Rio Grande silvery minnow
Salvage – 2012 Annual Report

Prepared For:
Middle Rio Grande Endangered Species Collaborative Program

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Executive Summary

Between 16 June and 22 October 2012, 51.0 unique miles of the main channel of the Middle Rio Grande became intermittent, with 19.2 miles in the Isleta reach and 31.8 miles in the San Acacia reach. A total of 5,014 Rio Grande silvery minnow (RGSM) was observed from isolated pools. Of these, 4,251 were transported and released alive at a location with flowing water within the same reach. The take by mortality observed was 304 Rio Grande silvery minnow and attributed to water operations in the Middle Rio Grande during the 2012 irrigation season (under the 2003 Biological and Conference Opinions on the effects of the Bureau of Reclamation's Water and River Maintenance Operations, Army Corps of Engineers Flood Control Operation, and related Non-Federal Actions on the Middle Rio Grande). The level of estimated incidental take (observed multiplied by 50) was 15,150 Rio Grande silvery minnows for 2012, and was well below the limits established under the determination of incidental take for the 2012 irrigation season of 396,146 individuals. The mortality of 463 additional Rio Grande silvery minnow was attributed to U.S. Fish and Wildlife Service permit activities. Going into the 2012 salvage season, lower pre-salvage catch rates meant that the allowed Incidental Take number was set lower in 2012 than 2011. Although we salvaged more miles and days in 2012, the number of fish observed both alive and dead was lower in 2012 compared to 2011, a similar trend is seen each year from 2007-2012. Each subsequent wetting and drying with each reach resulted in fewer salvaged Rio Grande silvery minnow per mile, finally resulting in local extirpation in dried areas.

Introduction

Every year since 2001, with the exception of 2008, salvage activities have been conducted on intermittent sections of the Rio Grande for RGSM (Smith 2001, Smith and Munoz 2002, Smith and Basham 2003, U.S. Fish and Wildlife Service 2005; U.S. Fish and Wildlife Service 2006b, Remshardt 2008, Remshardt 2010, Remshardt and Archdeacon 2011, Remshardt and Archdeacon 2012). These activities have been conducted under a variety of protocols and management actions to maximize effectiveness of RGSM salvage. The March 17, 2003 Biological Opinion (BO) describes a Reasonable and Prudent Alternative, Reasonable and Prudent Measures, and Conservation Measures that serve in part to secure adequate conditions for RGSM and flycatcher. As part of the March 17, 2003 BO, the Service established the annual incidental take limit for RGSM over 30 mm SL for water operations in the Middle Rio Grande. That limit is now amended annually, incorporating a formula that includes October standard monitoring data, habitat conditions during the spawn (spring runoff), and augmentation. Action agencies are apprised of the limit for incidental take by April 1 each year. Estimates of incidental take in the field are derived from surveys in which observed mortality is multiplied by 50, based on the assumption that the probability of observing a single mortality is 0.02. This value was an estimated value determined by U.S. Fish and Wildlife Service biologists. The amended incidental take limit for the 2012 irrigation season was 396,146 RGSM, which is equivalent to 7,923 RGSM observed dead (U.S. Fish and Wildlife Service 2012).

This report documents efforts during 2012 to reduce the mortality of post-larval RGSM when flow in the Middle Rio Grande became intermittent. Additionally, we relate environmental pool parameters to the number of Rio Grande silvery minnow collected from each pool, in order to predict what pool characteristics are associated with silvery minnow. We examine how the number of fish per mile changes with each re-wetting and drying, and we summarize the number of miles dried and RGSM observed in each summer from 2007-2012.

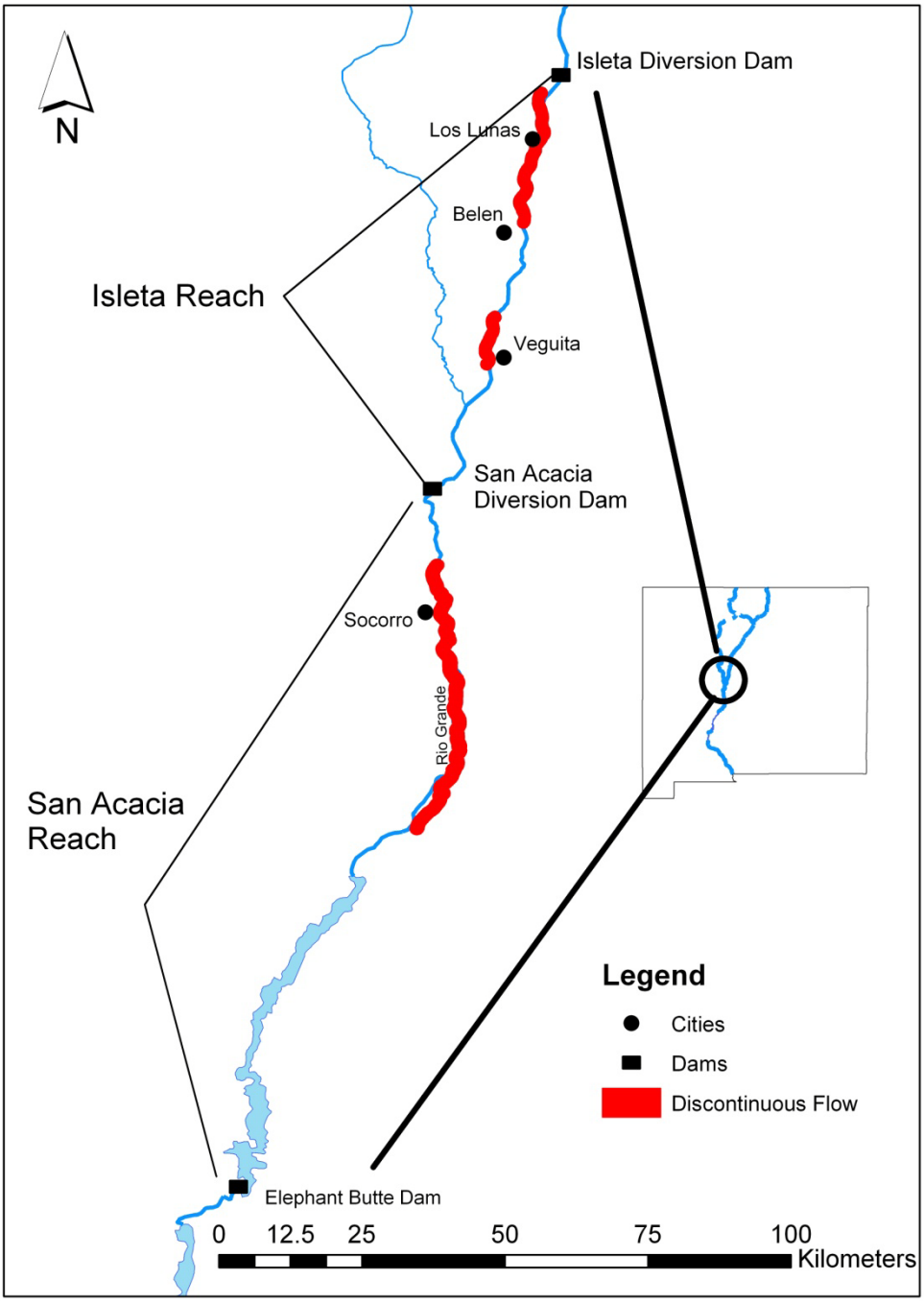

Figure 1-Reaches of the Middle Rio Grande in New Mexico. Salvage operations for Rio Grande Silvery minnow were conducted in the Isleta and San Acacia reaches in 2012. Red areas indicate discontinuous flows.

Methods

Determination of Incidental Take

Rio Grande silvery minnow mortality can occur with channel drying resulting from excessive drought conditions, and conditions resulting from federal mediated water operations. In the recent past, intermittent conditions have existed in significant portions (e.g., up to 68.0 miles – approximately 45 percent of the RGSM's contemporary range) of the river between Isleta Diversion Dam and Elephant Butte Reservoir. Efforts to salvage RGSM from intermittent reaches of river are intended to reduce RGSM mortality that occurs with channel drying resulting from water operations and drought conditions. In addition, salvage is meant to reduce the probability that mortality associated with water operations will exceed the limit for incidental take.

Rio Grande silvery minnow salvage operations progressed in synchrony with river recession, with priority given to river reaches in which the death of RGSM due to federal water operations would be considered incidental take. Incidental take of post embryonic RGSM is defined for two size classes, i.e., for those shorter than or equal to 30 mm SL and those longer than 30 mm SL. All smaller sized post embryonic RGSM (≤ 30 mm SL) are presumed to be taken as a result of federal water operations when the river dries downstream of Isleta Diversion (U. S. Fish and Wildlife Service 2003), but no limit on the amount of incidental take is calculated.

Determination of incidental take of these larger size class of post embryonic RGSM (> 30 mm SL) is conditional. Mortality of the larger sized post-embryonic RGSM that occurs in portions of the river that are rewetted due to forces that are not directly or indirectly related to the operations of the Action Agencies was not considered to be incidental take under the March 17, 2003 BO (U.S. Fish and Wildlife Service 2003). In contrast, rewetting and subsequent re-drying of river reaches that were directly or indirectly related to the operations of the Action Agencies was regarded as incidental take, including when dried outside of the timeframes provided in the 2003 BO. RGSM mortality, involving the larger sized individuals that occurred outside of the active river channel was generally not considered incidental take under the March 17, 2003 BO (U. S. Fish and Wildlife Service 2003). The exception to this generalization involves areas outside of the active channel that are wetted as a consequence of federal water pumping operations (i.e., water pumped from the low flow conveyance channel in an effort to maintain specified flows in the river) or river maintenance activities. Finally, the larger sized RGSM that are "rescued" and that die in transit to relocation sites were not considered to be incidental take under the 2003 BO, but were attributed to USFWS permitted activities during salvage operations. Likewise, RGSM that exhibited advanced clinical signs of poor health were deemed not salvageable and also (e.g., lethargy and hemorrhagic lesions) were not considered incidental take.

Salvage of RGSM

Field activities for salvage of RGSM have followed a standard protocol since 2007, with few modifications since. Collection of water depth and estimated area for each pool was added in 2011, as we as time of day each pool was salvaged. Transport tanks equipped with oxygen tanks were filled with water to near capacity (~50 gal) with water from reverse osmosis de-ionized water from a municipal source when possible, or water from flowing sections of river prior to

salvage operations. Salt (NaCl) was added to water in hauling vessels at the rate of 1.0 % NaCl solution, and Stress Coat was added at the rate of 0.26 ml/liter (1 ml/gallon).

Using seines of various sizes, we collected RGSM from isolated pools that formed as flow in the Middle Rio Grande becomes discontinuous. Prior to handling RGSM, personnel washed their hands to remove the residue of lotions (e.g., suntan lotions and mosquito repellant). Fish were handled with care using wetted hands. RGSM that exhibited advanced clinical signs of poor health (e.g., lethargy and hemorrhagic lesions) were not salvaged. Salvaged RGSM were immediately placed into five-gallon buckets filled with transport tank water and subsequently transferred to 50-gallon transport tanks attached to utility terrain vehicles.

Pure oxygen was supplied to transport tanks through micro-bubble oxygen diffusers. Flow of oxygen was adjusted with varying water temperatures and loading rates of fish to maintain dissolved oxygen levels near 100% saturation. Salvaged RGSM were transported and released in the nearest section of river with perennial flow, and within their reach of origin, that would not experience drying. Prior to releasing RGSM into the river, water in the transport tanks was tempered (by slowly adding river water to the transport tanks) until it was within 1° C of the water temperature of the river at the release site. We counted salvaged RGSM each day and noted other species of fishes encountered in isolated pools.

Once a location was identified as a potential salvage site, a set of primary and secondary biological criteria were applied to determine whether salvage should occur. These criteria were defined by tolerance limits of RGSM to environmental variables (Cho et al. 2009). Documentation of conditions, incidental take (if appropriate), and preservation of individuals followed.

Criteria for Salvaging

Primary (Water Quality)	1. Water temperature < 34°C 2. Dissolved Oxygen > 2.0 mg/liter 3. pH < 9.0
Secondary (Fish Health)	1. No Dead fish (any species) in pool 2. No lethargy and/or hemorrhagic lesions noticed from fish (any species) in pool

In the instances where salvage was deemed necessary and feasible, every effort was made to ensure that any fish to be moved had the highest probability of survival.

Monitoring Activities

During salvage, a variety of data were collected to document the conditions at the pools, including those data necessary to determine whether or not salvage would occur. These parameters included visually-estimated size of pool (m^2), depth (nearest 0.1m), dissolved oxygen (mg/l), water temperature (C), pH, time of day, location (nearest 0.1 river mile), and reach of river. We also documented dead fish or salvaged fish when these pools otherwise met the criteria.

All Rio Grande silvery minnow were characterized as adult, young of year < 30 mm SL (typically early season), or young of year > 30 mm SL (late season). All adults were examined for taggings indicating a hatchery released fish. Each RGSM was also labeled as salvaged, dead, or sick. Dead fish were then categorized as either incidental take (collected on first drying) or USFWS permit (collected on subsequent drying). Sick fish were not salvaged and counted towards USFWS permit. Young of year < 30 mm SL are counted as incidental take, but are not included in reports of incidental take hereafter. Upon release, any fish that died during transport were subtracted from the appropriate size class of salvaged fish, giving the final number of salvaged fish for that day and reach. Hatchery released fish were noted (determined by visual implant elastomer tags), red right dorsal for fish released in the San Acacia reach, yellow right dorsal for fish released in the Isleta Reach.

Analysis of Data

Reach-specific Data. We calculated reach and overall totals for all categories of RGSM encountered during salvage activities. We also summarized the temporal and spatial extent of each drying period.

Pool-Specific Data. We calculated the number of RGSM for each pool. Individual pools were not monitored over time, all relations between variables and time are from separate re-wetting events, e.g., pool size over time indicates size of pools after each re-wetting, not the size of an individual pool through time.

We examined counts of RGSM per pool. We used negative binomial models for count data (Crawley 2007; O'Hara and Kotze 2010). Explanatory variables included depth of pool, date, and reach.

Date-Specific Data. For daily data, we calculated the RGSM observed for each day of salvage, number of pools salvaged, number of river miles salvaged, and the amount of time required to salvage that distance. We used negative binomial models for count data relating RGSM to reach, date, and number of pools salvaged (Crawley 2007; O'Hara and Kotze 2010).

Effects of drying on RGSM per mile. We calculated the average number of RGSM collected per mile, per drying event, for each reach. We excluded the lower section of the Isleta reach from analyses because the exact amount of drying was unknown. We used analysis of covariance to predict the number of RGSM collected per mile based on the reach and the number of times the reach had been dried previously. Because of the small sample size, we calculated a Jackknife R^2 to cross-validate the regression (Efron and Gong 1983).

Salvage data summary. We examined the extent of drying and the total number of RGSM collected for each salvage season 2007-2012. We dropped 2008 from analyses as no drying occurred, and therefore no salvage occurred. We used a linear regression to predict the number of total RGSM collected from the total extent of drying. Because of the small sample size, we calculated a Jackknife R^2 to cross-validate the regression (Efron and Gong 1983).

Transformations (e.g., log+1 transformation) to the data were applied as necessary to meet the assumptions of the models. Dates were transformed to Julian dates, with 16 June 2012 set as the

origin (e.g., Day 0). We used program R for all statistical analyses (R Development Core Team 2011). A chronological summary of all collections appears in Appendix A. Detailed model outputs appear in Appendix B.

Results

Channel Drying

In 2012, drying occurred in two areas of the Isleta Reach, between a point about 3 miles downstream of the Isleta Diversion Dam (Figure 1) and about a mile below the Peralta Wasteway, and a second area near Veguita. In the San Acacia Reach, discontinuous flows occurred from the south boundary of Bosque del Apache National Wildlife Refuge to about Escondida, New Mexico (Figure 1). Multiple re-wetting and drying events were recorded in all three areas, as re-wetting and re-drying occurs with monsoons, increasing or decreasing human demand, or through irrigation system maintenance. The San Acacia reach dried six separate times, while the Isleta reach dried four separate times (Appendix A).

RGSM salvage operations generally progressed in synchrony with river recession over the course of the 2012 irrigation season in main channel habitats. Ultimately, 51.0 unique miles of the main channel of the Middle Rio Grande were dried, 31.8 in the San Acacia Reach and 19.2 miles in the Isleta (Table 2).

Salvage operations were conducted 68 days during the 2012 irrigation season, 40 days in the San Acacia Reach, and 28 days in the Isleta Reach. Salvage occurred between 16 June and 22 October 2012. In total, 136.3 river miles were salvaged in the San Acacia Reach, and 67.7 in the Isleta Reach from June to September (Table 2), which includes salvage operations in miles that experienced repeated drying events. For a chronological summary of salvage operations, see Appendix A.

Documentation of Incidental Take of RGSM

A total of 5,014 RGSM was observed within the river channel (Table 1). Of these 4,161 RGSM were transported to flowing sections within the same reach and released alive (97.9% transport survival of salvaged RGSM), and 304 were found dead during the first drying event, counting as incidental take. The average daily extent of drying aquatic habitat involved in salvage operations per day was at or below the 8.0 miles of drying per day rate allowed in the March 17, 2003 BO (U. S. Fish and Wildlife Service 2003), as modified on June 15, 2006 (U. S. Fish and Wildlife Service 2006a).

A total of 463 Rio Grande silvery minnow was counted towards the USFWS permit (Table 1). These individuals included those that perished between the act of salvage collection and when they were to be released back to the river, and those that were deemed not salvageable based on the criteria mentioned previously.

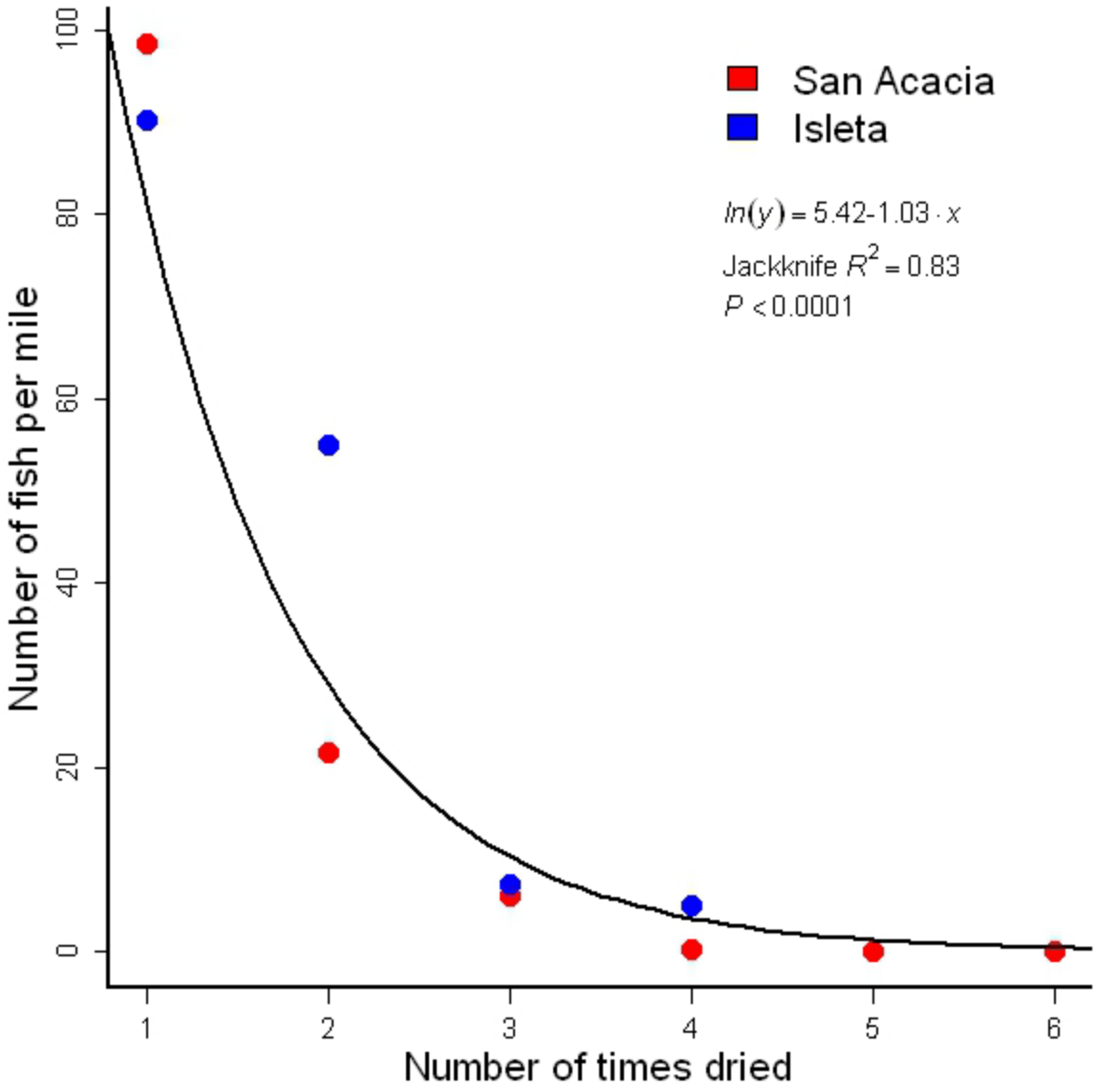

Figure 2-Number of Rio Grande silvery minnow encountered per river mile during each salvage event, June to October 2012, in the Middle Rio Grande, New Mexico.

Table 1-Summary of salvage operations for Rio Grande silvery minnow in the Middle Rio Grande, 2012. Total salvaged RGSM does not include transport losses. Age-0 <30 mm SL includes incidental take, USFWS permit, dead/dying fish, and live fish. Red and yellow VIE tagged fish are included in parentheses (red; yellow).

Reach	Age-0 <30 mm	Age-0 >30 mm	Adults	Salvaged	USFWS Permit	Incidental Take	Total RGSM
San Acacia	81	2	3,068 (1,770; 16)	2576	286	275	**3151**
Isleta	0	1	1,862 (0;55)	1675	177	29	**1863**
Total	81	3	4,930 (1,770; 71)	4,251	463	304	**5,014**

Table 2-Number of miles salvaged, extent of drying, and number of pools evaluated per reach during 2012 salvage operations. Extent of drying is the number of unique river miles of discontinuous flow observed for the season. The miles salvaged include repeated drying and wetting events in the same locations.

Reach	Number of Days	Number of Pools	Miles Salvaged	Extent of Drying
San Acacia	40	1,655	136.3	31.8
Isleta	28	1,119	67.7	19.2
Total	68	2,774	204.0	51.0

Table 3-Summary of salvage activities in the Middle Rio Grande, New Mexico, during summer intermittency, 2007-2012.

Year	Extent of drying	Miles Salvaged	Pools Salvaged	Total RGSM
2007	30.0	119.2	1,052	15,636
2008	0.0	0.0	0	0
2009	19.9	65.0	522	18,473
2010	28.2	118.2	1,232	12,349
2011	40.2	163.7	2,054	9,277
2012	51.0	204.0	2,774	5,014

Monitoring Activities

The number of RGSM encountered in a pool was dependent on, pool depth, date, and reach (Model 1, Appendix B). The number of RGSM per pool increased with increasing pool depth, and decreased through the season, with depth being the most important predictor. Fewer RGSM were found in pools in the San Acacia Reach compared to the Isleta Reach.

The number of RGSM encountered per day was dependent on number of miles salvaged, date and reach (Model 2, Appendix B). The number of RGSM encountered daily increased as river miles salvaged increased, but decreased slightly through the season. There were fewer RGSM collected during salvage activities in the San Acacia Reach compared to the Isleta Reach.

Effects of drying on RGSM per mile. Fewer and fewer RGSM were collected in subsequent dryings, until the number of fish per mile nearly reached zero, following a pattern of exponential decay (Figure 2). Although starting at different densities of fish per mile initially, the effect of reach was not a significant effect on RGSM per mile, and was subsequently dropped from the model (Model 3, Appendix B)

Salvage data summary. We found a strong negative correlation between the total extent of drying each summer and the total number of RGSM observed during that period (Model 4, Appendix B). The greater the linear extent of drying, the fewer RGSM were observed during salvage activities (Figure 3). In spite of increased efforts, salvaging more miles and more pools, fewer RGSM were found in years with a larger total extent of drying (Table 3).

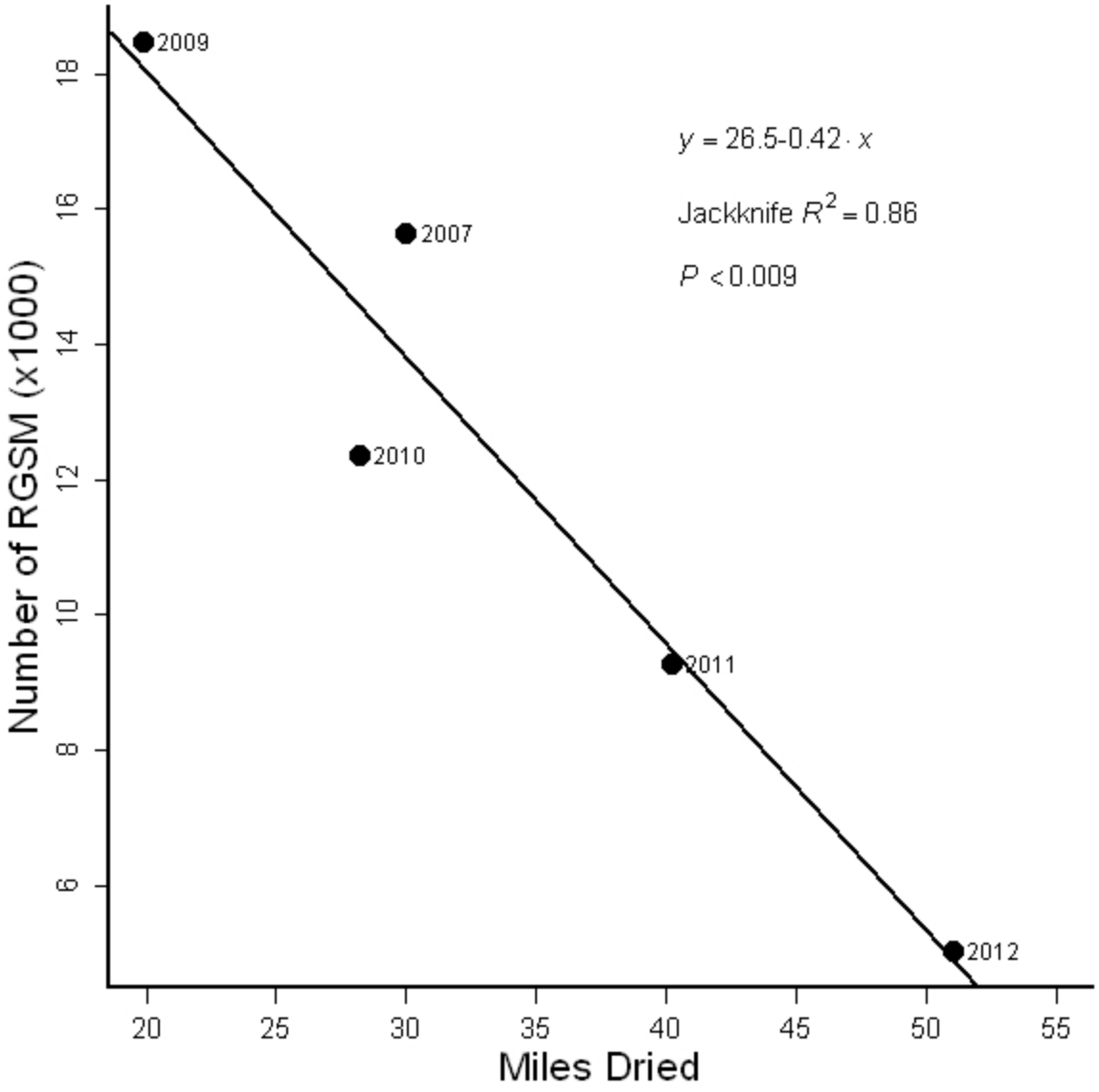

Figure 3-Number of RGSM collected (x1000) and the total extent of miles of river dried each year of salvage in the Middle Rio Grande, New Mexico.

Discussion

We found that fewer and fewer RGSM are present in periodically dewatered areas. Repeated wetting and drying cycles are associated with lower densities off RGSM per mile. In the San Acacia reach, local extirpations of RGSM occurred over large areas after the fifth re-wetting and drying event in 2012. Over the past five years, the larger the extent of drying, the fewer RGSM are observed during salvage activities. Available data clearly indicate there are correlations between spring run-off and recruitment success (e.g., Dudley and Platania 2011). However, poor run-off years resulting in poor recruitment are also years when the total extent of drying is greater. Drying, re-wetting, and repeated drying episodes are clearly damaging to the local abundance and distribution of RGSM, and more than two occurrences results in greatly reduced local abundance of RGSM during salvage operations. Further research is needed to determine the effects of river drying on the RGSM at the population level.

We were able to predict both the number of RGSM found in pools and found during each day during 2012. Both numbers decrease throughout the season. In each pool, number of RGSM increased with increasing pool size and depth. These observations agree with similar analyses performed in 2010 (Remshardt and Archdeacon 2011). Unlike 2010 but similar to 2011, we were able to predict the number of RGSM collected in a day based on the number of miles salvaged and the date. In 2012, total numbers of RGSM collected each day decreased as the season progressed, while still accounting for the number of miles salvaged each day. This agrees with the observation that fewer RGSM are collected from each pool later in the season. Although the effect is small, fewer RGSM are present in dewatered sections of the river after periodic wetting and drying cycles. This may be because few fish are moving downstream later in the season.

More than half (58.2%) of the fish collected in the San Acacia Reach during 2012 salvage operations were hatchery released fish, while only 55 hatchery fish were collected in the Isleta Reach (2.9%). In 2011, the nearest stocking site to the area that dried was U.S. 60 Bridge, approximately 2 miles downstream of the drying that occurred near Veguita (Figure 1). These fish had to move upstream 20 or more miles to be collected in the upper Isleta Reach. In San Acacia, three stocking sites in 2011 were located directly in the areas dried, leading to the majority of fish collected there being hatchery fish. No tagged hatchery fish from releases prior to 2011 were found during the 2012 irrigation season.

Compared to 2011, we salvaged more days, more miles, more pools, and the extent of drying was greater during 2012 salvage operations. However, in spite of the increased effort, we observed fewer overall RGSM, a pattern seen in every year since 2007. Drying also occurred near Veguita in the Isleta reach, an area that had not dried since prior to 2007. By the end of the 2012 irrigation season, the number and density of RGSM observed during salvage activities was the lowest since 2007, and much of the dewatered areas contained no RGSM after re-wetting and drying. Continued monitoring of salvage activities will increase the understanding about how river drying affects Rio Grande silvery minnow recruitment and survival.

Acknowledgments

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Personnel of the New Mexico Fish and Wildlife Conservation Office served to plan and coordinate salvage operations, and represented the core of the salvage workforce, including Tristan Austring, Judith Barkstedt, Sara Blocker, Andy Dean, Christine Stewart, and Cole Wolf. Field assistance was also provided by the Army Corps of Engineers staff including Sara Beck, Michael Porter, and Justin Reale, and the Albuquerque BioPark including Rachel Hand, Emily Hodson, Emma Mathews, Ava Otway, and Kim Ward. Special thanks to Bosque Del Apache National Wildlife Refuge for providing housing and logistical support.

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Appendix A: Chronology of salvage operations

Note: FWS permit includes those found dead that could not be attributed to Incidental Take including fish not salvaged due to health criteria, those sacrificed for research, or died prior to release. Salvaged fish are those released alive > 30 mm SL, number after the slash is the number of adults. Release locations: a - Isleta Diversion Dam, b - Peralta Wasteway, c - Highway 346 Bridge, d - U.S. 60 Bridge, e - 1 mile below San Acacia Diversion Dam, f - San Marcial Railroad Bridge, g - Escondida Bridge, n/a - no fish released.

16 Jun 2012	[e]San Acacia Reach	WJR12-1096
Rio Grande silvery minnow - Salvaged		146/146
Rio Grande silvery minnow - FWS Permit		3
Rio Grande silvery minnow - Incidental Take		10

17 Jun 2012	[f]San Acacia Reach	WJR12-1097
Rio Grande silvery minnow - Salvaged		161/161
Rio Grande silvery minnow - FWS Permit		23
Rio Grande silvery minnow - Incidental Take		45

19 Jun 2012	[f]San Acacia Reach	WJR12-1098
Rio Grande silvery minnow - Salvaged		271/271
Rio Grande silvery minnow - FWS Permit		16
Rio Grande silvery minnow - Incidental Take		10

20 Jun 2012	[f]San Acacia Reach	WJR12-1099
Rio Grande silvery minnow - Salvaged		88/88
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		3

21 Jun 2012	[f]San Acacia Reach	WJR12-1100
Rio Grande silvery minnow - Salvaged		121/121
Rio Grande silvery minnow - FWS Permit		3
Rio Grande silvery minnow - Incidental Take		1

23 Jun 2012	[f]San Acacia Reach	WJR12-1101
Rio Grande silvery minnow - Salvaged		256/256
Rio Grande silvery minnow - FWS Permit		98
Rio Grande silvery minnow - Incidental Take		92

24 Jun 2012	[f]San Acacia Reach	WJR12-1102
Rio Grande silvery minnow - Salvaged		145/145
Rio Grande silvery minnow - FWS Permit		11
Rio Grande silvery minnow - Incidental Take		12

25 Jun 2012	[f]San Acacia Reach	TPA12-029
Rio Grande silvery minnow - Salvaged		71/71
Rio Grande silvery minnow - FWS Permit		2
Rio Grande silvery minnow - Incidental Take		0

27 Jun 2012	[f]San Acacia Reach	WJR12-1103
Rio Grande silvery minnow - Salvaged		191/191
Rio Grande silvery minnow - FWS Permit		4
Rio Grande silvery minnow - Incidental Take		35

28 Jun 2012	[e]San Acacia Reach	WJR12-1104
Rio Grande silvery minnow - Salvaged		225/225
Rio Grande silvery minnow - FWS Permit		21
Rio Grande silvery minnow - Incidental Take		18

29 Jun 2012	[f]San Acacia Reach	TPA12-030
Rio Grande silvery minnow - Salvaged		37/37
Rio Grande silvery minnow - FWS Permit		8
Rio Grande silvery minnow - Incidental Take		4

30 Jun 2012	[e]San Acacia Reach	TPA12-031
Rio Grande silvery minnow - Salvaged		46/46
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		27

1 Jul 2012	[e]San Acacia Reach	TPA12-032
Rio Grande silvery minnow - Salvaged		29/29
Rio Grande silvery minnow - FWS Permit		1
Rio Grande silvery minnow - Incidental Take		3

2 Jul 2012	[f]San Acacia Reach	WJR12-1105
Rio Grande silvery minnow - Salvaged		63/63
Rio Grande silvery minnow - FWS Permit		3
Rio Grande silvery minnow - Incidental Take		3

3 Jul 2012	[e]San Acacia Reach	WJR12-1106
Rio Grande silvery minnow - Salvaged		48/48
Rio Grande silvery minnow - FWS Permit		1
Rio Grande silvery minnow - Incidental Take		1

4 Jul 2012	[e]San Acacia Reach	WJR12-1107
Rio Grande silvery minnow - Salvaged		19/19
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

4 Jul 2012	[a]Isleta Reach	TPA12-033
Rio Grande silvery minnow - Salvaged		8/8
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		1

5 Jul 2012	[b]Isleta Reach	WJR12-1108
Rio Grande silvery minnow - Salvaged		0/0
Rio Grande silvery minnow - FWS Permit		1
Rio Grande silvery minnow - Incidental Take		0

6 Jul 2012	[n/a]Isleta Reach	WJR12-1109
Rio Grande silvery minnow - Salvaged		0/0
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		1

11 Jul 2012	[a]Isleta Reach	TJA12-034
Rio Grande silvery minnow - Salvaged		12/12
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

15 Jul 2012	[a]Isleta Reach	TPA12-034
Rio Grande silvery minnow - Salvaged		127/127
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

16 Jul 2012	[a]Isleta Reach	TJA12-035
Rio Grande silvery minnow - Salvaged		357/357
Rio Grande silvery minnow - FWS Permit		29
Rio Grande silvery minnow - Incidental Take		0

16 Jul 2012	[a]Isleta Reach	TJA12-035A
Rio Grande silvery minnow - Salvaged		7/7
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

17 Jul 2012	[c]Isleta Reach	WJR12-1116
Rio Grande silvery minnow - Salvaged		48/48
Rio Grande silvery minnow - FWS Permit		2
Rio Grande silvery minnow - Incidental Take		1

18 Jul 2012	[a]Isleta Reach	WJR12-1117
Rio Grande silvery minnow - Salvaged		18/18
Rio Grande silvery minnow - FWS Permit		12
Rio Grande silvery minnow - Incidental Take		0

20 Jul 2012	[a]Isleta Reach	JMB12-006
Rio Grande silvery minnow - Salvaged		10/10
Rio Grande silvery minnow - FWS Permit		22
Rio Grande silvery minnow - Incidental Take		1

21 Jul 2012	[a]Isleta Reach	WJR12-1119
Rio Grande silvery minnow - Salvaged		6/6
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

21 Jul 2012	[a]Isleta Reach	WJR12-1118
Rio Grande silvery minnow - Salvaged		7/7
Rio Grande silvery minnow - FWS Permit		1
Rio Grande silvery minnow - Incidental Take		1

22 Jul 2012	[a]Isleta Reach	WJR12-1120
Rio Grande silvery minnow - Salvaged		172/172
Rio Grande silvery minnow - FWS Permit		68
Rio Grande silvery minnow - Incidental Take		14

23 Jul 2012	[d]San Acacia Reach	CJW12-001
Rio Grande silvery minnow - Salvaged		16/16
Rio Grande silvery minnow - FWS Permit		1
Rio Grande silvery minnow - Incidental Take		0

23 Jul 2012	[f]Isleta Reach	TJA12-036
Rio Grande silvery minnow - Salvaged		5/5
Rio Grande silvery minnow - FWS Permit		2
Rio Grande silvery minnow - Incidental Take		0

24 Jul 2012	[e]San Acacia Reach	TJA12-037
Rio Grande silvery minnow - Salvaged		246/246
Rio Grande silvery minnow - FWS Permit		58
Rio Grande silvery minnow - Incidental Take		0

25 Jul 2012	[e]San Acacia Reach	JMB12-007
Rio Grande silvery minnow - Salvaged		163/163
Rio Grande silvery minnow - FWS Permit		4
Rio Grande silvery minnow - Incidental Take		11

26 Jul 2012	[e]San Acacia Reach	WJR12-1123
Rio Grande silvery minnow - Salvaged		59/59
Rio Grande silvery minnow - FWS Permit		15
Rio Grande silvery minnow - Incidental Take		0

27 Jul 2012	[e]San Acacia Reach	WJR12-1124
Rio Grande silvery minnow - Salvaged		6/6
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

29 Jul 2012	[a]Isleta Reach	TJA12-038
Rio Grande silvery minnow - Salvaged		40/40
Rio Grande silvery minnow - FWS Permit		8
Rio Grande silvery minnow - Incidental Take		0

30 Jul 2012	[a]Isleta Reach	WJR12-1125
Rio Grande silvery minnow - Salvaged		18/18
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

1 Aug 2012	[a]Isleta Reach	TJA12-039
Rio Grande silvery minnow - Salvaged		3/3
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

1 Aug 2012	[d]Isleta Reach	TJA12-040
Rio Grande silvery minnow - Salvaged		7/7
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

2 Aug 2012	[d]Isleta Reach	JMB12-08
Rio Grande silvery minnow - Salvaged		6/6
Rio Grande silvery minnow - FWS Permit		2
Rio Grande silvery minnow - Incidental Take		0

2 Aug 2012	[a]Isleta Reach	WJR12-1129
Rio Grande silvery minnow - Salvaged		46/46
Rio Grande silvery minnow - FWS Permit		1
Rio Grande silvery minnow - Incidental Take		1

3 Aug 2012	[e]Isleta Reach	WJR12-1130
Rio Grande silvery minnow - Salvaged		671/670
Rio Grande silvery minnow - FWS Permit		9
Rio Grande silvery minnow - Incidental Take		9

4 Aug 2012	[e]San Acacia Reach	WJR12-1131
Rio Grande silvery minnow - Salvaged		3/3
Rio Grande silvery minnow - FWS Permit		1
Rio Grande silvery minnow - Incidental Take		0

4 Aug 2012	[e]Isleta Reach	WJR12-1132
Rio Grande silvery minnow - Salvaged		0/0
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

7 Aug 2012	[f]San Acacia Reach	TJA12-041
Rio Grande silvery minnow - Salvaged		10/10
Rio Grande silvery minnow - FWS Permit		2
Rio Grande silvery minnow - Incidental Take		0

8 Aug 2012	[e]San Acacia Reach	WJR12-1133
Rio Grande silvery minnow - Salvaged		25/25
Rio Grande silvery minnow - FWS Permit		6
Rio Grande silvery minnow - Incidental Take		0

9 Aug 2012	[e]San Acacia Reach	TJA12-042
Rio Grande silvery minnow - Salvaged		13/13
Rio Grande silvery minnow - FWS Permit		2
Rio Grande silvery minnow - Incidental Take		0

10 Aug 2012	[e]San Acacia Reach	TPA12-035
Rio Grande silvery minnow - Salvaged		36/35
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

13 Aug 2012	[a]Isleta Reach	CJW12-013
Rio Grande silvery minnow - Salvaged		10/10
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

14 Aug 2012	[c]San Acacia Reach	CJW12-014
Rio Grande silvery minnow - Salvaged		5/5
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

14 Aug 2012	[c]San Acacia Reach	TPA12-036
Rio Grande silvery minnow - Salvaged		3/2
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

19 Aug 2012	[a]Isleta Reach	WJR12-1134
Rio Grande silvery minnow - Salvaged		6/6
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

20 Aug 2012	[a]Isleta Reach	JMB12-09
Rio Grande silvery minnow - Salvaged		18/18
Rio Grande silvery minnow - FWS Permit		17
Rio Grande silvery minnow - Incidental Take		0

21 Aug 2012	[a]Isleta Reach	JMB12-10
Rio Grande silvery minnow - Salvaged		20/20
Rio Grande silvery minnow - FWS Permit		2
Rio Grande silvery minnow - Incidental Take		0

21 Aug 2012	[c]San Acacia Reach	TPA12-037
Rio Grande silvery minnow - Salvaged		2/2
Rio Grande silvery minnow - FWS Permit		1
Rio Grande silvery minnow - Incidental Take		0

28 Aug 2012	[a]Isleta Reach	JMB12-11
Rio Grande silvery minnow - Salvaged		18/18
Rio Grande silvery minnow - FWS Permit		1
Rio Grande silvery minnow - Incidental Take		0

29 Aug 2012	[c]Isleta Reach	TPA12-041
Rio Grande silvery minnow - Salvaged		1/1
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

30 Aug 2012	[c]Isleta Reach	TPA12-042a
Rio Grande silvery minnow - Salvaged		2/2
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

31 Aug 2012	[a]Isleta Reach	TJA12-043
Rio Grande silvery minnow - Salvaged		11/11
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

4 Sep 2012	[n/a]San Acacia Reach	TPA12-042b
Rio Grande silvery minnow - Salvaged		0/0
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

5 Sep 2012	[e]San Acacia Reach	TPA12-043
Rio Grande silvery minnow - Salvaged		1/1
Rio Grande silvery minnow - FWS Permit		1
Rio Grande silvery minnow - Incidental Take		0

6 Sep 2012	[n/a]Isleta Reach	JMB12-12
Rio Grande silvery minnow - Salvaged		0/0
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

7 Sep 2012	[e]San Acacia Reach	TJA12-044
Rio Grande silvery minnow - Salvaged		1/1
Rio Grande silvery minnow - FWS Permit		1
Rio Grande silvery minnow - Incidental Take		0

10 Sep 2012	[e]San Acacia Reach	TPA12-044
Rio Grande silvery minnow - Salvaged		2/2
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

11 Sep 2012	[e]San Acacia Reach	CTS12-25
Rio Grande silvery minnow - Salvaged		1/1
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

12 Sep 2012	[n/a]San Acacia Reach	TPA12-045
Rio Grande silvery minnow - Salvaged		0/0
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

19 Sep 2012	[n/a]San Acacia Reach	CTS12-026
Rio Grande silvery minnow - Salvaged		0/0
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

20 Sep 2012	[n/a]San Acacia Reach	TPA12-046
Rio Grande silvery minnow - Salvaged		0/0
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

21 Sep 2012	[n/a]San Acacia Reach	TPA12-047
Rio Grande silvery minnow - Salvaged		0/0
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

24 Sep 2012	[n/a]San Acacia Reach	CTS12-027
Rio Grande silvery minnow - Salvaged		0/0
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

10 Oct 2012	[a]Isleta Reach	TJA12-048a
Rio Grande silvery minnow - Salvaged		3/3
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

19 Oct 2012	[n/a]San Acacia Reach	CJW12-028
Rio Grande silvery minnow - Salvaged		0/0
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

22 Oct 2012	[n/a]San Acacia Reach	JMB12-13
Rio Grande silvery minnow - Salvaged		0/0
Rio Grande silvery minnow - FWS Permit		0
Rio Grande silvery minnow - Incidental Take		0

16 June - 22 October 2012	All Reaches	Grand Total
Rio Grande silvery minnow - Salvaged		4166/4163
Rio Grande silvery minnow - FWS Permit		463
Rio Grande silvery minnow - Incidental Take		304

Appendix B: R Model Output

Function calls

glm.nb = general linear model with a negative binomial error structure
lm = linear model with a normal error structure

Variables

total.minnows = total number of RGSM observed
depth = depth of pool (nearest 0.1m)
Date = Julian date with the first day of salvage as 0
reach = San Acacia or Isleta
rm.salvaged = Number of miles salvaged on that specific day
minnow.mile = Mean number of minnows per mile during that drying event
times.dried = Cumulative number of times the reach was salvaged
total.rgsm = total number of RGSM observed each year during salvage
miles.dried = total extent of drying each year during salvage

Model 1: Relation between total RGSM observed in a pool and depth of pool, date, and reach.

Call:
glm.nb(formula = total.minnows ~ depth + Date + reach, data = salvaged., init.theta = 0.2014466785, link = log)

Deviance Residuals:

Min	1Q	Median	3Q	Max
-1.6675	-0.8283	-0.6085	-0.2427	7.5724

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.673631	0.137814	12.144	< 2e-16 ***
depth	3.465165	0.236204	14.670	< 2e-16 ***
Date	-0.052522	0.002305	-22.790	< 2e-16 ***
reachsa	-0.722658	0.115573	-6.253	4.03e-10 ***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Negative Binomial(0.2014) family taken to be 1)

Null deviance: 2095.8 on 2417 degrees of freedom
Residual deviance: 1474.9 on 2414 degrees of freedom
(6 observations deleted due to missingness)
AIC: 6026.4

Number of Fisher Scoring iterations: 1
Theta: 0.2014
Std. Err.: 0.0103

2 x log-likelihood: -6016.3890

Model 2: Relation between total RGSM observed during a single day of salvage and the date, reach, and number of miles salvaged that day.

Call:
glm.nb(formula = total.minnows ~ Date + reach + rm.salvaged, data = sal.sum, init.theta = 0.5874600037, link = log)

Deviance Residuals:

Min	1Q	Median	3Q	Max
-2.2545	-1.1260	-0.5007	-0.0641	3.6325

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	6.607018	0.361230	18.290	< 2e-16 ***
Date	-0.060948	0.005985	-10.184	< 2e-16 ***
reachSanAcacia	-1.300754	0.329718	-3.945	7.98e-05 ***
rm.salvaged	0.160145	0.056275	2.846	0.00443 **

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Negative Binomial(0.5875) family taken to be 1)

Null deviance: 147.577 on 72 degrees of freedom
Residual deviance: 83.048 on 69 degrees of freedom
AIC: 656.8

Number of Fisher Scoring iterations: 1
Theta: 0.5875
Std. Err.: 0.0933

2 x log-likelihood: -646.8000

Model 3: Relation between the observed number of RGSM per mile and the number of times the reach previously dried.

Call:
lm(formula = log(minnow.mile + 1) ~ times.dried, data = drying)

Residuals:

Min	1Q	Median	3Q	Max
-1.10285	-0.27404	-0.04642	0.41191	0.74629

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	5.4247	0.4134	13.122 1	.08e-06 ***
times.dried	-1.0285	0.1188	-8.654	2.47e-05 ***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.593 on 8 degrees of freedom
Multiple R-squared: 0.9035, Adjusted R-squared: 0.8914
F-statistic: 74.9 on 1 and 8 DF, p-value: 2.469e-05

Model 4: Relation between total RGSM observed during an entire salvage season (divided by 1000) and the greatest extent of drying in the year.

Call:
lm(formula = total.rgsm/1000 ~ miles.dried, data = all.but.2008[all.but.2008$reach ==
"both",])

Residuals:

3	6	9	12	18
0.1081	-0.1918	-2.1931	0.4219	1.8549

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	26.46426	2.48824	10.636	0.00178 **
miles.dried	-0.42277	0.07005	-6.035	0.00912 **

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.681 on 3 degrees of freedom
Multiple R-squared: 0.9239, Adjusted R-squared: 0.8985
F-statistic: 36.42 on 1 and 3 DF, p-value: 0.009122