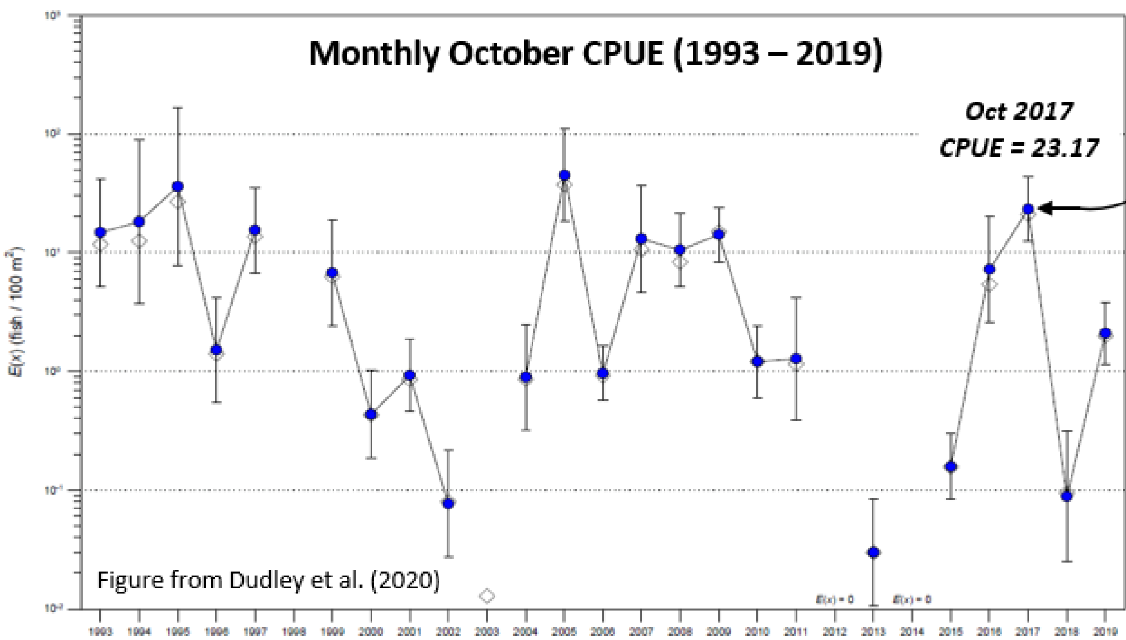


Figure 4. Basic sampling and computational design for mean monthly CPUE of RGSM in the MRG. The data used to compute CPUE in this example are from the population monitoring database (PMDB) for October 2017. Specific numbers associated with each of the 20 seine hauls are shown in the upper left table (light gray cells) for site 10 at RM 127. The sum of numbers for the 19 other standard sites are in the upper right table (white cells) as total area seined, total numbers of RGSM, and CPUE by site. The October CPUE displayed annually in the figure above from the population monitoring reports (e.g., Dudley et al., 2020, Figure 7) is computed as the mixture model mean CPUE with 95% confidence intervals (CI) for the 20 standard sites identified in Fig. 3. The PMDB is available at: https://webapps.usgs.gov/MRGESCP/documents/default.html

Table 1. Numbers of sites sampled by month for 1993-2019. The 20 sites sampled starting in 2002 are identified in Figure 3. Sampling was not conducted in 1998 or from January to August 2009. October CPUE is used as the annual census period. Numbers were tabulated from the PMDB.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Totals
1993		5	10		14		16			16			61
1994		15	1		13	2	16			15			62
1995		13			14			16		16			59
1996		16			16	16				18			66
1997			16				11	15		15			57
1998										[a]			
1999		15		15			15	15		15		15	90
2000		15		15		15		15		15		15	90
2001		20		14	6	19		19		20		20	118
2002	20	20	20	20	20	20	20	20	20	20	20	20	240
2003	15	25	20	20	13	22	25	20	20	20	20	20	240
2004	20	20	20	20	20	20	20	20	20	20	20	20	240
2005	20	20	20	20	20	20	18	22	20	20		20	220
2006	20	20	20	20	20	20	20	20	20	20		20	220
2007		20		20	20	20	20	20	20	20		20	180
2008		20		20	20	20	20	20	30	10[b]		20	180
2009									20	20		20	60
2010		20		20	20	20	20	20	30	10[b]		20	180
2011		20		20	20	20	20	40	20	[b]	5	15	180
2012		20		20	20	20	20	20	20	20		20	180
2013		20		20	20	20	20	20	20	20		20	180
2014		20		20	20	20	20	20	20	20		20	180
2015		20		20	20	20	20	20	20	20		20	180
2016		20		20	20	20	20	20	20	20		20	180
2017				30	20	20	20	20	21	30[c]	80[d]		241
2018				30	21	22	23	20	20	31[c]	80[d]		247
2019				40	10	20	20	20	20	30[c]	80[d]		240
Monthly Totals	95	384	127	424	387	396	404	442	381	481	305	345	4171

[a] no samples were collected in 1998
[b] samples taken in late September were used as the October samples
[c] ten additional sites annually were requested by the PMWG for April and October starting in 2017
[d] repeated sampling across multiple sampling occasions is conducted during November to estimate site occupancy rates and to evaluate sampling variation

2.2 Key Scientific Assumptions

This review found that the fish monitoring plan relies on two key scientific assumptions, each with levels of uncertainty that warrant further evaluation, as addressed by the recommendations in section 7.0:

1. **The mean annual October CPUE index represents the overall density of RGSM in the MRG.**
    a. The CPUE index is obtained from an aggregate of 20 sampling sites, each about 200 m long, altogether representing about 2.5 of 160 miles (1.6%) of habitat occupied by RGSM.
    b. Additional sampling and analyses are recommended to determine if the current number of sampling sites is suitable to represent the density of RGSM throughout the MRG.
2. **The October CPUE index incorporates and reflects the effects of natural flow and flow management in the MRG on the overall RGSM population.**

a. Mean annual October CPUE of RGSM is assumed to reflect the sum of river flow and water operations in the MRG that are managed principally through facilities located upstream of RGSM occupied habitat (e.g., Heron, El Vado, Abiquiu, Cochiti dams).

b. This relationship is integral to the 2016 BiOp and has been shown with a RGSM population model as a positive correlation between hydrology and abundance of RGSM, but specific mechanisms have not been parsed to evaluate causation.

2.3 Uses of Fish Monitoring Data by the MRGESCP

The mean annual October CPUE for RGSM and the data of all months sampled are used in a number of ways by signatories of the MRGESCP (Fig. 5), including:

- **Annual October Census**. The October CPUE is used as the annual index for overall RGSM population abundance (e.g., Dudley et al., 2020).
- **Criteria for RGSM Recovery Plan**. The October CPUE is used by the USFWS to gage recovery criteria for the Rio Grande Silvery Minnow Recovery Plan (USFWS, 2010).
- **Measure for ITS of 2016 BiOp.** The October CPUE is used by the USFWS as a surrogate measure of incidental take for RGSM (i.e., Incidental Take Statement [ITS]) in the 2016 Biological Opinion (BiOp; USFWS, 2016).
- **Help Determine Augmentation (Stocking) Targets of RGSM**. The September CPUE is used by the USFWS to determine augmentation (stocking) targets of RGSM (e.g., Archdeacon, 2019).
- **Evaluate BiOp Compliance for River Operations and Maintenance**. The CPUEs for RGSM in various months are used by Reclamation to evaluate compliance with the 2016 BiOp for river operations and maintenance.
- **Environmental Flow Analyses**. The May to July CPUEs are used by the ACOE for analyzing RGSM habitat use during spring floodplain inundation (e.g., Harris et al., 2018).
- **PVA, Hydrologic, and Integrated Models**. Monthly sampling provides data on CPUE and population demographic parameters that help inform the life history of the RGSM and are used to parameterize models that assess flow to RGSM relationships (e.g., Miller, 2012; Goodman, 2012a; Walsworth and Budy, 2020; Yackulic, 2020).

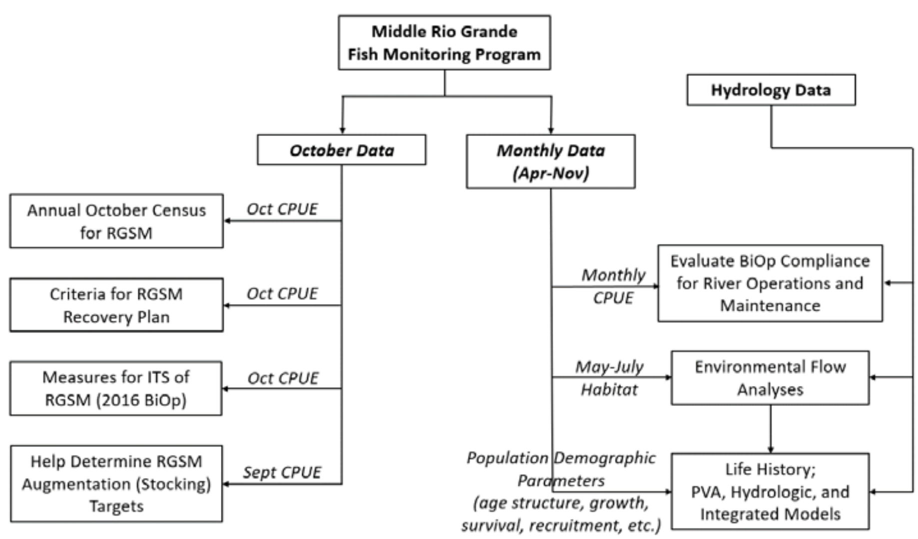


Figure 5. Uses of fish monitoring in the MRG.

2.4 Context for the Current Monitoring Plan

Systematic sampling of the MRG fish community began with a five-year investigation (1992-1996) funded by Reclamation and designed to determine the distribution and abundance of the RGSM, causes for decline, and recommendations for recovery, as the species was about to be federally listed as endangered (Platania, 1995). An extensive sampling inventory was conducted in 1992 at over 100 sampling localities between Cochiti Dam and Elephant Butte Reservoir. Each site was sampled twice (summer and autumn), generating over 200 samples. The 1992 fish inventory was used as the baseline data to document the most recent distribution and abundance of the RGSM, and for site selection of a fish monitoring program.

A subset of the 100 sampling sites was selected starting in 1993, as sites to be sampled under a Rio Grande Silvery Minnow Population Monitoring Program (Platania and Dudley, 2003). Sites were initially sampled quarterly (1993-1997), but the marked decline of RGSM recorded in 1996-1997 necessitated an increase in the frequency of sampling (from bimonthly for 1999-2001 to monthly for 2002-2004). The lack of timely issuance of federal endangered species permits precluded sampling in 1998, and sampling in 2009 was delayed until September because of contracting issues. From 2004 to 2016, sampling was conducted in 9-11 months annually, and starting in 2017, eight months were sampled annually (April-November). In the 26 years of sampling (1993-2019, except 1998), the month of October is the only month sampled in every year, and it is used as the annual census period for the RGSM (see Table 1).

Evaluating the efficacy of the MRG fish monitoring plan requires an understanding of the type of monitoring currently being conducted and the type of monitoring needed or expected (PAP, 2005). MacDonald et al. (1991) identified seven types of monitoring that can be used to better understand the type of monitoring currently being done in the MRG:

1. **Trend monitoring** is used to determine the long-term trend in a particular parameter from measurements taken at regular, well-spaced time intervals.
2. **Baseline monitoring** is used to characterize existing resource conditions, and to establish a database for planning or for future comparisons.
3. **Implementation monitoring** is used to assess whether activities are being carried out as planned, such as best management practices (BMPs) or proposed compliance measures.
4. **Effectiveness monitoring** is used to determine if a specific activity is having the desired effect.
5. **Project monitoring** is used to assesses the effect of a particular project or activity.
6. **Validation monitoring** is the quantitative evaluation of a particular standard or parameter.
7. **Compliance monitoring** is used to determine if certain preset criteria are being met.

The MRG fish monitoring plan is used as a **trend** or **baseline monitoring** program that provides an ongoing CPUE index of overall RGSM population abundance in the MRG. The fish community has been sampled at approximately the same locations and times, and with the same methods for 26 years. Data are collected annually and monthly within mesohabitat types at each of 20 sites and used to compute a mean annual October CPUE. This CPUE index is used to characterize the long-term trend of the RGSM population and to show the approximate magnitude of annual changes. The current monitoring plan is used to evaluate population-level responses to actions (e.g., stocking of RGSM), but is not designed for **project monitoring**, to evaluate RGSM response to specific actions or projects.

The October CPUE is also used for **effectiveness monitoring**, where CPUE point estimates of 1.0 and 0.3 fish per 100 m^2 are used as surrogate measures of incidental take of RGSM as part of the 2016 BiOp for water operations in the MRG (USFWS, 2016). The October CPUE of 5.0 fish per 100 m^2 is also used as recovery criteria for the species recovery plan (USFWS, 2010). It is assumed under the monitoring plan that the October CPUE index represents the overall RGSM density through all three reaches of the MRG, or ~160 miles of occupied habitat, and that changes in the October CPUE index reflect the effects of river flow on the RGSM population from overall MRG water operations that are managed principally through facilities located upstream of occupied habitat (e.g., Heron, El Vado, Abiquiu, Cochiti dams). The assumption that the October CPUE index represents the overall density of the RGSM is indicated by an independent study (Archdeacon et al., 2020; see section 5.1, question #1), but it is unclear if an assumed measure of density occurs at other abundance levels. The assumption that the October CPUE index reflects flow of the MRG is indicated by population models (Walsworth and Budy, 2020; Yackulic, 2020), but specific mechanisms have not been parsed to evaluate causation.

Monitoring the status and trend of a small, short-lived fish species like the RGSM is challenging because of the variability of the habitat in the MRG, the stochasticity of the RGSM population, and the need to use CPUE as an index of abundance. These factors affect or limit the precision of the CPUE and are described as:

1. **Dynamics of the MRG hydrology and geomorphology.** The MRG is a dynamic system that is characterized by high variability in seasonal and annual flow and sediment, and by a shifting sand-bed channel that imposes constant changes and stressors on fish habitat (Makar and AuBuchon, 2012; Mortensen et al., 2019). These physical variabilities create different conditions with every sampling event that are reflected in the variability of the CPUE index. No adjustments are made to CPUE to account for this variability, except to sample by mesohabitat type. An additional adjustment could be made by accounting for mesohabitat-specific capture probability of RGSM.
2. **Stochasticity of the RGSM population.** The numbers of RGSM in the MRG can vary dramatically by month and year (Dudley et al., 2020). This inherent stochasticity, combined with a schooling behavior, can contribute to a highly variable CPUE index.
3. **Physiological characteristics of RGSM.** The RGSM is censused with a CPUE index because of its small average size (~35 mm TL) and short life span (1-2 years). The CPUE index is a measure of the number of fish captured in an area of river and reflects the variability described in factors 1 and 2 above. Other more statistically robust census methods, such as mark-recapture estimators, can help resolve some of the variability, but these require a long-term mark or tag for each fish (e.g., Passive Integrated Transponder [PIT] tag) that is impractical for the RGSM because of its small size and short life span.

The system variability of the MRG, and the stochasticity of the RGSM population, limit the level of precision possible for a CPUE index, and may limit the efficacy of any sampling design to measure, with a high level of precision, the true status of the RGSM and its response to specific management actions or projects.

3.0 Task 1 Results and Findings

The purpose of Task 1 was to evaluate the CPUE index and associated methodology through a workshop of external scientists and technical experts from the program signatories. The following is a summary of the results and findings for Task 1.

3.1 Survey of Executive Committee Members

To gage the EC's understanding of the fish monitoring program, the PMWG requested in May 2014 that EC members individually complete a survey on the importance of the monitoring program for ten pre-identified needs (Fig. 6), and how well the program addressed each need (DBSA, 2015). The EC was not provided with any information about the monitoring plan prior to the survey. The results of this survey were used to help formulate four primary questions posed to the CPUE workshop science panel (see section 3.2). The survey was divided into the following two categories:

A. The level of importance of each identified need, based on a scale of 1 to 6, with 1=not needed, 2=may be needed, 3=needed, 4=important need, 5=critical need, and 6=don't know.
B. How well the current monitoring program addresses each identified need, based on a scale of 1 to 6, where 1=poor, 2=fair, 3=well, 4=very well, 5=excellent, 6=don't know.

Eleven of the 17 EC members responded as shown in Figure 6 and summarized below:

- Median scores of 3-5 for category A (blue bars) indicate that the respondents felt that the monitoring program was important or critical to the stated needs.
- Median scores of 1-3 for category B (orange bars) indicate that the respondents felt that the monitoring program addressed the 10 stated needs as poor to well.

Importantly, most respondents opined that evaluating species response to management actions was a critical need that was currently being poorly addressed by the current monitoring program.

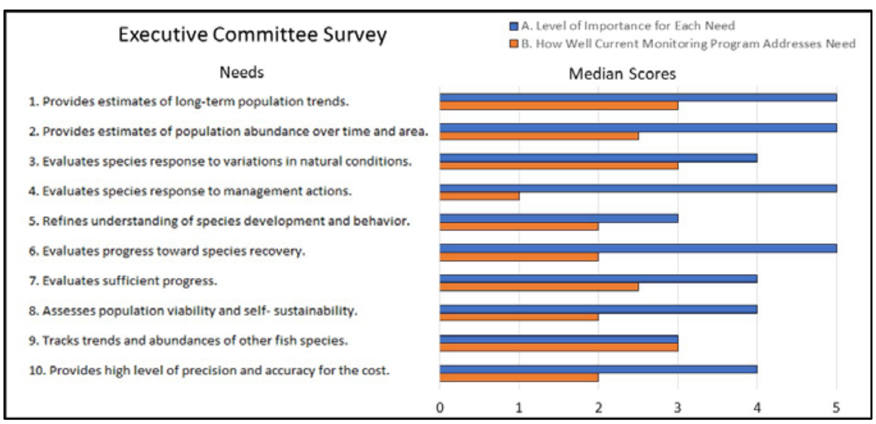


Figure 6. Results of Executive Committee survey, May 2014.

3.2 CPUE Workshop

The workshop recommended by the USFWS (see section 1.1) was held December 8–10, 2015 at the Isleta Resort and Casino near Albuquerque, NM. The purpose of the workshop was to evaluate CPUE as an index of RGSM population abundance, and to resolve issues surrounding population estimation and population monitoring of the RGSM. Workshop logistics and administration were coordinated by the PMWG and a Reclamation contractor, Atkins North America. The workshop was held in a large conference room with 17 technical experts representing the signatories of the MRGESCP and three independent external scientists (science panel) selected from a pool of nationally recognized experts. The workshop was open to the public and the chair of the science panel facilitated the sessions.

Four primary questions were posed by the PMWG in advance of the workshop and addressed by the science panel and workshop participants. The science panel produced a final report on April 13, 2016 including workshop proceedings and recommendations (Hubert et al., 2016). The following are the four questions with the science panel responses italicized. Each of the responses was used by the science panel to provide a foundation for their recommendations for monitoring, as described in section 4.0.

1. **Is the CPUE index appropriate for monitoring the Rio Grande silvery minnow in the Middle Rio Grande?**
   The expert panelists concluded that CPUE indices are appropriate for monitoring RGSM in the MRG, but the indices may be improved if the current data recording and computational techniques are modified as described below.

2. **Are the monitoring plan and sampling design appropriate for tracking the status and trend of the RGSM in the Middle Rio Grande?**
   The panelists concluded that the monitoring plan and sampling design with the small-mesh seines are appropriate for tracking the status and trends in abundance and occurrence of the most recent cohort of RGSM…except when sampling sites are observed to be dry. Similarly, the monitoring plan and sampling design for fine-mesh seines are appropriate for larval RGSM, but may also produce naughty naughts[3] when dry sampling sites are observed. The panelists identified five considerations for survey designs applicable to the Population Monitoring program: (1) random versus non-random site selection, (2) fixed-site versus variable-site sampling, (3) adequate sample size, (4) sub-population inclusion, and (5) consistent site-scale sampling protocols sufficient to capture natural habitat variability.

3. **A. Are the statistical analyses used in the Monitoring Program appropriate and in line with data distributions and characteristics?**
   In general, the mixture model approach currently used in the Monitoring Program to analyze the catch data is appropriate given the distribution of the data and the characteristics of those data. However, as pointed out above, improvements are needed in the manner in which data are handled (e.g., zero observations from dry sample sites, catches from multiple gears) prior to statistical analysis with mixture models.

   B. Are there additional analytical techniques that could be used that would improve the use of CPUE?
   Additional analytical techniques may be explored, but it is unclear if such approaches would reduce bias or improve precision of CPUE estimates. Comparative analyses or simulation studies are needed to ascertain if analytical improvements can be obtained or the possible magnitude of improvements.

4. **What revision can be made to the sampling design to improve accuracy, precision, and power to detect change in RGSM abundance?**
   Although a revision should not be implemented without strong empirical evidence that an alternative sampling design and method provide more accurate and precise estimates of CPUE, the expert panelists feel that several possible revisions could further strengthen the program.

[3] "naughty naughts" refers to zero CPUE being assigned to dry sites.

4.0 Task 2 Results and Findings

4.1 Science Panel Recommendations Implemented into the Fish Monitoring Plan

The workshop science panel provided 22 recommendations for CPUE computation, survey design, and future research (Hubert et al., 2016). Following the science panel report, the PMWG prepared a memorandum to Reclamation (PMWG, 2017) requesting inclusion of those recommendations that would be most easily implement in a revised monitoring contract. Reclamation agreed to include eight recommendations as tasks in the 2017 SOW (Reclamation, 2017a), and all or part of these were implemented into the monitoring plan (Fig. 7). The results of these recommendations are evaluated in section 5.0 of this report. The following is a description of each implemented recommendation:

1. **Additional Sites**. For two of the seven monthly sampling events, increase the total number of sites by 10 additional sites, representing 10 sites in each of the three reaches (total of 30). This shall occur once in either March or April, and again in October. Sampling in the other five months shall occur at the standard 20 sites. An "Additional Sites Protocol" was provided to the PMWG (Reclamation, 2017b). This recommendation was implemented in 2017.
2. **Replacement Sites**. If any of the 20 standard sites are dry at the time of sampling, alternative replacement sites are selected to bring the sample total back to 20 sites. Any of the 20 standard sites that are dry shall be recorded as such, according to the current monitoring protocol (Dudley et al., 2020). Replacement sites, as needed, shall be kept the same to the extent possible for use in subsequent years, when needed. A "Replacement Sites Protocol" was provided to the PMWG (Reclamation, 2017c). This recommendation was implemented in 2017.
3. **Additional Monthly Sampling**. Conduct monthly sampling in two additional months (December and February) with the same protocol as the standard 20 sites. This was implemented in 2017.
4. **Additional Sites in Option Year**. Increase the number of sample sites to 20 sites per reach (total of 60 sites) at two of the monthly sampling events – once in either March or April, and again in October. This was not implemented because of cost and logistical considerations, and only 10 sites were added for a total of 30 sites (10 sites per reach; see recommendation #1 above).
5. **Intensive Sampling Month**. Conduct field sampling to determine site-specific sampling variation one month of the year (i.e., November). This was implemented in 2017.
6. **Additional Data Per Seine Haul**. During monthly sampling, collect the following additional data for each seine haul, identifying the associated mesohabitat type and include in the monthly and annual reports: (a) current velocity, (b) depth, and (c) substrate size (visually determine). For each site (not per seine haul), collect three measurements each of (d) turbidity and (e) water temperature. Items d and e were implemented in 2017, but not a through c.
7. **CPUE Calculations**. Specific CPUE calculations and reporting elements are required as part of the SOW, including: (a) across the 20 standard sites, which does not include dry sites, (b) across the 30 total sites during the two months (March or April and October), (c) compare CPUE from 20 standard sites with 30 sites during the two months (March or April and October), (d) compare the CPUE with and without replacement sites, and (e) report the number of RGSM in each mesohabitat type, including zero detections. These were implemented in 2017.
8. **Other CPUE Calculations and Reporting**. Other CPUE calculations and reporting elements were required as part of the SOW, including: (a) CPUE calculation specific to the small mesh seine for YOY fish only, across all sites, (b) CPUE calculation specific to the small mesh seine for non-YOY (all older age classes combined) fish, across all sites, and (c) CPUE calculation specific to the fine mesh seine for larval fish only, across all sites. These were implemented in 2017.

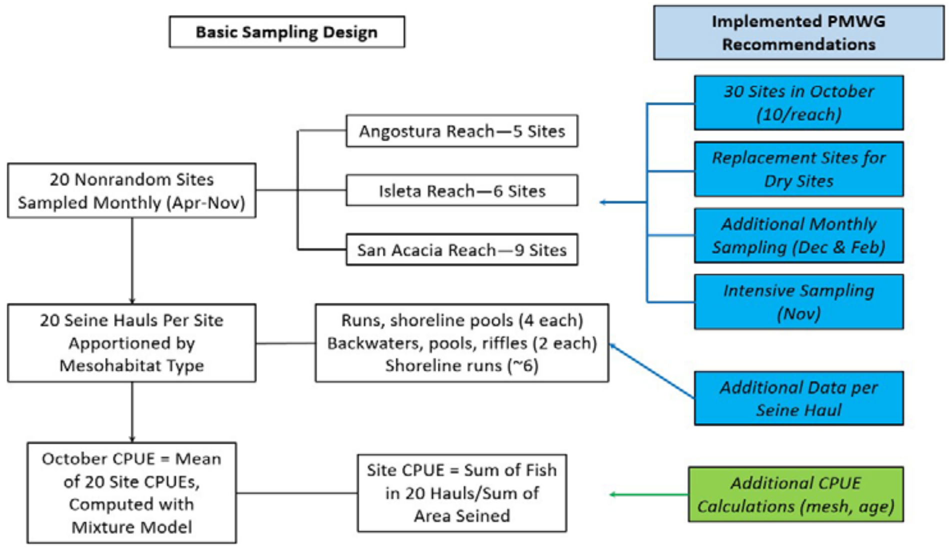


Figure 7. Basic sampling design and implemented PMWG recommendations for the fish monitoring plan in the MRG.

4.2 Evaluation and Prioritization of Science Panel Recommendations

The PMWG evaluated and prioritized the recommendations of the two science panels, including 22 from the Hubert panel (Hubert et al., 2016) and 19 from the Noon panel (Noon et al., 2017) for further analysis and to help inform the monitoring plan evaluation under Task 2. The recommendations of the Hubert panel are linked to all six of the Task 2 objectives (as reflected in the four questions, see section 3.2), and the Noon panel recommendations linked to the last three objectives (Fig. 8).

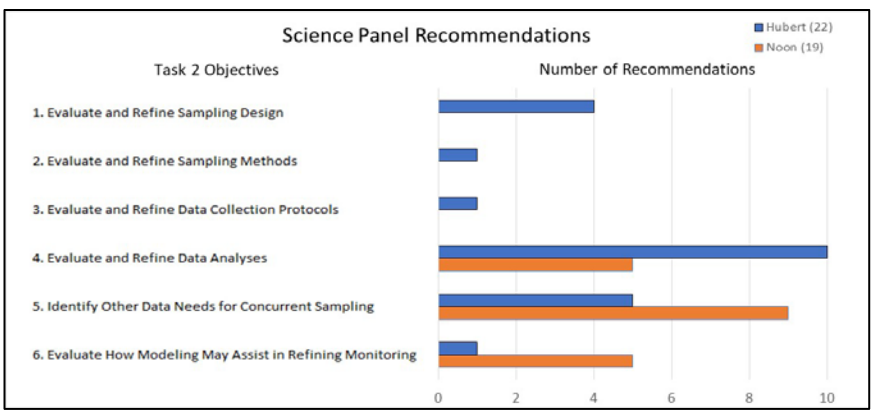


Figure 8. Number of Science Panel Recommendations linked to each of the six Task 2 objectives.

To more easily address the recommendations of the two science panels, the PMWG consolidated the 41 recommendations into 22 “science topics” that reflected commonalities (Table 2; Valdez and Marcus, 2020). Not all of the topics were related to monitoring, and the integration of those recommendations relevant to the monitoring plan are reflected in the basic questions addressed in section 5.0. Of the 22 science topics, five are completed, six have preliminary results with further evaluation needed, seven are ongoing model analyses, and four have not been implemented. The six topics with preliminary results will be further evaluated through recommendations described in this report. The seven model analyses are part of an ongoing integrated modeling exercise involving members of the PMWG. The four topics that have not been implemented were either scheduled for implementation under Task 3, or involve complex analyses that require additional statistical expertise and assistance.

Table 2. Findings and status for 22 science topics consolidated from 41 recommendations of the Hubert and Noon science panels, listed by Task 2 objectives. Recommendation numbers from the Hubert and Noon science panel reports correspond to each of the science topics. The science topics are listed numerically for reference and are not in any particular order or priority. The status of each science topic evaluation is color coded and summarized in section 4.2. Blue = evaluation completed, green = preliminary results—further evaluation needed, yellow = ongoing model analysis, and red = evaluation not implemented.

Science Topic by Task 2 Objective	Recommendation Number		Findings	Status
	Hubert	Noon		
1. Evaluate and Refine Sampling Design				
1. Consolidation of mesohabitats for monitoring RGSM	--	E3	• Analysis of PMDB showed that select mesohabitat types yield different mean annual Oct CPUEs than current monitoring, may not all be present at sampling sites, and cannot be used for standard monitoring (Valdez, 2019; see section 5.1). See also Marcus (2020).	Evaluation Completed
2. Effect of increased sample size on RGSM monitoring	12, 13	--	• Field study showed little change in mean CPUE and variability between 15 and 20 seine hauls by site, confirming that the 20 hauls currently taken is sufficient (Archdeacon et al., 2020). • Field study showed that variability in CPUE decreased from 20 to 40 sites sampled (Archdeacon et al., 2020), indicating that precision is improved by sampling 40 sites (Archdeacon et al., 2020). • Power analysis with PMDB showed decreased variability in CPUE up to about 60 sites, indicating that precision is improved by sampling up to 60 sites (Valdez, 2019).	Evaluation Completed
3. Implement studies using different sampling designs	19	--	• Not implemented, would be done under Task 3.	Evaluation Not Implemented
2. Evaluate and Refine Sampling Methods				
4. Develop and deploy "vertically-integrating" Moore egg collectors	--	B1, E2	• A vertical, multi-level egg collector has been designed by the ACOE and was evaluated in a wadeable channel (i.e., the low flow conveyance channel of the MRG) (Porter et al., 2021).	Evaluation Completed
5. Selectivity of gears used to sample RGSM	--	E1	• An independent study (Gonzales et al., 2012a) found that beach seines were most effective for sampling fish in the main channel of the MRG, and fyke nets were more effective at sampling fish in floodplains and side channels. • Regular and larval seines capture a full range of RGSM sizes available, but other gears not used in monitoring are more efficient at catching small larvae (dip nets) and large RGSM (fyke nets) (Valdez et al., 2020); the latter indicates that large RGSM are present and not captured with regular seines during monitoring (see section 5.2).	Preliminary Results—Further Evaluation Needed
3. Evaluate and Refine Data Collection Protocols				
6. Effect of environmental factors on seine capture probability	7, 8	--	• This analysis is ongoing as part of the RGSM integrated population model (Yackulic, 2020) (see section 5.6).	Ongoing Model Analysis
4. Evaluate and Refine Data Analyses				
7. Relationship of CPUE and true population size of RGSM	--	A1	• Field study conducted 2008-2011 showed a correlation between CPUE and depletion estimator within a small enclosure (Dudley et al., 2012); some question the dependence of the two estimates and additional evaluation is recommended (Goodman, 2011; Valdez, 2018b) (see section 5.4).	Preliminary Results—Further Evaluation Needed
8. Age-specific survival of RGSM	--	A2, A3	• Annual survival of 0.03, 0.03, and 0.11 for age-0, age-1, and age-2 RGSM, respectively, using CPUE data in a negative exponential function (Valdez, 2018d) is within a range of annual adult survival (0.02−0.06) derived with an integrated RGSM model (Yackulic, 2020) (see section 5.6).	Ongoing Model Analysis

Science Topic by Task 2 Objective	Recommendation Number		Findings	Status
	Hubert	Noon		
9. Age composition of RGSM population	--	C, E1	• Age determination from scales and otoliths indicate that the RGSM population is dominated by age-0 fish with some age-1 and few age-2+ (Horwitz et al. 2018). • Modal separation analyses for lengths of RGSM from the PMDB indicate that larger and older fish are present in the population than captured by monitoring, but their numbers and significance to reproductive potential are uncertain and should be further evaluated with an integrated model (Valdez 2018c).	Ongoing Model Analysis
10. Compute CPUE from larval and standard seines by age	1, 2, 3	--	• CPUE for larval and standard (regular) seines has been computed annually starting in 2017 (Dudley et al., 2020) (see sections 4.1 and 5.4).	Evaluation Completed
11. Evaluate effect of zero catches on CPUE and sample design	4, 5, 6	--	• Dry sites have been replaced, and CPUE and variance with and without "replacement sites" has been computed annually starting in 2017 (Dudley et al., 2020) (see sections 4.1 and 5.4).	Evaluation Completed
12. Mixture model and alternatives for computing RGSM CPUE	10, 11, 14, 17	--	• Not implemented, requires additional statistical expertise.	Evaluation Not Implemented
13. Use classification and regression trees, boosted regression trees, or random forests to examine relationships of hydrologic variables and CPUE	18	--	• Not implemented, requires additional statistical expertise.	Evaluation Not Implemented
5. Identify Other Data Needs for Concurrent Sampling				
14. Size and age-specific fecundity of RGSM	22	A4, B3	• Batch fecundity (total number of spawned eggs) ranged from 2,029 eggs in age-1 fish to 10,588 eggs in age-4 for captive fish (Caldwell et al., 2019); additional work needed with wild fish.	Preliminary Results—Further Evaluation Needed
6. Evaluate How Modeling (e.g., PVA) May Assist in Refining Monitoring				
15. Relationship of demographic rates and abiotic and biotic factors	10, 24	A5	• This analysis is ongoing as part of the RGSM integrated population model (Yackulic, 2020) (see section 5.6).	Ongoing Model Analysis
16. Evaluate existence and strength of density dependence to limit population	21	A6	• This analysis is ongoing as part of the RGSM integrated population model (Yackulic, 2020) (see section 5.6).	Ongoing Model Analysis
17. Effect of augmentation on RGSM population	--	A7	• Augmentation of RGSM is being documented as it occurs (e.g., Archdeacon, 2019). This analysis is ongoing as part of the RGSM integrated population model (Yackulic, 2020) (see section 5.6).	Ongoing Model Analysis
18. Contribution of salvaged RGSM to population dynamics	--	A8	• Rescue of RGSM is being documented as it occurs (e.g., Archdeacon, 2018). This analysis is ongoing as part of the RGSM integrated population model (Yackulic, 2020) (see section 5.6).	Ongoing Model Analysis
19. Effect of environmental cues on spawning onset and activity	--	B2, D2	• Field studies show preliminary results on timing of spawning from daily ages of RGSM larvae (Valdez et al., 2019, 2020; Zipper et al., 2020). Further investigations ongoing by USFWS.	Preliminary Results—Further Evaluation Needed
20. Spatial extent and historical availability of habitat and hydraulic quality used by RGSM	16	D1	• Part of ongoing work by Reclamation (Yang et al., 2019).	Preliminary Results—Further Evaluation Needed
21. Roles and relative contributions to fish production by age in channel and floodplain habitats	--	D3	• Ongoing work in floodplains (Valdez et al., 2019, 2020; Harris et al., 2018).	Preliminary Results—Further Evaluation Needed
22. Evaluate management potential for fish production by reach	--	D4	• Not implemented, requires integrated population modeling.	Evaluation Not Implemented

5.0 Evaluation of Task 2 Objectives

The purpose of Task 2 was to review and evaluate the MRG fish monitoring plan through six objectives. This section describes the evaluation and analyses for each of the objectives using information from the two science panels, independent studies, reports, and publications; as well as analyses and presentations by the members of the PMWG (see Literature Cited for specific references). The six objectives of Task 2 are:

1. Evaluate and refine sampling design, including statistical properties of spatial aspects (longitudinal locations of sample sites, habitats in which samples are taken) and temporal aspects (frequency of sampling, times of year when samples are taken);
2. Evaluate and refine sampling methods, including gear types, sampling strategies, etc.;
3. Evaluate and refine data collection protocols, including types of data collected, recording methods, quality control, electronic storage, and data custody;
4. Evaluate and refine data analyses;
5. Identify other data needs for concurrent sampling during fish monitoring to support other studies (e.g., augmentation, fish movement, drying, genetics, adaptive management) as part of a programmatic monitoring program; and
6. Evaluate how modeling (e.g., PVA) may assist in refining monitoring.

For each objective, one or more basic questions are posed in the ensuing subsections, with responses that help focus the evaluation on the most pertinent and relevant issues of the monitoring plan. These questions were derived from the science panel reports and recommendations, and from discussions in meetings of the PMWG. They are numbered sequentially, highlighted in red italics, and described in sections 5.1 to 5.6. Responses to questions are provided in gray boxes, followed by a series of bulleted statements that explain the question and the response. The basic questions, responses, critical uncertainties, and recommendations are summarized in Table 3. Critical uncertainties and recommendations are topics or issues that the SAMC may choose to further investigate as part of the fish monitoring plan.

Of the 18 questions associated with the six objectives of Task 2, the PMWG analyses led to responses and identified critical uncertainties that resulted in six recommendations. Two more recommendations were identified (i.e., continue to implement the current fish monitoring plan, and draft a clear and concise MRG Fish Monitoring Plan) for a total of eight technical recommendations (see section 7.0). These are separate and apart from the eight recommendations of the Hubert et al. (2016) science panel that were advanced to Reclamation and incorporated into the 2017 SOW for fish monitoring (see section 4.1). Additional recommendations were not reached under Task 3 before the PMWG was dissolved by the EC in December 2020 as part of the transition to a new Program structure.

This section references a number of reports and publications in the Literature Cited section of this report. Members of the PMWG authored 16 documents that were relevant to evaluating the fish monitoring plan. The data analyzed for 12 of these documents were from the population monitoring database (PMDB), available at: https://webapps.usgs.gov/MRGESCP/documents/default.html. The remainder were collected for independent studies and are available from the cited authors. The hydrology data are from the U.S. Geological Survey Surface Water Data for the Nation, New Mexico, available at: https://waterdata.usgs.gov/nm/nwis/dv/?referred_module=sw. Documents authored by members of the PMWG are identified with footnotes in the Literature Cited section.

Table 3. Basic questions, responses, critical uncertainties, and recommendations for the 18 basic questions for the six objectives of Task 2. See sections 5.1–5.6 for information on each basic question.

No.	Basic Question	Responses	Critical Uncertainties	Recommendations
1. Evaluate and Refine Sampling Design				
1	How many sites should be sampled?	• At least 30 sites should be sampled in October and increased to as many as 60 sites to improve mean annual CPUE precision and to provide greater representation of CPUE for RGSM in the MRG. • All other months can be sampled at 20 sites. • An independent field study and a separate power analysis found improved precision of CPUE (95% CI, relative variability, CV) by increasing total numbers of sites to between 40 and 60.	• The current monitoring program samples fish at 20 sites monthly, each about 200 m long; hence, sampling in 2.5 miles of the MRG (1.6%) is used to represent the density of the RGSM in about 160 miles of occupied habitat. • Increasing from 20 to 30 sites in October from 2017 to 2020 has improved precision with a similar CPUE. • The numbers of sites necessary for CPUE to represent density of RGSM in the MRG is uncertain.	• Increase the number of sampling sites in October up to 60 to evaluate improved precision and representation.
2	Should sample site selection be random or nonrandom?	• Sampling in the MRG is done at nonrandom sites that should be evaluated to determine if CPUE from these sites is representative of RGSM density through occupied habitat. • An independent study found no significant difference for fish species composition and CPUE of RGSM for random vs nonrandom sites in the MRG, but a transferability study is recommended to determine if these results can be applied to the standard monitoring sites.	• Transferability of the findings of the independent study to the 20 standard monitoring sites in the MRG, with respect to representation, is uncertain and should be evaluated.	• Conduct a transferability study to determine if the nonrandom sampling sites are representative of RGSM density and free of bias.
3	How many seine hauls should be taken?	• An independent study showed a diminished improvement in precision of CPUE with more than about 15 seine hauls per site; the 20 hauls currently taken are sufficient to detect RGSM presence at sites. • The study also showed that increasing the size (area) of each seine haul did not significantly affect CPUE variability; hence the area currently seined with each haul is sufficient.	• None	• None
4	Which mesohabitat types are sampled most often and which have the highest CPUE?	• Ten mesohabitat types comprised 97% of all seine hauls taken for 2002-2017, but only four of these had the highest mean CPUEs (MCSHPO, BW, MCPO, SCSHPO). • The six mesohabitat types with the highest mean CPUEs were from pools (MCPO, MCSHPO, SCPLPO, SCPO, SCSHPO) and backwaters (BW).	• None	• None
5	Can a reliable CPUE be obtained from sampling certain mesohabitat types?	• No—six types with highest October CPUE (see Question #4) yielded a higher CPUE than the current plan, and not all mesohabitat types were available at all sites sampled 2002-2017.	• None	• None
6	Is annual monitoring for April through November necessary?	• Yes—annual monitoring is necessary because the RGSM is short-lived and the population can vary considerably by year. • However, monthly samples from April through November may not be necessary, as data for population demographic parameters may be procured from fewer months (e.g., Jun-Oct).	• Uncertain if fewer months can be sampled to procure data necessary for population demographic parameters of RGSM, including age structure and vital rates (e.g., age structure, growth rate, survival, recruitment, etc.).	• Continue to sample monthly from June to November with 20 sites per month, except for October with up to 60 sites. • Samples in April and May add little to population demographic parameters (e.g., age, growth, survival, recruitment) and could be eliminated.
7	Is October the best census month?	• Yes—resource and environmental variability are low in October; i.e., CPUE is least variable and flow variability is moderate among months.	• None	• None

No.	Basic Question	Responses	Critical Uncertainties	Recommendations
		• An October census does not represent year-class strength for the following spawning year, as would a census in March or April, which would have high variabilities in CPUE and flow.		
2. Evaluate and Refine Sampling Methods				
8	Are beach seines the appropriate gear for sampling RGSM?	• Yes—the Hubert et al. (2016) science panel found that small-mesh and fine-mesh seines used to sample RGSM in the MRG are appropriate, when CPUE is computed separately. • An independent study found that beach seines were the best gear for sampling fish in the MRG main channel, but fyke nets collected more fish in floodplains and side channels.	• Other gear types have been used in the MRG, but none has been evaluated as part of standardized monitoring, including dip nets, fyke nets, block seines, boat and backpack electrofishing.	• Evaluate the use of other fish sampling gear types, in addition to beach seines, as a discrete study of catchability to inform and possibly supplement the current monitoring plan. • A number of gear types are used to sample the RGSM in the MRG; these gears should be evaluated to determine if species and sizes of RGSM captured can inform the monitoring plan.
9	Are all sizes of RGSM captured during monitoring?	• Yes—small and fine-mesh seines capture a nearly full range of RGSM sizes in the MRG (5-90 mm SL), but capture smaller proportions of larvae and large adults than other gears, possibly because these are used in habitats (e.g., floodplains) not normally sampled for monitoring.	• It is uncertain if the numbers of large RGSM not caught during monitoring are significant to CPUE and to estimates of annual production and recruitment in some years.	• Evaluate sizes of RGSM captured with gear types (i.e., dip nets, fine-mesh seines, small-mesh seines, dual seines, fyke nets, electrofishing) to determine if sizes of RGSM captured during monitoring are representative of the RGSM population.
10	Does the sampling scheme match the spatial distribution of the RGSM?	• No—the current sampling scheme does not appear to match the spatial distribution of the RGSM, as most samples are taken in mesohabitats containing few or no fish. • The current sampling design is akin to a stratified random design, where mesohabitat types within each site are sampled proportional to their availability in order to estimate fish density for the entire river.	• Question is unresolved on the effectiveness of the current sampling program for an aggregated (i.e., schooling) species that tends to concentrate in few mesohabitat types.	• Evaluate how well fine and small-mesh seines in mesohabitat types sample schooling RGSM.
3. Evaluate and Refine Data Collection Protocols				
11	Are the data collection protocols appropriate?	• Yes—the current data collection, recording, and storage protocols are appropriate. • These provide a set of data from a systematic sampling design that are used in a number of ways by program participants.	• None	• None
4. Evaluate and Refine Data Analyses				
12	Is the mixture model appropriate for computing RGSM CPUE?	• Yes—the mixture model is used to compute mean CPUE of RGSM to resolve two issues: (1) seine haul data contain many zeros resulting in a CPUE with a negative binomial distribution, and (2) CPUE values have a wide range (0-1,000+) and the residuals (error term) exhibit an inconstant variance, resulting in the statistical condition of heteroscedasticity. • An essential benefit of the mixture-model is that the estimated parameters and accompanying generalized linear models provide direct and meaningful insight into key factors affecting the long-term population dynamics of the RGSM.	• Uncertain if binomial model, or other models, would be better than mixture model. • The Hubert and Noon science panels recommended evaluating other methods for computing RGSM CPUE.	• Evaluate and compare other analytical methods against the current mixture model and determine if other methods are more suitable for computing RGSM CPUE. • The mixture model addresses the zero-inflated CPUE data and the negative binomial distribution, but can be difficult to deploy and understand, and other models may be as effective and more easily applied.
13	Is the October CPUE sensitive to detecting change in the RGSM population?	• No—the October CPUE for RGSM is not sufficiently sensitive to detect statistical changes, only trends. • A power analysis shows that for the current monitoring plan, CPUE would have to change by about 100% (at low CPUEs) and by about 35% (at high CPUEs) to be statistically detectable.	• Uncertain if the sampling design and method could be revised or augmented to improve precision sufficient to detect changes in RGSM from specific management actions.	• As part of refining the current monitoring plan, evaluate different sampling strategies to optimize precision of the October CPUE to detect species response to specific management actions, at acceptable program costs.

No.	Basic Question	Responses	Critical Uncertainties	Recommendations
		• Increasing the number of sites to 60 improves change detection to about 57% (at low CPUEs) and about 20% (at high CPUEs). • The CVs show low precision in the mean annual October CPUE, but the options for reducing this precision may be limited by funding, logistics, and inherent system variability.		• The refinement should consider, but not be limited to: numbers and locations of sampling sites, random vs nonrandom sites, months sampled, use of other gear types, and additional measurements.
14	How does CPUE relate to total population size?	• Linear models showed a significant correlation between population estimates and corresponding CPUE by year (2008-2011) for the Isleta, San Acacia, and combined reaches, but a weak correlation for the Angostura reach. • This analysis included only four years of population estimates (two years of low October CPUE and two years of moderately high October CPUE), and the results do not represent a full range of CPUEs and RGSM abundance.	• It is uncertain if the positive relationship between the expanded abundance from box enclosures and CPUE from beach seines is predictive or deterministic dependence, as each is fundamentally an expanded estimate of fish density. • It is uncertain if the previous results apply to different RGSM abundances and if these change over time.	• Re-evaluate the relationship of CPUE to total abundance of RGSM, as a discrete study to derive independent estimates of the total numbers of RGSM in the MRG simultaneous to estimates of CPUE. • This relationship was developed for data collected in 2008-2011, but may change over time or with different RGSM abundance levels.
5. Identify Other Data Needs for Concurrent Sampling				
15	What additional data should be collected?	• Two data formats (by-haul, by-station) provide a comprehensive database for monitoring.	• The only additional data requested are: (a) current velocity, (b) depth, (c) substrate, and (d) cover for representative mesohabitat types for hydraulic habitat models	• Characterize the physical parameters of the principal mesohabitat types sampled as part of the fish monitoring plan to inform fish population models and hydraulic habitat models. • Measurements from representative mesohabitat types should include at least: depth, velocity, substrate, and cover.
6. Evaluate How Modeling (e.g., PVA) May Assist in Refining Monitoring				
16	How are the monitoring data used in modeling?	• Monitoring data have been used to parameterize four models, including two PVA models, a mixed effects model, and an integrate RGSM population model.	• None	• None
17	Does modeling have a role in the fish monitoring plan?	• Yes—integrated population models can help identify and reconcile complex relationships affecting monitoring, such as effects of catchability, prior year class strength, salvage, and stocking on CPUE. • Models can also be used to prospectively forecast the effects of management actions on RGSM, in lieu of CPUE indices that may be too variable to quantify fish response.	• Uncertain if models can be more effective at prospectively evaluating response of RGSM to management actions than current highly variable CPUE.	• Develop and regularly evaluate integrated population models to help identify and reconcile complex environmental and resource influences on monitoring and RGSM CPUE, and determine if these models can be used to help evaluate RGSM response to management actions in the MRG. • Influences may include effects of habitat and river discharge on capture probability, prior year class strength, capture frequencies for small- and large-bodied RGSM, and salvage and stocking of RGSM.
18	Does monitoring provide data for population demographic parameters?	• Yes—monthly samples provide data for estimating RGSM population demographic parameters, including age structure and vital rates (e.g., growth rate, survival, recruitment), that help to better understand RGSM life history and provide data for models. • Data for some years may be incomplete or highly variable and can be reconciled with fisheries and population models.	• Data collected for some months are important to estimating vital rates (growth, survival, recruitment).	• As part of refining the current monitoring plan, evaluate and determine the months necessary for data collection to estimate population structure and vital rates (growth, survival, recruitment) of RGSM.

5.1 Objective 1: Evaluate and Refine Sampling Design

The sampling design involves the statistical properties of spatial aspects (longitudinal locations of sample sites, habitats in which samples are taken) and temporal aspects (frequency of sampling, times of year when samples are taken). A description of the sampling design is available with each annual monitoring report (e.g., Dudley et al., 2020), and an overview of the basic design is provided in section 2.1 of this report.

1. *How many sites should be sampled?*

- **At least 30 sites should be sampled in October and increased to as many as 60 sites to improve mean annual CPUE precision and to provide greater representation of CPUE for RGSM in the MRG; all other months can be sampled at 20 sites.**
- **An independent field study and a separate power analysis found improved precision of CPUE (95% CI, relative variability, CV) by increasing total numbers of sites to between 40 and 60.**

- The Hubert and Noon science panels recommended evaluating the effects of more than 20 sampling sites on CPUE and the associated variability and precision. The PMWG requested 20 additional sites per reach, but only 10 were added for April/May and October starting in 2017.
- Although there were no significant differences in CPUE with 20 vs 30 sites, CPUE for 30 sites was higher in 3 of the 4 sampling events (Fig. 9), and more precise for all CPUEs from 30 sites (Dudley et al., 2020).
- An independent field study of the MRG found improved precision (95% CI and relative variability) with increased numbers of sites sampled from 20 to 40 (Fig. 10; Archdeacon et al., 2020). This analysis showed that 95% CI were narrowed, and that the variability was reduced when the number of sites was increased to 40.

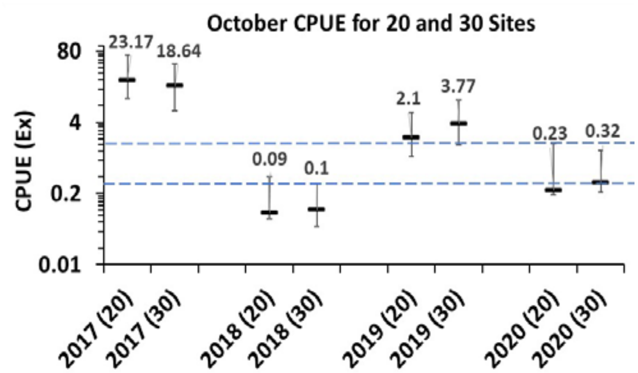


Figure 9. RGSM CPUE for standard (20) and additional (30) sites for October, 2017-2020. Vertical bars are 95% CI. Data from Table 7 of Dudley et al. (2021). Dashed horizontal lines are CPUE = 1.0 and 0.3, as incidental take criteria from the 2016 BiOp.

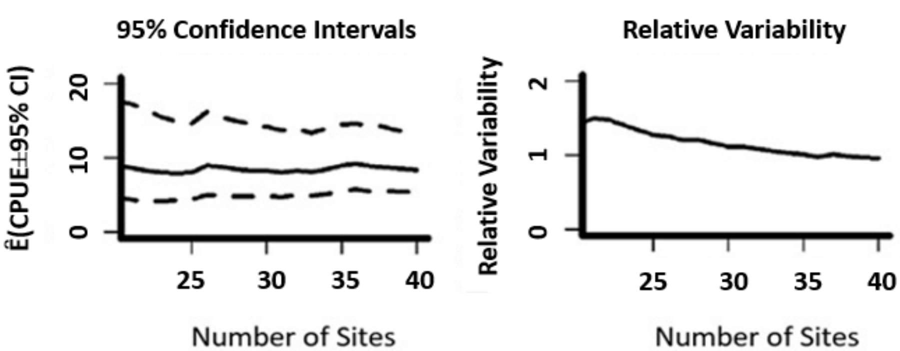


Figure 10. Cumulative expected catch-per-unit-effort (ÊCPUE) and relative variability of ÊCPUE for age-0 RGSM in cumulative seine hauls, as sampling sites increased from 20 to 40 in the MRG. Relative variability is the range of the 95% CI divided by the mean. Base figures from Archdeacon et al. (2020).

- The effect of increased numbers of sampling sites was also evaluated through a simulation, as described by Hubert and Fabrizio (2007) and recommended by Hubert et al. (2016). A power analysis (i.e., bootstrap) of CPUE data for 2017-2019 showed that precision (95% CI and coefficient of variation [CV]) improved with the number of sites sampled up to about 60 (Fig. 11; Valdez, 2019). There was a diminished improvement in precision for more than about 60 sites, which was the number of sites recommended for sampling by the Hubert et al. (2016) science panel. This analysis also showed that precision increased with the magnitude of CPUE, such that CV was highest (low precision) for low CPUE and lowest (high precision) for high CPUE.
- The analyses by Archdeacon et al. (2020) and Valdez (2019) show that CPUE precision can be improved by sampling more than the 20 sites currently sampled, and up to about 60 sites, but improved precision is increasingly reduced with more than about 60 sites.

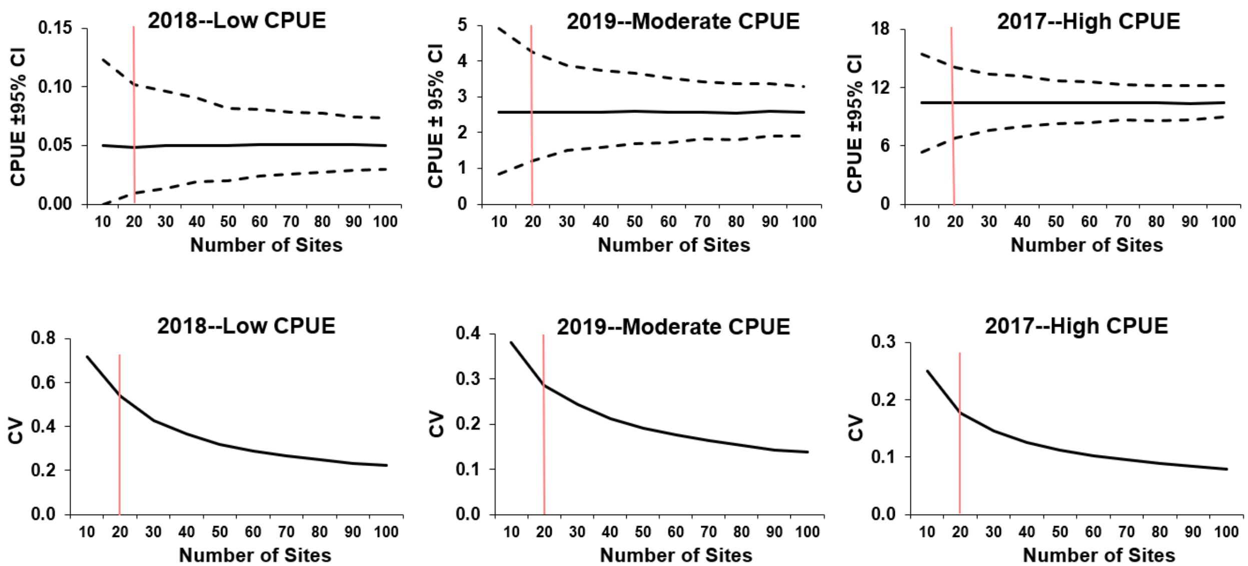


Figure 11. Effect of number of sampling sites on 95% CI and CV at low, moderate, and high CPUE for RGSM. Power analysis simulation for data from 20 sample sites for October 2017, 2018, and 2019 (Valdez, 2019). Data from the PMDB.

2. Should sample site selection be random or nonrandom?

> - **Sampling in the MRG is done at nonrandom sites that should be evaluated to determine if CPUE from these sites is representative of RGSM density through occupied habitat.**
> - **An independent study found no significant difference for fish species composition and CPUE of RGSM for random vs nonrandom sites in the MRG, but a transferability study is recommended to determine if these results can be applied to the standard monitoring sites.**

- Sampling is currently done at 20 nonrandom sites in 151 miles of the MRG (see Fig. 3). An independent field study in the MRG found that fish community data and RGSM CPUE from 20 nonrandom sites did not differ significantly from 20 random sites in summer and autumn of 2014 (Archdeacon et al., 2015), a year of very low RGSM abundance (October CPUE = 0).
- The study also showed that fish species compositions was similar for summer and autumn, and nearly identical for autumn surveys. Also, CPUE for RGSM was consistent between surveys, where summer random surveys estimated 0.32 fish per 100 m^2, and summer nonrandom surveys estimated 0.37 fish per 100 m^2.

- No other studies in the MRG have evaluated the effect of random vs nonrandom sites. Generally, samples should be drawn randomly from a population of interest to ensure a sample is representative of the entire population. When samples are drawn nonrandomly or by using subjective criteria, measured attributes are usually biased (Hansen et al., 2007), and detection of differences in abundance may be hindered by changes in habitat use through time (Quist et al., 2006). Where randomized site selection may be limited by access, such as property ownership, nonrandom sites may be desirable if the sites are representative of the population (Noble et al., 2007). A random site design generally requires more sites and higher costs because of the chance of sampling sites with widely disparate fish densities.
- Transferability of the findings from the independent study to the 20 standard monitoring sites in the MRG, with respect to representation, is uncertain and should be evaluated. The current monitoring program samples fish at 20 sites monthly, each about 200 m long; hence, sampling in 2.5 miles of the MRG (1.6%) is used to represent the density of the RGSM in about 160 miles of occupied habitat.

3. How many seine hauls should be taken?

> - **An independent study showed a diminished improvement in precision of CPUE with more than about 15 seine hauls per site; the 20 hauls currently taken are sufficient to detect RGSM presence at sites.**
> - **The study also showed that increasing the size (area) of each seine haul did not significantly affect CPUE variability; hence the area currently seined with each haul is sufficient.**

- A field study in the MRG found that increasing the size (area) of a sample (seine haul) did not significantly affect variability, but increasing the number of samples (seine hauls) within a site improved precision (Fig. 12; Archdeacon et al., 2020). This analysis indicates that precision is substantially improved up to about 15 hauls, but not proportionately from 15 to 20 hauls; suggesting that the current 20 seine hauls per site is sufficient for monitoring RGSM in the MRG.
- The study also showed that increasing the size (area) of each seine haul did not significantly affect CPUE variability; hence seine haul length of <15 m is sufficient.

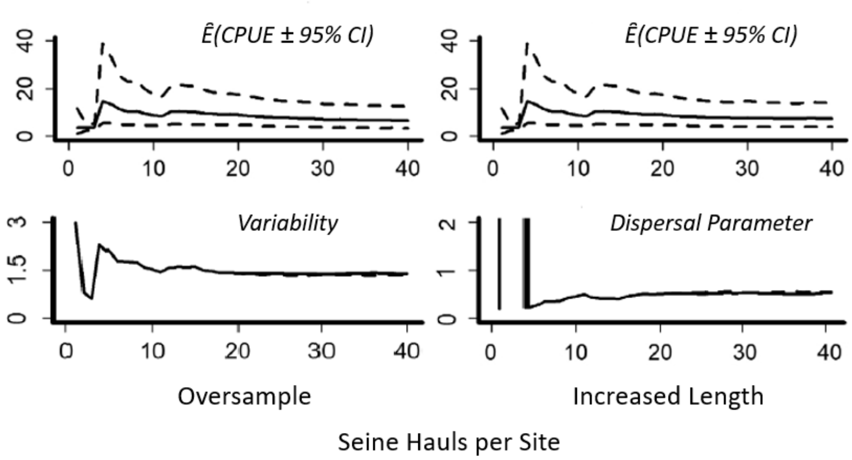


Figure 12. Expected catch-per-unit effort for RGSM in cumulative seine hauls collected at 20 random sites in the MRG. Figures in the left column are from sites 200 m in length (oversample) and figures in the right column are from sites 400 m in length (increased length). Base figures from Archdeacon et al. (2020).

4. Which mesohabitat types are sampled most often and which have the highest CPUE?

- **Ten mesohabitat types comprised 97% of all seine hauls taken for 2002-2017, but only four of these had the highest mean CPUEs (MCSHPO, BW, MCPO, SCSHPO).**
- **The six mesohabitat types with the highest mean CPUEs were from pools (MCPO, MCSHPO, SCPLPO, SCPO, SCSHPO) and backwaters (BW).**

- Discrete mesohabitats are sampled monthly at each of the 20 sites. Altogether, 26 different mesohabitat types have been sampled for 2002-2017 with 10 comprising 97% of all seine hauls, but only four of these had the highest CPUEs (MCSHPO, BW, MCPO, SCSHPO; Valdez, 2018a).
- Six mesohabitat types had the highest CPUEs that included five pool types (MCPO, MCSHPO, SCPLPO, SCPO, SCSHPO) and backwaters (BW; Fig. 13), indicating that highest CPUE for RGSM is from pool and backwater habitats**.**

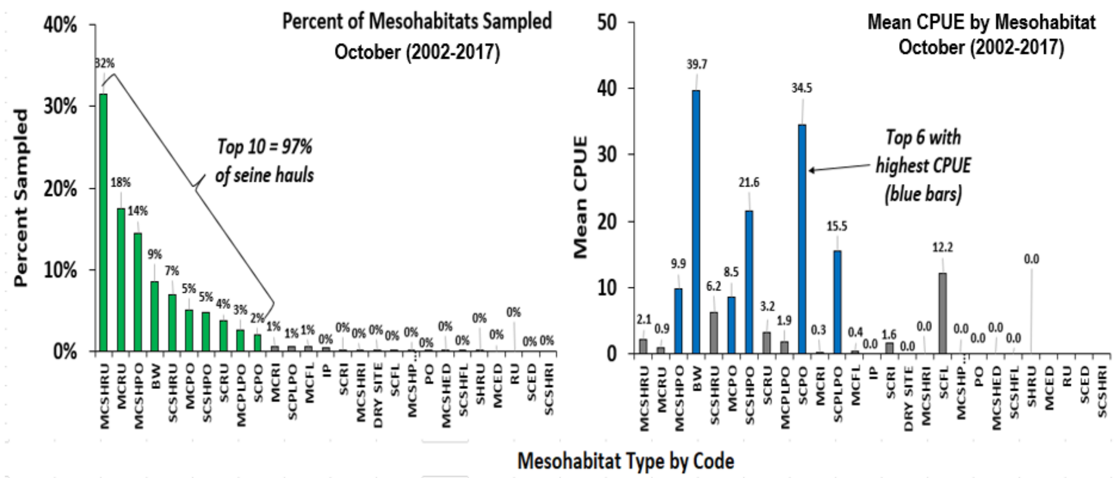


Figure 13. Percent of seine hauls and mean by-haul CPUE for each of 26 mesohabitat types in October 2002–2017 (Valdez, 2018a). Data from the PMDB.

5. Can a reliable CPUE be obtained from sampling certain mesohabitat types?

- **No—six types with highest October CPUE (see Question #4) yielded a higher CPUE than the current plan, and not all mesohabitat types were available at all sites sampled 2002-2017.**

- The two science panels recommended sampling only mesohabitats with highest expected CPUE for RGSM to improve precision. Of the six mesohabitat types with the highest CPUEs (5 pool and 1 backwater; see Question #4), mean October CPUEs for the pool types were different from all 26 mesohabitat types in all years, 2002-2017 (Fig. 14). Mean October CPUE for the pool types plus backwaters were also different, and consistently higher because of the high CPUE in backwaters (Valdez 2020).
- This analysis shows that sampling only pool mesohabitat types, or pools plus backwaters, yields October CPUEs that differ from those of the current monitoring plan, although the CPUEs were not significantly different.

- Using a limited suite of mesohabitat types may not yield a reliable CPUE, as pools and/or backwaters may not be available at a particular site during sampling.
- Of the 16 years evaluated (2002-2017), pool habitats were not available at a total of nine sites in 5 years (2002, 2003, 2004, 2016, 2017), and pool + backwater habitats were not available at a total of four sites in 3 years (2003, 2016, 2017) (Marcus, 2019).

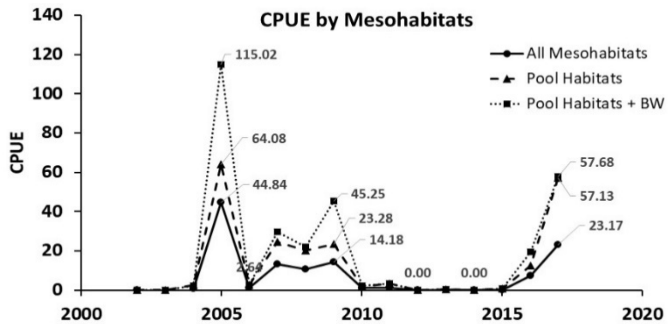


Figure 14. Mean October CPUE for all 26 mesohabitat types compared to five pool types and five pool types + backwaters, 2002−2017 (Valdez, 2020). “All mesohabitats” CPUE from Table 7 in Dudley et al. (2020). “Pool Habitats” and “Pool Habitats +BW” CPUE computed from PMDB.

6. Is annual monitoring for April through November necessary?

> - **Yes—annual monitoring is necessary because the RGSM is short-lived and the population can vary considerably by year.**
> - **However, monthly samples from April through November may not be necessary, as data for population demographic parameters may be procured from fewer months (e.g., Jun-Oct).**

- Annual monitoring of the RGSM is necessary because the species is short-lived and the population can vary considerably by year (see Fig. 4). Fish monitoring in the MRG has been conducted annually since 1993, except for 1998.
- Monthly samples provide data on age structure, growth rate, survival, and recruitment as important population demographic parameters for better understanding the life history of the RGSM. For 18 years of monitoring, from 2002 to 2019, most samples were taken in February and from April to December (Fig. 15).
- Population demographic parameters could be estimated with data from fewer month; e.g., monthly samples could be reduced from eight months (Apr-Nov) to five months (Jun-Oct).
- The age-0 RGSM recruit into the small-mesh seines in June or July, and the cohort can be followed monthly through the census period in October.
- June-July data are used by the ACOE as the most robust for environmental flow analysis (Harris et al., 2018), compared to October.
- Monthly data from September are used by the USFWS to help determine augmentation (stocking) targets.
- Various monthly data are used by Reclamation to ensure BiOp compliance, depending on the timing of the work (e.g., to evaluate effect of activities, such as river maintenance).
- Only October could be sampled if an annual census was all that was necessary, but data for population demographic parameters would not be gathered.

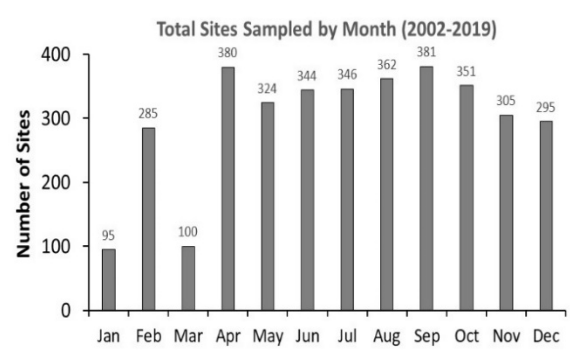


Figure 15. Total number of sites sampled by month in the MRG over 18 years (2002-2019). Data from PMDB.

7. *Is October the best census month?*

> - **Yes—resource and environmental variability are low in October; i.e., CPUE is least variable and flow variability is moderate among months.**
> - **An October census does not represent year-class strength for the following spawning year, as would a census in March or April, which would have high variability in CPUE and flow.**

- The best census periods are those with the least resource and environmental variability (Noble et al., 2007).
- Variability of CPUE (as CV) is lowest in October and highest in May when young RGSM are first captured with the beach seines (Fig. 16).
- Flow variability of the MRG, as mean daily change in river discharge, is highest in May, lowest in January, and intermediate in September-December (Fig. 16).
- October is the best month to monitor RGSM for an annual census, based on low CPUE variability and moderate flow variability.
- However, the census in October does not represent year-class strength for the following spawning year, as would a census in March or April, when flow and CPUE variability are high.

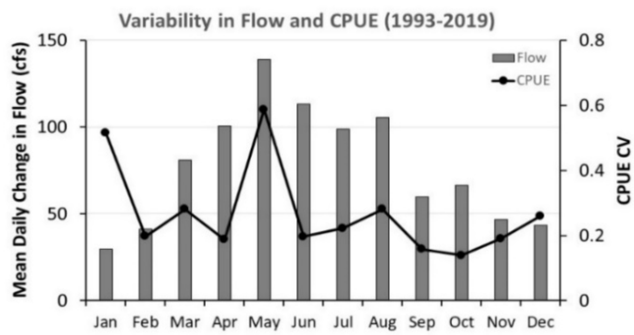


Figure 16. Variability of river discharge (as mean daily change in flow, Rio Grande at Albuquerque, USGS data) and CPUE of RGSM (as coefficient of variation, CV) on a monthly basis for 1993−2019 (minus 1998). Data from PMDB.

5.2 Objective 2: Evaluate and Refine Sampling Methods

The sampling methods involve the manner in which the fish are collected, including sampling gear types and strategies.

8. *Are beach seines the appropriate gear for sampling RGSM?*

> - **Yes—the Hubert et al. (2016) science panel found that small-mesh and fine-mesh seines used to sample RGSM in the MRG are appropriate, when CPUE is computed separately.**
> - **An independent study found that beach seines were the best gear for sampling fish in the MRG main channel, but fyke nets collected more fish in floodplains and side channels.**
> - **Other gear types have been used in the MRG, but none has been evaluated as part of standardized monitoring, including fyke nets, block seines, boat and backpack electrofishing,**

- The RGSM is a small-bodied fish that is usually found in schools (Sublette et al., 1990; Hutson et al., 2018), mostly in pools and backwaters. Fish are sampled in the MRG with beach seines that are drawn through the water in specific mesohabitat types (e.g., pools, runs, riffles, etc.; Fig. 17).
- Beach seines are commonly used to sample small-bodied fish (Hubert and Fabrizio, 2007). The Hubert et al. (2016) science panel determined that the small-mesh and fine-mesh seines used to monitor RGSM in the MRG are appropriate, but the CPUEs should be computed separately by seine type because the two mesh sizes captured different size fish.

Figure 17. Standard small-mesh seine being used to sample fish in the MRG as part of standardized monitoring. Individual behind the seine is the recorder and is measuring the length of the seine haul. Photo from Dudley et al. (2019).

- An independent field study of four gear types used to sample fish in the MRG (Gonzales et al., 2012a) also showed that beach seines were the best gear to sample a variety of fish species in the main channel of the MRG, including the RGSM. The study reported that for the main channel, beach seines (1) showed highest species richness, (2) had the highest species detections (similar to backpack electrofishing), and (3) yielded the greatest species composition.
- The Gonzales et al. (2012a) study also found that for floodplains and side channels, fyke nets collected 1.5 to 5.5 times as many RGSM as beach seines or electrofishing. The mean length and range of RGSM captured with the four gear types in floodplains and side channels was not significantly different.
- The four gear types were (1) small-mesh beach seines (3.1 × 1.8 m, 5 mm mesh), backpack electrofishing (Smith Root LR-24), mini fyke nets (D-frame 2.1 m length x 1.0 m width x 0.60 m height, 5 cm diameter throat; double-wings 0.6 m height x 4.6 m length, 3.1 mm delta mesh), and bag seines (1.8 m x 15.2 m, 5 mm mesh).
- Other gear types have been used in the MRG, but have not been evaluated as part of standardized monitoring, including fyke nets, block seines, boat and backpack electrofishing, and larval dip nets (Fig. 18).

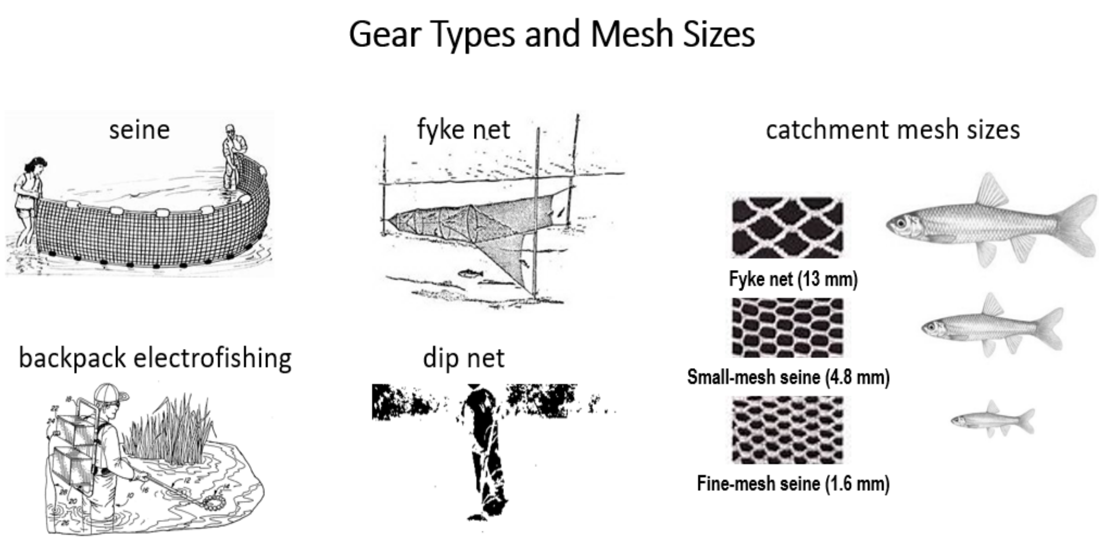


Figure 18. Gear types and mesh sizes used to sample RGSM in the MRG.

9. *Are all sizes of RGSM captured during monitoring?*

- **Yes—small and fine-mesh seines capture a nearly full range of RGSM sizes in the MRG (5-90 mm SL), but capture smaller proportions of larvae and large adults than other gears, possibly because these are used in habitats (e.g., floodplains) not normally sampled for monitoring.**
- **It is uncertain if the numbers of large RGSM not caught during monitoring are significant to CPUE and to estimates of annual production and recruitment in some years.**

- RGSM are sampled in the MRG with beach seines that are (a) small-mesh (3.1 m x 1.8 m, 4.8 mm mesh) for juveniles and adults in all months, and (b) fine-mesh (1.2 m x 1.2 m, 1.6 mm mesh) for larval fish from April to October.
- The small-mesh seines capture RGSM that range in length from 7 to 90 mm SL, with a mean of 36.7 mm SL (Fig. 19). The fine-mesh seines capture RGSM that range in length from 5 to 76 mm SL, with a mean of 17.3 mm SL.

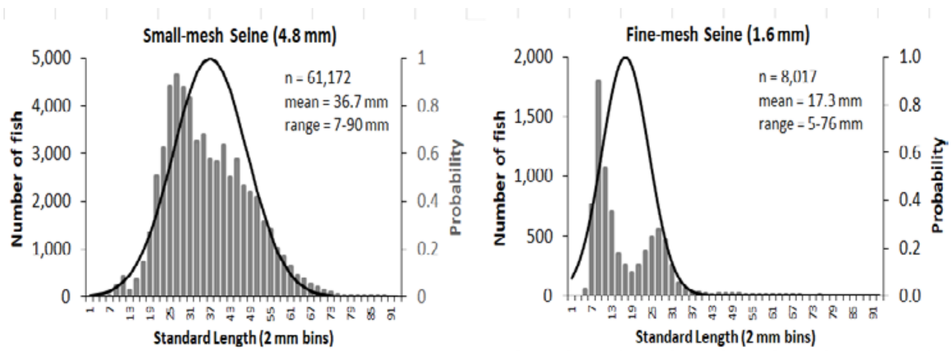


Figure 19. Normal probability distributions fit to histograms of lengths for RGSM captured with small-mesh and fine-mesh beach seines used in the population monitoring plan, 1993-2017 (Valdez, 2020). Data from the PMDB.

- The lengths of RGSM captured with the two beach seines used in monitoring span much of the range of fish lengths found in the MRG (4 mm at hatching [Brandenburg et al., 2018] to maximum recorded size of 97 mm SL captured with fyke nets [ACOE unpublished data, 2016]), but these seines capture smaller proportions of larvae and large adults otherwise caught with other gear types (Fig. 20; Valdez, 2020).
- Other gear types not used in monitoring capture smaller and larger fish sizes (Fig. 20). Dip nets used in spring floodplains capture the small newly-hatched larvae (e.g., Valdez et al., 2019, 2020), and fyke nets in spring floodplains capture large adults (Gonzales et al., 2012b). These are specialized gear types used for particular studies.
- Small and fine-mesh seines may not capture the smallest larvae or the largest RGSM adults because these occur in habitats not sampled during monitoring, including spring-time floodplains and irrigation returns in summer. Some large fish may occur in monitored habitats, but the largest adult RGSM can swim faster than the smaller fish (Bestgen et al., 2010), and possibly escape the beach seines as they are drawn through the water.
- The capture efficiency of the paired-net sampling (small-mesh beach seine with a second block seine) found larger numbers of RGSM of greater size in the block seine for simultaneous samples (Porter, 2018).
- The effect of not including a full range of fish sizes in monitoring is unclear and should be further evaluated with available empirical data using integrated models.

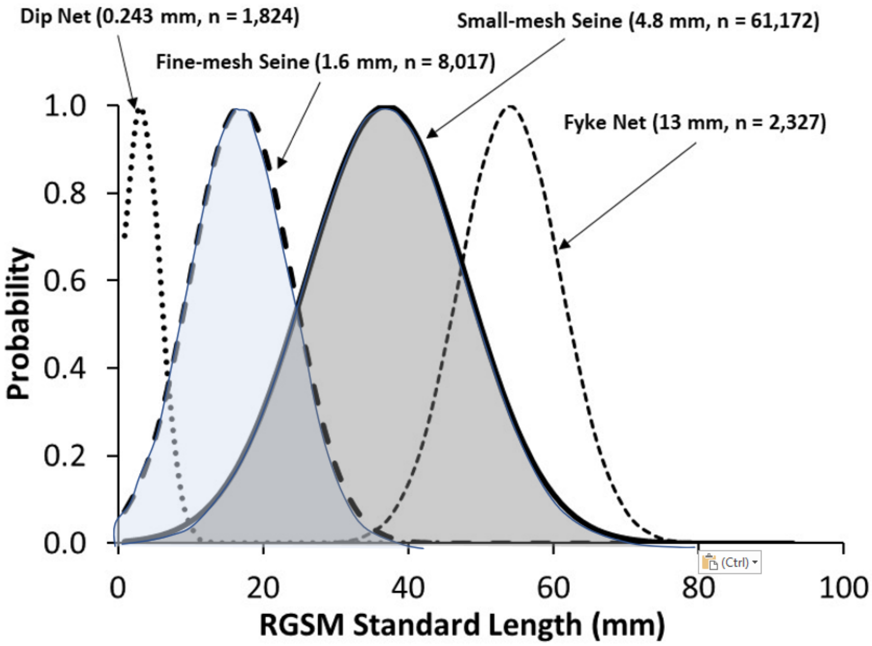


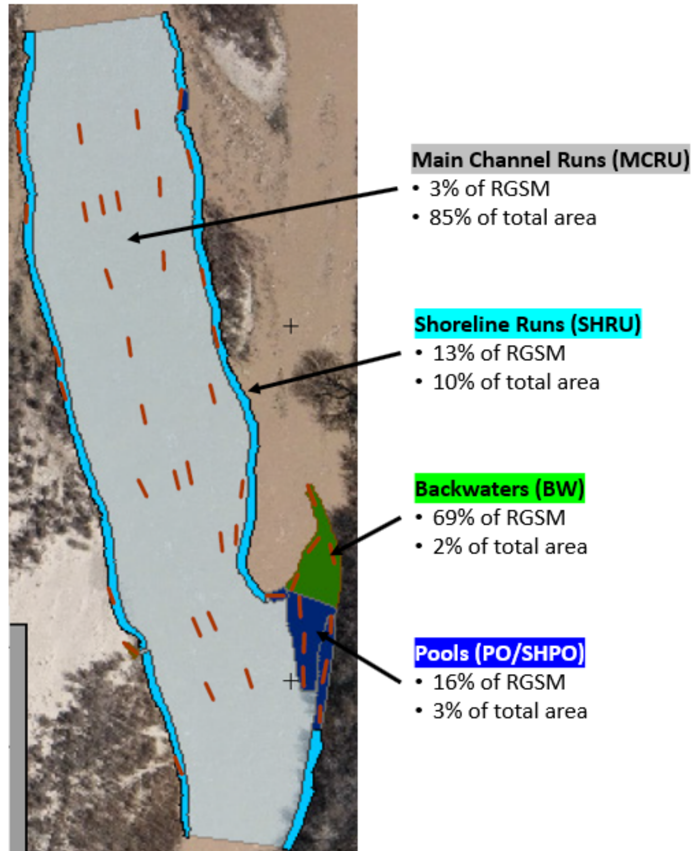
Figure 20. Normal probability distributions representing the sizes of RGSM captured in the MRG with four gear types (mesh size and numbers of fish). The shaded areas represent the range of fish sizes captured with the fine-mesh seines (light blue) and the small-mesh seines (gray) used in the monitoring plan, 1993-2017 (Valdez, 2020). Each distribution was fit to actual data collected with a particular gear type, including dip net data from Valdez et al. (2019), fine-mesh and small-mesh data from the PMDB, and fyke net data from Gonzales et al. (2012b).

10. Does the sampling scheme match the spatial distribution of the RGSM?

- **No—the current sampling scheme does not appear to match the spatial distribution of the RGSM, as most samples are taken in mesohabitats containing few or no fish.**
- **The current sampling design is akin to a stratified random design, where mesohabitat types within each site are sampled proportional to their availability in order to estimate fish density for the entire river.**
- **Question is unresolved on the effectiveness of the current sampling program for an aggregated (i.e., schooling) species that tends to concentrate in few mesohabitat types.**

- The RGSM is often found in schools (Sublette et al., 1990), and principally uses mesohabitat types with low velocity and moderate depth, often with cover (Dudley and Platania, 1997).
- Like many riverine fish species, the RGSM uses mesohabitats that occur the least frequently; i.e., fish often concentrate in specific habitats, with a few scattered across the rest of the river.
- This clumped distribution of RGSM is illustrated in a 200-m unit of the MRG sampled as part of a population estimation project (Fig. 21; Dudley et al., 2010). This example shows that the majority (69%) of fish were captured in backwaters that comprised only 2% of the total area of habitat in the unit.
- About 16% of RGSM were caught in pools and shoreline pools (PO/SHPO) that comprised only 3% of the habitat. Notably, only 3% of RGSM were caught in main channel runs that comprised 85% of the habitat.

- When the sampling design includes habitats not frequently occupied by the RGSM—and the fish occur in schools—many samples (seine hauls) yield small fish numbers or no fish (zero CPUE). The characteristic distribution of data that includes a lot of zeros and fewer large numbers is referred to as a negative binomial and is explained with Question #12.
- A negative binomial distribution is also characteristic of data collected from a population that is distributed over the landscape (or in a river) in a clumped manner, where few individuals are scattered across the landscape and most are found in clumps (Elliott, 1973), such as in the example in Figure 21. This distribution affects catchability or capture probability (Hubert and Fabrizio, 2007).
- The RGSM is distributed in clumped fashion at the local scale, and seine hauls in shallow runs are likely to yield few or no fish, whereas seine hauls in pools or backwaters are likely to yield more fish.
- The difficulty of matching the sampling design to the spatial distribution of the fish is that the same complement and proportions of mesohabitat types do not occur consistently across sites or within the same site over time; i.e., habitat heterogeneity (Dutilleul and Legendre, 1993).



Mesohabitat	Area (m²)	Percent	No. RGSM	Percent	CPUE
BW	263	2%	368	69%	768
MCRU	9537	85%	17	3%	9
PO/SHPO	355	3%	84	16%	78
SHRU	1075	10%	68	13%	50
Total	11230	100%	537	100%	109

Figure 21. A 200-m unit of the MRG with color-coded mesohabitat types and lines showing sampling locations for population estimation, October 22, 2009 (Dudley et al., 2010, Fig. B-8). Percent of RGSM and percent of total area for each mesohabitat type are on the right, and an inset table shows area and percent of each mesohabitat type and number, percent, and CPUE for RGSM.

- The current sampling design includes 4 seines hauls each from runs and shoreline pools, 2 each from backwaters, pools, and riffles, and the remaining 6 hauls from shoreline runs, for a total of 20 seine hauls. The highest CPUEs are expected from 4 shoreline pools, 2 backwaters, and 2 pools for a total of 8 of the 20 seine hauls (see section 2.2). The majority of hauls (12 of 20) are taken in mesohabitat types expected to yield few or no fish.
- The current sampling design is akin to a stratified random design (Hansen et al., 2007), where mesohabitat types within each site are sampled proportional to their availability. This design attempts to estimate fish density for the entire river, but it is unknown if the 20 standard sampling sites can be used to represent the density of RGSM in the MRG (see Question #1).

5.3 Objective 3: Evaluate and Refine Data Collection Protocols

Data collection protocols include types of data collected, recording methods, quality control, electronic storage, and data custody.

11. Are the data collection protocols appropriate?

> - **Yes—the current data collection, recording, and storage protocols are appropriate.**
> - **These provide a set of data from a systematic sampling design that are used in a number of ways by program participants (see section 2.1).**

The following is a summary and evaluation of the data collection protocols, based on descriptions provided by Dudley et al. (2020).

- Monthly sampling has allowed for ongoing determination of general spatial and temporal changes in population structure and species abundance since 1993.
- Ten additional sites sampled in April and October since 2017 help to evaluate the effect of sample site numbers on CPUE and variance, and help to provide a greater representation of CPUE for RGSM in the MRG.
- Repeated sampling across multiple sampling occasions during November is used to estimate site occupancy rates and to characterize sampling variation.
- Continued and uninterrupted monitoring from April to November help to satisfy key aspects of the 2016 BiOp (USFWS, 2016).
- Fish are collected with a 3.1 m x 1.8 m small-mesh seine (ca. 4.8 mm mesh) in discrete mesohabitats (< 15 m long). Runs and shoreline pools are sampled four times at each site, (when available); backwaters, pools, and riffles are sampled two times each (when available); and any remaining samples are taken in shoreline runs.
- A 1.2 m x 1.2 m fine-mesh seine (ca. 1.6 mm mesh) is used to selectively sample shallow low-velocity mesohabitats for larval fish (two samples per site) from April to October.
- Seine hauls are spaced several meters apart to minimize disturbance of other mesohabitats during sampling.
- Mesohabitats with similar conditions that do not exceed reasonable depths or velocities for efficient seining are sampled regardless of flow conditions.
- Water quality metrics are recorded at each site, along with digital photos of river conditions.
- Fish are briefly handled for identification and enumeration, kept in a submerged mesh enclosure (ca. 4.8 mm mesh) during sampling (i.e., to avoid recapture), and released after sampling is completed. During repeated sampling, fish are released back into sampled mesohabitats after each seine haul to avoid disturbing the site for subsequent repeated sampling efforts.
- RGSM are examined for the presence of Visible Implant Elastomer (VIE) tags (i.e., stocked fish) and tag colors and locations are recorded. Individuals are also scanned for PIT tags using handheld readers to obtain the unique hexadecimal codes.
- All wild and stocked RGSM are measured as standard length (mm), or measurements of individual fish are taken to determine length range for large collections. Each fish is classified by age-class, based on age-length relationships by sampling month (Dudley et al., 2009). Standard length is measured because of its wide acceptance in taxonomic studies, and because it is

reliable even when the caudal fin is malformed or damaged. Total length (TL) can be derived from SL based on the relationship (TL = 1.203(SL) + 2.454; R 2 = 0.99; n = 257) from Horwitz et al. (2018).

- A report and associated dataset are provided for each month sampled, and a final report and annual database are provided after each year of sampling.
- The data are provided for each month sampled and at the end of each year in Excel and csv files in fixed row and column format that is stored in a consolidated population monitoring database (PMDB).
- The entire database was quality checked in 2018, and data continue to be quality checked annually.

5.4 Objective 4: Evaluate and Refine Data Analyses

Data analyses refer to the mathematical and statistical methods used to analyze the data.

12. Is the mixture model appropriate for computing RGSM CPUE?

- **Yes—the mixture model is used to compute mean CPUE of RGSM to resolve two issues: (1) seine haul data contain many zeros resulting in a CPUE with a negative binomial distribution, and (2) CPUE values have a wide range (0-1,000+) and the residuals (error term) exhibit an inconstant variance, resulting in the statistical condition of heteroscedasticity.**
- **An essential benefit of the mixture-model is that the estimated parameters and accompanying generalized linear models provide direct and meaningful insight into key factors affecting the long-term population dynamics of the RGSM.**
- **The science panels recommended evaluating other methods for computing RGSM CPUE.**

- A mixture model is used to compute mean CPUE of RGSM to resolve two issues: (1) seine haul data contain many zeros resulting in a CPUE with a negative binomial distribution that is not resolved through transformation; and (2) CPUE values have a wide range (0-1,000+) and the residuals (error term) exhibit an inconstant variance, resulting in the statistical condition of heteroscedasticity. The mixture model is explained in Appendix D of the Final Report for Rio Grande Silvery Minnow Population Monitoring (Dudley et al., 2020).
- Density data (fish per 100 m^2) for RGSM comprise either zeros (i.e., fish not detected) or positive (nonzero) values (i.e., fish detected) at each of the 20 standard sites (see Fig. 3). The nonzero data can range widely across sites, from many small numbers to a few very large values, when a seine haul yields large numbers of fish. This distribution of CPUEs is best described as a negative binomial distribution (Fig. 22).
- Data distributed as a negative binomial cannot be analyzed with standard parametric statistics used for normally distributed data, particularly for multiple means comparisons (e.g., ANOVA).
- An essential benefit of the mixture-model approach is that the estimated parameters, and accompanying generalized linear models, provide direct and meaningful insight into key factors affecting the long-term population dynamics of RGSM. This is because both the occurrence probability (based on δ) and fish density (based on μ and σ) are estimated and individually analyzed. Additionally, diverse environmental covariates are used to model the key parameters (δ and μ), which collectively lend insight into the fundamental, complex, long-term ecological relationships of RGSM (Dudley et al., 2020).

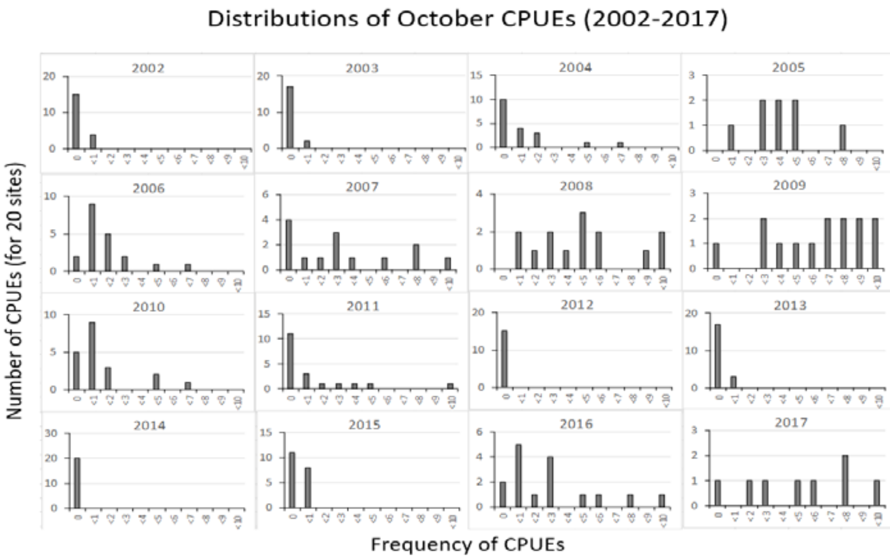


Figure 22. Frequency distributions for October CPUE for the 20 standard sampling sites by year, 2012-2017. Each CPUE was computed from the total number of RGSM captured by site divided by the total area seined and multiplied by 100, as shown in Figure 4. This figure illustrates the distributions of CPUEs described by a negative binomial model (Zar, 1974) and computed with a mixture model (Dudley et al., 2020, Appendix D [Statistical Methods]). Data from the PMDB.

13. Is the October CPUE sensitive to detecting change in the RGSM population?

- **No—the October CPUE for RGSM is not sufficiently sensitive to detect statistical changes, only trends.**
- **A power analysis shows that for the current monitoring plan, CPUE would have to change by about 100% (at low CPUEs) and by about 35% (at high CPUEs) to be statistically detectable.**
- **Increasing the number of sites to 60 improves change detection to about 57% (at low CPUEs) and about 20% (at high CPUEs).**
- **The CVs show low precision in the mean annual October CPUE, but the options for reducing this precision may be limited by funding, logistics, and inherent system variability.**

- Some monitoring plans are designed with the primary purpose of detecting change in target populations so as to evaluate the effect of specific management actions (see section 2.3). Detecting change in fish population abundance requires sufficient precision for significance using statistical analyses. Occupancy models are used in the current monitoring program to account for imperfect detection of RGSM and to determine the probability of the true presence or absence of a species at a site, but these models do not account for change detection.
- A simulation using power analysis showed that for the current monitoring plan with 20 sites, mean percent detectable change in CPUE ranged from nearly 100% for low CPUE (such as in 2018) to about 35% for a high CPUE (such as in 2017) (Fig. 23; Valdez, 2019). This means that at low CPUEs, the RGSM population would have to change by an average of about 100%, or double, to be statistically detectable. At high CPUEs, a mean change in CPUE index of less than about 35% would not be detectable.
- Increasing the number of sites to more than 20 improves change detection, but at low population levels (low CPUE) the best detectable change with 60 sites is about 57%, and at high population levels (high CPUE), it is about 20%.

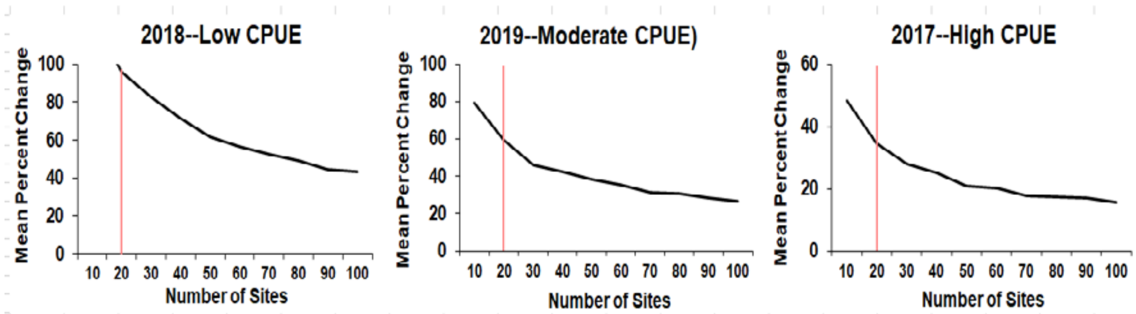


Figure 23. Effect of number of sampling sites on mean percent change in CPUE at low, moderate, and high CPUE for RGSM (Valdez 2019). Power analysis simulation based on 20 sample sites for October 2017, 2018, and 2019 (Data from the PMDB). Mean change detection is the average difference of the high and low 95% CI, where the high interval is larger than the low because of the non-normal CPUE distribution (see Fig. 23).

- The precision needed for monitoring is determined by the needs of the program. A substantial management actions would be expected to induce a population change large enough to be easily detected, whereas a smaller action is likely to produce a more subtle change that may not be detected with a less precise index.
- The need to distinguish normal temporal or spatial population variability from a change in the population index due to a management action is an important consideration. Under the current plan, the population would have to change considerably at either low or high CPUEs to be statistically detected.
- Another way to look at the precision of the current monitoring plan is to visually examine the annual October CPUE and the associated 95% CI (Fig. 24). In most years, the 95% CI overlaps with those of the adjacent years, indicating no significant difference in population change. Hence, a change in the population (i.e., CPUE index) caused by a management action would have to exceed the confidence bounds to be detected statistically.

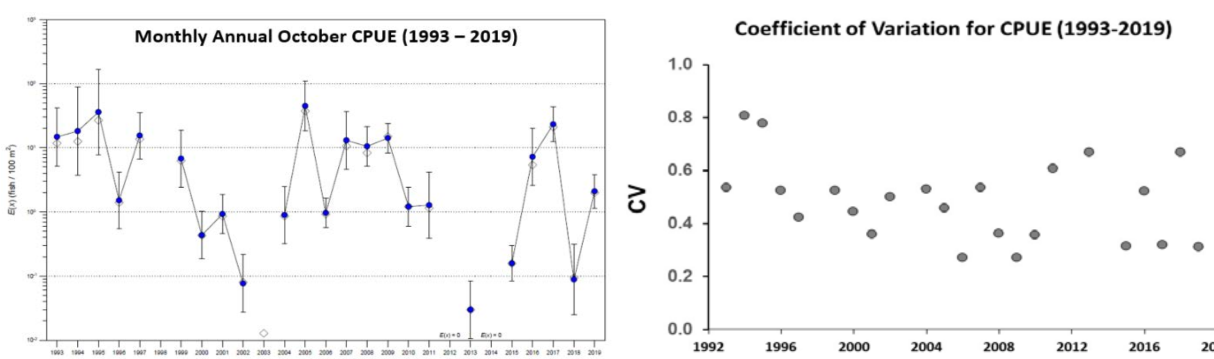


Figure 24. Mean annual October CPUE and 95% CI (left, Fig. 7 in Dudley et al., 2020) and CV (right) for 1993-2019; CV was computed as standard error/mean from data provided in Table 7 in Dudley et al. (2020).

- Another measure of data precision is the coefficient of variation (CV), which is the standard error of the mean CPUE divided by the mean CPUE. The standard error is used instead of the standard deviation because of the non-normally distributed CPUE data (Pollock et al., 1990). The CV for mean annual October CPUE for 1993–2019 ranges from 0.27 in 2006 and 2009 to 0.81 in 1994 (Fig. 24). As a comparison with other programs, for mark-recapture population estimates of humpback chub in the Upper Colorado River Basin, CVs of > 25% are considered low precision, 10-25% as moderate precision, and < 10% as high precision (Hines et al., 2020). An accepted precision standard is a CV of ≤ 0.20 (Pollock et al., 1990).

- A CPUE index is inherently less precise than mark-recapture estimates (Hubert and Fabrizio, 2007). However, in circumstances like the RGSM, where the species is small and short-lived and where individual tagging is impractical, a CPUE index is desirable for estimating abundance. The CVs shown in Figure 24 reflect low precision in the mean annual October CPUE, but the options for reducing this precision may be limited by funding, logistics, and inherent system variability.

14. How does CPUE relate to total population size?

- **Linear models showed a significant correlation between population estimates and corresponding CPUE by year (2008-2011) for the Isleta, San Acacia, and combined reaches, but a weak correlation for the Angostura reach.**
- **Four years of CPUE and population estimates (two years of low abundance and two years of moderately high abundance) have been compared, and the results do not represent a full range of CPUEs and RGSM abundance.**
- **It is uncertain if the positive relationship between the expanded abundance from box enclosures and CPUE from beach seines is predictive or deterministic dependence, as each is fundamentally an expanded estimate of fish density. Further evaluation of this relationship is recommended.**

- Population estimates and CPUE of RGSM in the MRG were compared for October 2008–2011 to evaluate the relationship between the annual CPUE index and true population size (Dudley et al., 2011a, 2011b, 2011c, 2012). It was acknowledged that this relationship may change with time (Dudley et al., 2012).
- Population estimates were derived from the depletion of fish removed from a box enclosure (2 m wide, 5 m long, and 1.5 m high, 4.8 mm mesh), using Program MARK and the Huggins model.
- Population estimates and corresponding CPUE by year (2008-2011) showed similar patterns of scale for the two parameters within the three reaches (i.e., Angostura, Isleta, and San Acacia), indicating strong correspondence between the annual estimates and CPUE (Fig. 25).
- Linear models showed a significant and positive correlation between the two estimates for the Isleta, San Acacia, and combined reaches, with p-values of 0.044, 0.011, and 0.034, respectively; but a weak relationship for the Angostura reach ($p = 0.082$) (Fig. 26).
- This analysis included only four years of population estimates (two years of low October CPUE and two years of moderately high October CPUE), and the results may not be representative of a full range of CPUEs and RGSM abundance.
- Further, it is uncertain if the positive relationship between the expanded abundance from box enclosures and CPUE from beach seines is predictive or deterministic dependence (Goodman, 2012b; Stinnett et al., 2005); i.e., removal estimates from a box enclosure and river-wide expansion are analogous to computing CPUE from a beach seine for river-wide expansion. Each is an expanded estimate of fish density.
- The Noon et al. (2017) science panel recommended further evaluation of this relationship with estimating catchability, which combines traditional seine-based survey methods with more intensive capture and removal methods (as in Dudley et al. 2012). The latter estimates are more accurate (if extensive numbers of removals are made in each unit) and can be used to calibrate the CPUE index methods using ratio estimates.

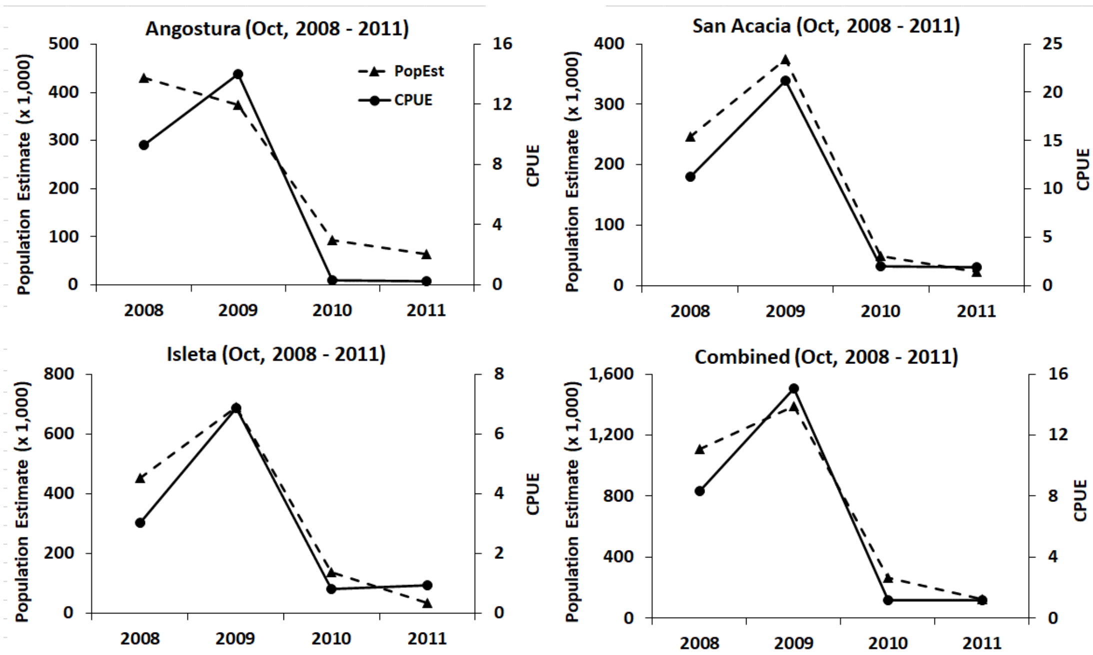


Figure 25. Estimates of population size for Rio Grande silvery minnow and corresponding CPUE by reach and year (2008-2011) (Valdez, 2018b). Population estimate data from Dudley et al. (2011a, 2011b, 2011c, 2012), and CPUE computed from the PMDB.

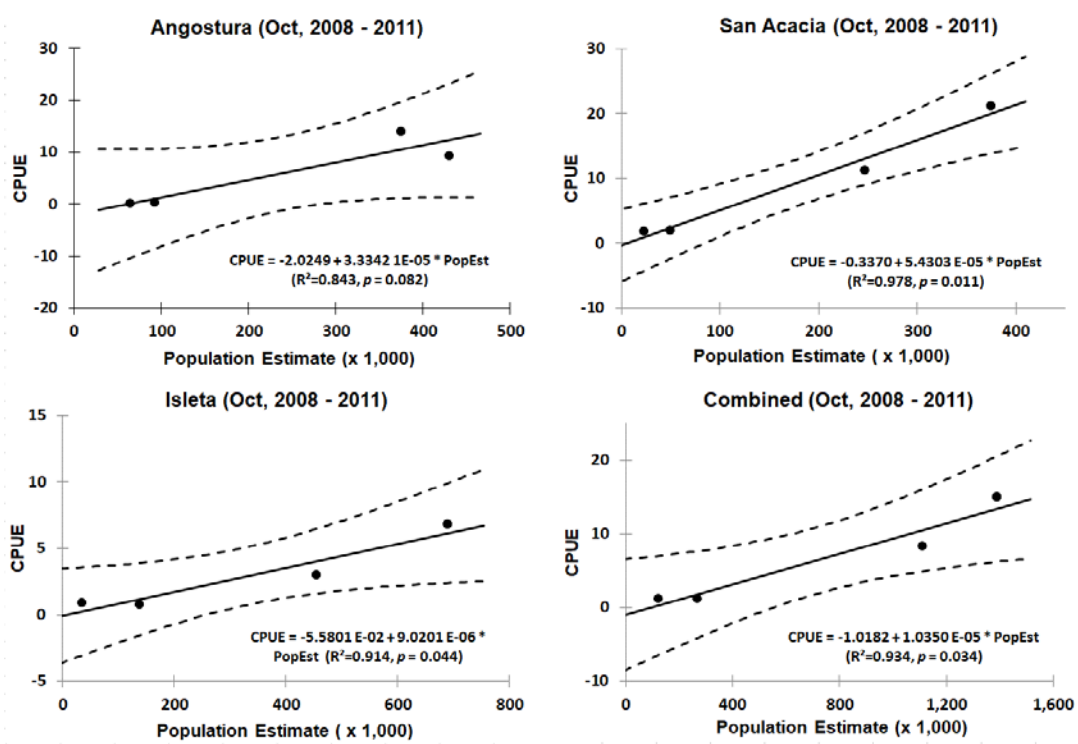


Figure 26. Correlation between annual population estimates and corresponding CPUE for RGSM in the Angostura, Isleta, and San Acacia reaches (see Fig. 25). Estimates of population size and mean by-site CPUE were taken in the month of October, 2008-2011 (Dudley et al., 2011a, 2011b, 2011c, 2012). Black circles are corresponding population estimates and CPUEs for October of each year. The straight line is the line of best fit for the least squares regression, and the dashed bands represent the 95% CI for the regression line (Valdez, 2018b).

5.5 Objective 5: Identify Other Data Needs for Concurrent Sampling

Other data needs refer to data from concurrent sampling that support other studies (e.g., augmentation, fish movement, drying, genetics, adaptive management) as part of fish monitoring.

15. What additional data should be collected?

- **Two data formats (by-haul, by-station) provide a comprehensive database for monitoring.**
- **The only additional data requested are: (a) current velocity, (b) depth, and (c) substrate size for representative mesohabitat types for hydraulic habitat and population models.**

- Two data formats are provided monthly and annually for the monitoring data, a by-station dataset and a by-haul dataset. The by-station dataset contains 27 parameters collected for each of the 20 standard sites sampled on a monthly basis (Table 4). The by-haul dataset contains 44 parameters collected for every seine haul monthly at each of the 20 standard sites.

- The following additional measures were recommended by Noon et al. (2017) and are requested for population models (e.g., Yackulic, 2020): during monthly sampling, collect the following additional data for each seine haul by identified mesohabitat type: (a) current velocity, (b) depth, and (c) substrate size.

Table 4. Lists of parameters recorded for by-station and by-haul datasets from the PMDB.

No.	By-Station	No.	By-Haul	No. (cont'd)	By Haul
1	Station	1	Station	28	Electrofishing?
2	Drainage	2	Drainage	29	Closed?
3	State	3	State	30	Effort_m^2
4	County	4	County	31	Nelson Num
5	Quad	5	Quad	32	Family
6	Reach	6	Reach	33	Genus
7	RM Start	7	RM Start	34	Species
8	Locality	8	Locality	35	Species Codes
9	UTM Zone	9	UTM Zone	36	Length (SL, mm)
10	UTM Easting	10	UTM Easting	37	Sum Of SPEC
11	UTM Northing	11	UTM Northing	38	Sum Of REL
12	Date Collected	12	Date Collected	39	Sum Of Larval
13	Sampling Period	13	Sampling Period	40	Stage
14	Effort m^2	14	Secchi Depth	41	Age Class
15	Nelson Num	15	Salinity Min	42	VIE Colors
16	Family	16	Temp Min	43	VIE Locations
17	Genus	17	Air Temp Min	44	Projects
18	Species	18	DO Min		
19	Species Codes	19	Conductivity True		
20	Sum Of SPEC	20	Conductivity Specific		
21	Sum Of REL	21	pH Min		
22	Sum Of Larval	22	Station + Haul		
23	Age Class	23	Haul		
24	VIE Colors	24	Depletion #		
25	VIE Locations	25	Habitat		
26	Projects	26	Debris?		
27	Sort	27	Gear		

5.6 Objective 6: Evaluate How Modeling (e.g., PVA) May Assist in Refining Monitoring

Mathematical models can help to better understand complex relationships found in fish monitoring not easily discerned through standard analyses.

16. How are the monitoring data used in modeling?

> - **Monitoring data have been used to parameterize four models, including two PVA models, a mixed effects model, and an integrate RGSM population model.**

The data of the fish monitoring program have been used to parameterize four models:

- A frequentist PVA that used a RAMAS platform to evaluate the extinction probability of the RGSM under different environmental correlates and management scenarios (Miller, 2012).
- A Bayesian PVA in FORTRAN to evaluate the extinction probability of the RGSM for various environmental correlates (Goodman, 2010, 2012a).
- A mixed-effects hurdle model that used principal components to evaluate the effect of hydrologic controls on abundance and distribution of the RGSM (Walsworth and Budy, 2020).
- An integrated population model used to evaluate the effect of environmental correlates on the RGSM (Yackulic, 2020).

The first two models were PVAs (population viability analysis) used to inform and evaluate a biological opinion and recovery criteria for the RGSM Recovery Plan (USFWS, 2010). The third model evaluated the probability of meeting recovery criteria under different flow management scenarios. The fourth model is currently under development in collaboration with members of the PMWG, and is designed to evaluate specific aspects of RGSM dynamics (e.g., effects of prior year class strength, salvaged fish, and stocked fish on the RGSM population and the CPUE) not otherwise identified with other models.

17. Does modeling have a role in the fish monitoring plan?

> - **Yes—integrated population models can help identify and reconcile complex relationships affecting monitoring, such as effects of prior year class strength and stocking on CPUE.**
> - **Models may also be used to help evaluate the response by RGSM to management actions when CPUE indices are too variable to quantify fish response.**

- In evaluating the fish monitoring plan for the MRG, the PMWG encountered complex and interrelated issues and questions that require indepth analyses, and it was concluded that a population model would be helpful. The PMWG, through its members (ABCWUA and NMISC), contracted the services of a biometrician from the USGS starting in November 2018.
- Integrated models help identify and reconcile complex relationships affecting monitoring and vital rates (e.g., survival, growth, recruitment) that help to understand RGSM life history (e.g., Yackulic, 2020).
- It is uncertain if models can be used to help evaluate the response by RGSM to management actions when CPUE indices are too variable to quantify fish response.

18. Does monitoring provide data for population demographic parameters?

- **Yes—monthly samples provide data for estimating RGSM population demographic parameters, including age structure and vital rates (e.g., growth rate, survival, recruitment), that help to better understand RGSM life history and provide data for models.**
- **Data for some years may be incomplete or highly variable and can be reconciled with fisheries and population models.**

Part of the goal of the EC charge to the PMWG was the identification and development of population demographic parameters for the RGSM. This section describes how the data collected from monthly monitoring can be used to quantify age structure, growth rate, survival, and recruitment. The analytical methods (i.e., fisheries models) used in this section can be found in the cited reports and publications and in Guy and Brown (2007) and a manual on stock assessment by Sparre and Venema (1998).

Age Structure

- The Noon et al. (2017) science panel recommended establishing the age composition of the RGSM population by using the monthly length data and modal separation techniques to distinguish ages of fish from length-frequency histograms.
- Valdez (2018c) used the Bhattacharya method and the NORMSEP routine (a modal separation technique) to discern the age structure of the RGSM from monthly length data represented as length-frequency histograms.
- As an example, the probability distribution functions for presumed age groups are shown for length distributions of RGSM from monthly samples in the year 2010 (Fig. 27).

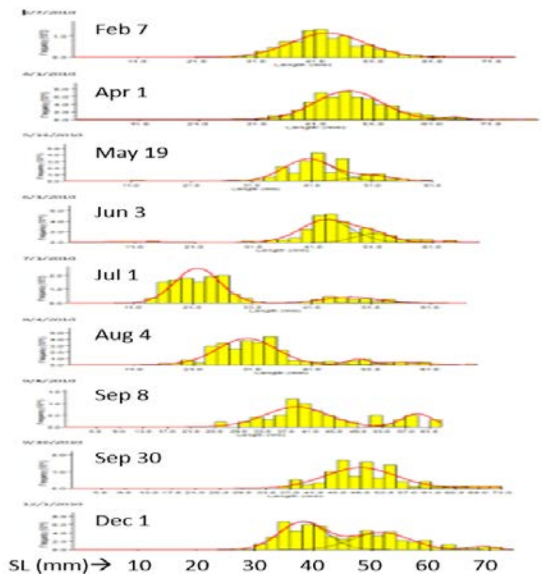


Figure 27. Example length-frequency histograms for RGSM at indicated capture dates in 2010, and probability distribution functions fit over presumed age groups using the Bhattacharya method (Valdez, 2018c). Data from PMDB.

- Of 73 frequency histograms evaluated with modal separation for 64,470 lengths of RGSM (1993-2016), the most common number of size groups were 2 (27, 37%) and 3 (26, 35.6%), and the occurrence of 1, 4, and 5 size groups were 4 (5.5%), 14 (19.2%), and 2 (2.7%), respectively. The two size groups were presumed age-0 and age-1, and the five size groups possibly included age-4 fish.
- The monthly length data of RGSM are reliable for discerning the age-0 and age-1 fish, but slowed growth after age-1 causes considerable overlap in sizes of fish; the slowed growth, overlapping sizes and small numbers of older fish render the Bhattacharya method effective for only the first two or possibly three presumed ages.

Growth Rate

- The von Bertalanffy growth function (VBGF) was fit to the monthly length data of the RGSM for each of 21 year classes (1993-2015, not 1998 and 1999). The VBGFs shown in Figure 28 were developed to fit the actual data of each year class for the first 3 years of life and extended to 5 years to reflect the size of possibly older individually in the population.

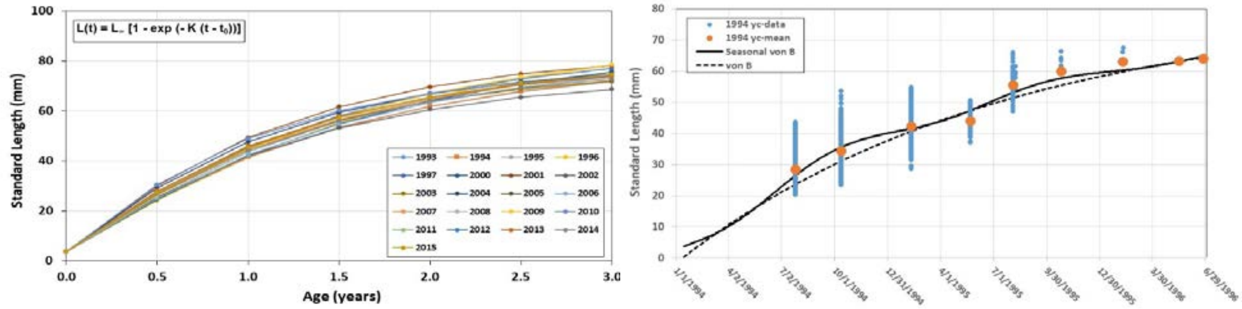


Figure 28. Length-at-age for RGSM by year class for 1993-1997 and 2000-2016, as represented by the von Bertalanffy growth function (left), and a seasonally-adjusted VBGF fit to monthly lengths of RGSM for 1994 (blue circles are individual lengths and red circles are mean monthly lengths; Valdez, 2018c). Data from the PMDB.

- The von Bertalanffy growth function (VBGF) was fit to the monthly length data of the RGSM for each of 21 year classes (1993-2015, not 1998 and 1999; Valdez, 2018c). The VBGFs shown in Figure 28 were developed to fit the actual data of each year class for the first 3 years of life and extended to 5 years to reflect the size of possibly older individually in the population. These data were also analyzed for a VBGF with Bayesian statistics (Winter, 2018).
- Mean predicted lengths of RGSM at presumed ages 1, 2, 3, 4, and 5 (years from hatching) were 45, 65, 74, 79, and 80 mm SL, respectively, assuming a length of 3.7 mm at hatching.
- The monthly length data of RGSM are reliable for estimating growth of RGSM. The data fit closely to a VBGF, and reflect seasonal over-winter decreases in growth rate that can be described with a seasonally-adjusted VBGF. The VBGF fit the growth of the RGSM starting in the post-larval phase (>40 mm SL), but do not fit the rapid growth in the larval phase.

Survival

- The Hubert et al. (2016) and the Noon et al. (2017) science panels each recommended estimating age-specific survival rates of RGSM using regression estimators where the survival of an initial cohort of RGSMs is followed over a yearly time-step.
- Estimates of annual RGSM survival by age were derived from the monitoring data by Goodman (2009) by plotting mean monthly CPUE on a log-scale over time and using the slope of the regression as survival (S); estimated annual survival of age-0 for the 2007 year class was 0.058.
- Valdez (2018d) also estimated annual survival of RGSM by year class for 1993-2017 (Fig. 29) using a monthly time step of mean CPUE by age and applying the negative exponential function $N_t = N_o e^{-Zt}$, where N_o and N_t are the CPUEs at the start and end of time, t, and Z is the instantaneous mortality rate (Sparre and Venema, 1998; Miranda and Bettoli, 2007).

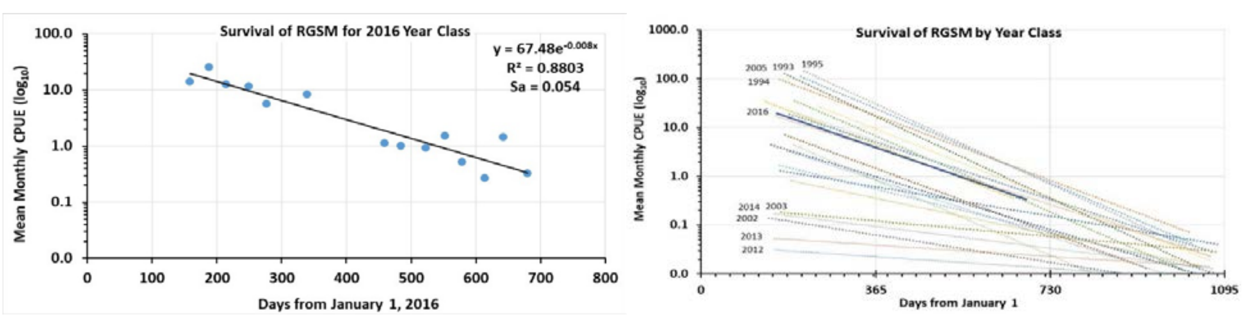


Figure 29. Survival of RGSM for the 2016 year class (left; S_{annual} = 0.054), and by year class for 1993-2017 (right). Data from the PMDB.

- Survival of age-0 RGSM cannot be determined from the monitoring data for the first 40-50 days, until small-mesh seines capture sufficient numbers of fish, which usually occurs in June or July.
- The development of a RGSM integrated population model by Yackulic (2020) enabled the PMWG to view preliminary analyses of survival using the population monitoring data. The range of annual adult survival for RGSM in the three reaches of the MRG (0.02−0.06; Fig. 30) is consistent with annual survival of 0.03, 0.03, and 0.11 for age-0, age-1, and age-2, respectively, using a negative exponential function for unmarked fish from the monitoring database in all three reaches (Valdez, 2018d).
- The range of modeled survival for June−October (0.15−0.25; Fig. 30) is also consistent with annual survival of 0.22, 0.22, and 0.40 for age-0, age-1, and age-2, respectively (Valdez, 2018d). These analyses using different methodologies reveal similar survival rates, which is only possible if the consecutive monthly CPUE indices are reflective of the mortality of the population.

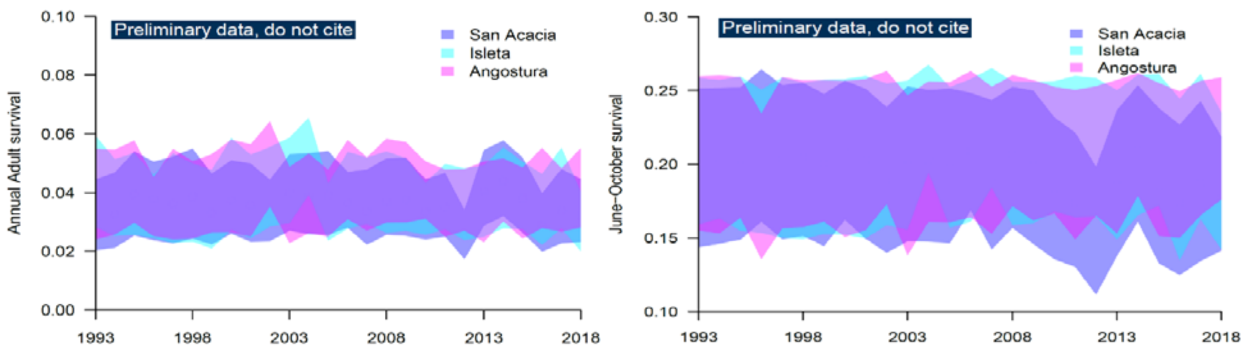


Figure 30. Annual adult survival (left) and survival for June−October (right) for RGSM by reach. This analysis is preliminary. Figures from Yackulic (2020).

Recruitment

- The Hubert et al. (2016) and the Noon et al. (2017) each urged the determination of recruitment for the RGSM. Recruitment is defined as the number of new young fish that enter the population in a given year.
- The monthly monitoring data provide an estimate of the number of individuals by age-0, age-1, and age-2+. These data can be evaluated on an annual basis as the number of young (age-0) produced by some number of adults (age-1+).
- The annual adult abundance of RGSM and the subsequent age-0 abundance estimated from April to September are represented in Figure 31 (Yackulic, 2020). Years of low recruitment of age-0 (e.g., 2018) become evident and explain the low October CPUE of 2018.
- This integrated model demonstrates how population demographic parameters can be resolved and reconciled from the monthly monitoring data, and better explain the effect of other variables, such as stocking or salvaging fish.

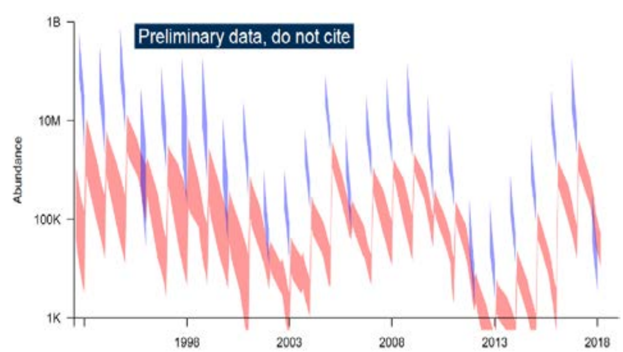


Figure 31. Annual adult abundance of RGSM (red bands) and subsequent age-0 abundance estimated from April to September (blue slashes). This analysis is preliminary. Figure from Yackulic (2020).

6.0 Findings

The following are the findings of the PMWG review of the fish monitoring plan for the MRG. Each of the findings is stated in bold text and followed by a list of explanatory statements, taken largely from the information provided for the 18 questions in section 5.0.

1. **The MRG fish monitoring plan provides systematic sampling that tracks year-to-year trends in relative abundance of the RGSM, but lacks the spatial and temporal resolution to evaluate species response to specific management actions.**
    a. Starting in 1993, the monitoring plan has followed an appropriate pattern of testing, learning, and adjusting in its sampling design, and has maintained enough consistency to sustain a comparable set of CPUE data for RGSM.
    b. The systematic sampling provides a valuable long-term record of the fishes of the MRG and importantly the relative abundance of the RGSM.
    c. Annual and monthly monitoring of the RGSM is necessary as the species is short-lived with high intra- and inter-annual variability in abundance.
    d. The annual October CPUE is used to show the year-to-year trends in relative abundance of the RGSM, but precision of the CPUE is low and could be improved by sampling more sites in October.
    e. Sample sites are not located in sufficient numbers to detect spatial changes in CPUE, nor is sampling sufficiently frequent to detect temporal changes in CPUE as a consequence of a specific management action; i.e., tests of the hypothesis, CPUE1 = CPUE2, is likely to be accepted and could result in a type II error.
2. **The plan provides monthly data for estimating population demographic parameters of the RGSM, including age structure and vital rates (e.g., growth, survival, recruitment), that help to better understand the species' life history.**
    a. Part of the goal for the PMWG was to evaluate the fish monitoring plan to determine if population demographic parameters could be estimated from the data. This review found that monthly samples provide periodic measures of age, length, weight, and density of RGSM that can be used to determine age structure and estimate vital rates (e.g., growth rate, survival, and recruitment). In some years or months, these data may be incomplete or highly variable, and various fisheries models and integrated population models can be used to reconcile these parameters.
    b. Age groups of RGSM can be determined from modal analysis of length-frequency data using the Bhattacharya method.
    c. Growth rate of RGSM can be computed by age with a von Bertalanffy growth function from the monthly lengths of RGSM.
    d. Survival of RGSM can be estimated by age with a Ricker negative exponential function fitted to the monthly CPUEs, and recruitment can be determined from the ratios of CPUE by age over time.
3. **The hydrologic and geomorphic variabilities of the MRG, combined with the stochasticity of the RGSM population, limit the level of precision for the CPUE index, and may limit the efficacy of any practical sampling design to measure, with a high level of precision, the true status of the RGSM and its response to specific management actions.**

a. The inherent variabilities of the RGSM population, as well as the dynamic flow and habitat of the MRG limit the precision of CPUE estimates.

b. This system variability includes the intra- and inter-annual dynamics in numbers of RGSM, the variable MRG flow, the changing habitat of the shifting sand-bed river channel, as well as the interactions of these factors.

c. These variabilities often lead to different environmental conditions with every sampling occasion that is not currently adjusted in computation of CPUE.

4. **A complete redesign of the fish monitoring plan is not currently warranted, but refinements could improve the precision of the CPUE, provide a better estimate of species status, and better represent the density of RGSM with CPUE, while providing cost-effective, consistent, and ongoing indices of trends in RGSM and monthly data for demographic parameters.**

   a. The current fish monitoring plan could be improved with increased precision and at reduced costs.

   b. Any changes to the current monitoring plan should utilize empirical data to determine if a revised plan can continue to provide regular, reliable, and precise estimates of RGSM CPUE for year-to-year trends and monthly data for population demographic parameters, at acceptable program costs.

   c. Adjustments to the plan should evaluate the potential benefits, risks, and costs of rearranging or changing sampling effort while still providing consistent monitoring data and information.

   d. The monitoring plan may be modified and adjusted through adaptive management, provided there is appropriate overlap and consistency in monitoring prior to the implementation of any newly modified plan.

   e. Any change to the current monitoring plan should allow for back-cast comparisons to past-years monitoring data.

7.0 Recommendations (order does not reflect priority)

The following are the recommendations of the PMWG following its review of the fish monitoring plan for the MRG. The recommendations are divided into two categories. Category 1 includes proposed studies and refinements to the monitoring plan that may involve additional field work. Category 2 includes proposed analyses and refinements to the monitoring plan with no additional field work.

Category 1: Studies and Refinements to Monitoring Plan—May Involve Additional Field Work

1. **Continue to implement the MRG fish monitoring plan, as conducted during 2017-2020 that includes the recommendations of the Hubert et al. (2016) science panel.**
    a. The current monitoring plan should continue to be implemented annually, as modified by recommendations from the Hubert et al. (2016) science panel and the PMWG, starting in 2017, including continued sampling of "additional" (30) sites in April and October, use of "replacement sites" when dry sites are encountered, and CPUE computation by seine type and age of RGSM; all other months should be sampled at 20 sites.
    b. The plan should continue to track the long-term population trend of the RGSM, and continue to collect monthly data for population demographic parameters, including age structure and vital rates (growth, survival, recruitment), pending refinements that may be made under other recommendations.
2. **Evaluate the use of other fish sampling gear types, in addition to beach seines, as a discrete study of catchability to inform and possibly supplement the current monitoring plan.**
    a. A number of gear types are used to sample the RGSM in the MRG; these gears should be evaluated to determine if species and sizes of RGSM captured can inform the monitoring plan.
    b. Beach seines are commonly used to sample small-bodied fish (Hubert and Fabrizio, 2007), and small and fine-mesh beach seines are appropriate for monitoring RGSM in the main channel of the MRG (Gonzales et al., 2012b; Hubert et al., 2016).
    c. Other gear types have been used to sample fish in the MRG, including fyke nets, block seines, boat and backpack electrofishing, and larval dip nets, but these have not been evaluated as part of standardized monitoring. These gear types can capture higher proportions of small and large RGSM than the small and fine-mesh seines.
    d. These and other gear types should be evaluated to determine if they could be used to supplement the monitoring data, or yield more reliable and precise estimates of CPUE and population demographic parameters.
3. **Re-evaluate the relationship of CPUE to total abundance of RGSM, as a discrete study to derive independent estimates of the total numbers of RGSM in the MRG simultaneous to estimates of CPUE.**
    a. This relationship was developed for data collected in 2008-2011, but may change over time or with different RGSM abundance levels (Dudley et al., 2012).
    b. Population estimates and CPUE of RGSM in the MRG were compared for October 2008–2011 to evaluate the relationship between the annual CPUE index and true population size (Dudley et al., 2011a, 2011b, 2011c, 2012).

c. Population estimates and corresponding CPUE by year (2008-2011) showed similar patterns of scale for the two parameters within the three reaches (i.e., Angostura, Isleta, and San Acacia), indicating strong correspondence between the annual estimates and CPUE.

d. Linear models showed a significant and positive correlation between the two estimates for the Isleta, San Acacia, and combined reaches, with p-values of 0.044, 0.011, and 0.034, respectively; but a weak relationship for the Angostura reach ($p = 0.082$).

e. It is uncertain if the positive relationship between the expanded abundance from box enclosures and CPUE from beach seines is predictive or deterministically dependent (Goodman, 2012b; Stinnett et al., 2005). In other words, removal estimates from a box enclosure and river-wide expansion are analogous to computing CPUE from a beach seine for river-wide expansion. Each is an expanded estimate of fish density.

f. This analysis included only four years of population estimates (two years of low October CPUE and two years of moderately high October CPUE), and the relationship may not represent the full range of CPUEs and RGSM abundance.

g. The Hubert et al. (2016) and the Noon et al. (2017) science panels each recommended further evaluation of this relationship with estimated catchability of seine hauls, or with independent mark-recapture estimates of total population size. Other methods of independent estimates may be available and should be explored.

4. Characterize the physical parameters of the principal mesohabitat types sampled as part of the fish monitoring plan to inform fish population models and hydraulic habitat models.

a. Data users and modelers have requested more information on the physical attributes of mesohabitat types sampled in the MRG.

b. Physical characteristics of mesohabitat types are important in understanding the kinds of habitats used by RGSM.

c. Measurements from representative mesohabitat types should include at least: depth, velocity, substrate, and cover.

Category 2: Analyses and Refinements to Monitoring Plan—No Field Work Needed

5. Refine the current monitoring plan to optimize precision and representation of the October CPUE, and continue to provide monthly data for estimating population demographic parameters, at acceptable program costs.

a. The refinement should use empirical data to develop a plan that continues to provide a consistent and reliable October CPUE for RGSM and monthly data for demographic parameters.

b. The refinement should use empirical data to develop a plan that continues to provide a reliable October CPUE for RGSM and monthly data for demographic parameters.

c. The refinement should consider, but not be limited to: numbers and locations of sampling sites, random vs nonrandom sites, months sampled, use of other gear types, and additional measurements.

d. Monitoring currently consists of sampling 20 sites, each about 200 m long, in 151 miles of the MRG. This represents about 2.5 of 160 miles (1.6%) of habitat occupied by the RGSM. How well this level of sampling represents the density of the RGSM in the MRG is uncertain and should be determined.

e. Sampling from 2017 to 2020 at 30 sites in April and October has yielded a mean October CPUEs with higher precision in 3 of the 4 years.

f. These results, as well as an independent field study and a probability analysis indicate that a greater number of sampling sites will likely yield higher precision and better representation of CPUE.

g. The optimal number of sites should be determined and implemented into October sampling, which is the standard census month for the RGSM. Precision is optimized when CPUE variability is weighed against sampling effort and cost.

h. Two or three alternative sampling designs should be developed and evaluated from empirical data to help determine how alternative designs may provide more accurate and precise indices of RGSM abundance at acceptable program costs.

i. This evaluation should determine the minimum and optimum numbers of sites necessary for optimal precision of RGSM CPUE and representation of density, and the minimum and optimum numbers of months necessary for population demographic parameters of RGSM, at acceptable program costs.

6. **Evaluate and compare other analytical methods against the mixture model and determine if other methods are more suitable for computing RGSM CPUE.**

    a. The mixture model addresses the zero-inflated CPUE data and the negative binomial distribution, but can be difficult to deploy and understand, and other models may be as effective and more easily applied.

    b. The Hubert et al. (2016) science panel recommended evaluating other methods for computing CPUE, besides the mixture model, including a negative binomial model, to deal with the large numbers of zero CPUEs and the large range of CPUE numbers.

    c. Additional numbers of sites in October could influence the distribution of CPUE data to become more normalized, and improve the precision that would allow the use of other computational models, including parametric statistics following a log-transformation.

7. **Develop and regularly evaluate integrated population models to help identify and reconcile complex environmental and resource influences on monitoring and RGSM CPUE, and determine if these models can be used to help evaluate RGSM response to management actions in the MRG.**

    a. The monitoring data can reflect complex interactions with environmental and resource factors that can complicate and confound RGSM CPUE and associated data.

    b. Integrated population models that use the monitoring data can help reconcile these complex interactions, including prior year class strength, capture frequencies for small- and large-bodied RGSM, and salvage and stocking of RGSM.

    c. Integrated population models should also be evaluated to determine if they can be used to prospectively forecast the effects of management actions on RGSM, in lieu of CPUE indices that may be too variable to quantify fish response.

8. **Draft a clear and concise MRG Fish Monitoring Plan for review and approval by the SAMC and the EC.**

    a. A complete and independent MRG Fish Monitoring Plan should be developed to archive the sampling design and methodologies used to monitor the RGSM.

b. A drafted MRG Fish Monitoring Plan should be made available for review and approval by the SAMC and the EC.
c. The plan should include an updated detailed description of fish sampling methodology; data analytical methods, including all variables and covariates of the model(s) used to compute CPUE; the rationales for site selection and apportionment of mesohabitat types sampled; and the intended result and use of the monitoring data.
d. A clear and concise plan will be helpful for future reference and to ensure transparency and reproducibility for sampling and analyses related to fish monitoring.

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[1]relevant study by member of PMWG with analysis of data collected by author.

[2]relevant study by member of PMWG with analysis of data from population monitoring database (PMDB) available at: https://webapps.usgs.gov/MRGESCP/documents/default.html.

Appendix A: Glossary and Abbreviations

Accuracy	Closeness of estimates or measurements to the true value or to a specific value (see also Precision)
ACOE	U.S. Army Corps of Engineers
EC	Executive Committee of the MRGESCP
CI	Confidence intervals as estimates of uncertainty associated with a sample, computed from the statistics of the observed data; e.g., a CPUE of 3.0 with 95% CI of 1.0 means that of 100 samples, 95 would be expected to fall within a range of 2.0 and 4.0
CPUE	Catch-per-unit effort, measured as the number of fish captured in 100 m^2 of area seined
CV	Coefficient of variation, standard error divided by the mean
GRTS	Generalized random tessellation stratified design used to spatially balance samples (i.e., sites in the MRG) to provide statistically reliable measurements
Mesohabitat	A distinct area of river comprised of similar depth, velocity, and substrate; e.g., pools, riffles, runs are distinct mesohabitat types
Mixture model	A statistical method for computing CPUE of RGSM that considers the statistical nuances of the catch data including the negative binomial distribution; mixture model CPUE is expressed as $\hat{E}$CPUE
MRG	Middle Rio Grande
MRGESCP	Middle Rio Grande Endangered Species Collaborative Program
Negative binomial	A discrete probability distribution that models the large number of seine hauls with zero or few RGSM and the smaller numbers of hauls with many RGSM
PIT	Passive Integrated Transponder, a glass encapsulated microchip that is injected into the musculature or peritoneum of a fish; a tag is activated electromagnetically for a unique 10-digit alpha-numeric identifier
PMDB	Population monitoring database found at: https://webapps.usgs.gov/MRGESCP/documents/default.html
PMWG	Population Monitoring Workgroup
Precision	Consistency or closeness of results for repeated measurements; e.g., wide 95% confidence intervals around a mean CPUE are less precise than narrow confidence intervals (see also Accuracy)
PVA	Population viability analysis, a method for evaluating species extinction risk using population models
Reclamation	U.S. Bureau of Reclamation
RGSM	Rio Grande silvery minnow
RM	River mile as river distance upstream from Elephant Butte Dam
Sites-additional	Ten established sites added to the 20 standard sites in April and November of each year to bring the sites per reach to 10 and the total to 30
Sites-replacement	Established sites that are used to replace a sample when a standard site has become dry
Sites-standard	Twenty fixed river locations in the MRG where sampling is routinely conducted for population monitoring, with ~20 seine hauls/month; identified as a “station” in the database
Status	The current condition of a population or species, measured as estimates or indices of abundance
Trend	The long-term trajectory of a population or species, measured as year-to-year pattern in abundance
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VIE	Visible Implant Elastomer tags, a color-coded elastomer injected beneath the skin of a fish to identify groups or batches of fish
WEST	Western EcoSystems Technology
YOY	Young-of-year, fish less than one calendar year of age, also referred to as age-0