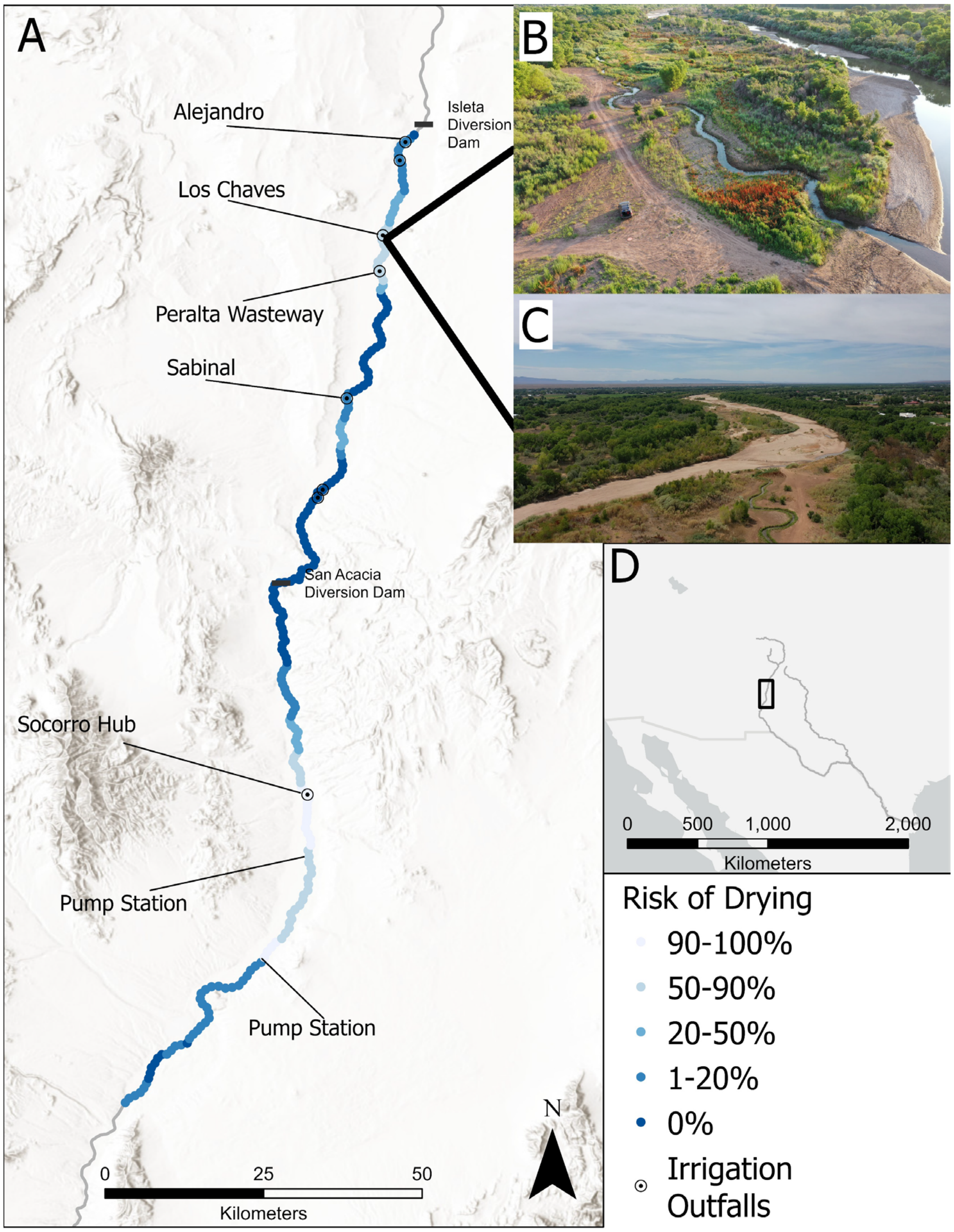
PRIORITIZING LOCATIONS FOR IRRIGATION INFRASTRUCTURE TO CREATE DROUGHT REFUGE HABITATS

New Mexico Fish and Wildlife Conservation Office



Thomas P. Archdeacon & Mallory E. Boro

United States Fish and Wildlife Service
New Mexico Fish and Wildlife Conservation Office
3800 Commons N.E.
Albuquerque, New Mexico 87109

PRIORITIZING LOCATIONS FOR IRRIGATION INFRASTRUCTURE TO CREATE DROUGHT REFUGE HABITATS

Funded through U.S. Bureau of Reclamation

Prepared by:

Thomas P. Archdeacon & Mallory E. Bedwell Boro

U.S. Fish and Wildlife Service
New Mexico Fish and Wildlife Conservation Office
3800 Commons N.E.
Albuquerque, New Mexico 87109

U.S. Bureau of Reclamation Interagency Agreement No. R23PG00039

Submitted to:

U.S. Bureau of Reclamation
Albuquerque Area Office
Albuquerque, New Mexico

20 June 2023

DISCLAIMER

The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service. This work was funded under U.S. Bureau of Reclamation Interagency Agreement No. R23PG00039.

Photo credit: Quantina Martine, Audubon Southwest

Suggested citation:

Archdeacon, T. A. and Bedwell Boro, M. E. 2023. Prioritizing locations for irrigation infrastructure to create drought refuge habitats. U.S. Bureau of Reclamation Interagency Agreement No. R23PG00039. Report to Bureau of Reclamation, Albuquerque, New Mexico.

EXECUTIVE SUMMARY

Rio Grande Silvery Minnow *Hybognathus amarus* (RGS minnow) is a small, short-lived minnow species dependent on spring runoff for successful reproduction. Reducing the effects of drought and channel drying is important for 1) improving juvenile fish survival in successful recruitment years and 2) improving adult survival in years when recruitment is poor so that enough fish survive to spawn the following year. Currently, the species relies heavily on augmentation with hatchery-produced fish to compensate for years with low or failed reproduction. Reducing the effects of drought and channel drying are important for preserving genetic diversity and demographic resilience (the ability of the species to recover quickly from disturbances). Years of low recruitment are often coupled with extensive channel drying, reducing the number of adults that might survive and contribute spawning in the following year, leading to spawner limitation in some years.

Irrigation flow returns, water diverted from, but returned to, the main channel after agricultural use may be used to reduce channel drying. Optimizing limited amounts of water involves a tradeoff among delivery locations, and potentially delivery timing. We investigated how irrigation return flows might be used to reduce channel drying and prioritize locations to deliver limited water to benefit RGS minnow within a single irrigation season. We used multiple data sources to identify high-density areas of RGS minnow and use of existing irrigation infrastructure. To accomplish this, we used statistical models to parcel out the contribution of spatial location to the variability in numbers of RGS minnow collected in areas prone to drying.

Off-channel habitats created by irrigation infrastructure (canals, ditches, etc.) likely have little impact on RGS minnow persistence, as relatively few have been observed in them, and there is no evidence of significant recruitment in off-channel irrigation infrastructure. However, we identified area of higher RGS minnow relative abundance in the main channel where targeted flows could improve the survival of RGS minnow. In the San Acacia Reach, the Socorro Hub area had higher abundance of both adults and young-of-year RGS minnow compared to surrounding areas and should be considered a priority area for maintaining surface flows. In some years so few RGS minnow occurred near outfall structures that maintaining surface flows would have minimal effects on the RGS minnow population. Future analyses should incorporate multi-year strategies to benefit RGS minnow populations, instead of single-year optimizations.

TABLE OF CONTENTS

DISCLAIMER........ 3
EXECUTIVE SUMMARY 4
TABLE OF CONTENTS 5
LIST OF TABLES 6
LIST OF FIGURES 7
INTRODUCTION........ 8
METHODS 9
  Species background........ 9
  Data collection........ 10
    Average Flow Permanence 10
    Fish Rescue 11
  Analysis 1–Rio Grande Silvery Minnow use of existing irrigation outfall structures........ 11
  Analysis 2–Identifying high-density patches of Rio Grande Silvery Minnow 12
RESULTS 14
  Flow permanence........ 14
  Fish Rescue........ 16
  Analysis 1........ 17
  Analysis 2........ 19
DISCUSSION 22
RECOMMENDATIONS........ 24
ACKNOWLEDGMENTS 25
DATA AVAILABILITY 25
LITERATURE CITED 26
APPENDICES........ 31

LIST OF TABLES

Table 1-Summary numbers of adult and young-of-year (YOY) Rio Grande Silvery Minnow observed in isolated pools in the Middle Rio Grande, New Mexico, during summer drying, 2007-2022. Total KM rescued does not necessarily represent the linear extent of drying. Data collected prior to July 1 each year is censored for YOY. 16

Table 2-Largest single-sample collections of Rio Grande Silvery Minnow in irrigation outfalls in the Middle Rio Grande, New Mexico. Sampling gear varied by year, a = electrofishing, b = seining, c= depletion sampling with seines, d = mixed electrofishing and seining. 17

Table 3-Untransformed parameter estimates, standard errors, and P-values for factors driving numbers of RGS minnow rescued from isolated pools in the Middle Rio Grande, New Mexico, 2009-2022. Parameters were estimated from a negative binomial model (log link function), and discharge represents the river reach-specific average May discharge during the hatching year and was log-transformed and scaled. Days represents the number of days since April 1 (adults) or July 1 (YOY; young-of-year) to account for mortality. 19

LIST OF FIGURES

Figure 1-A) Annual flow permanence (2007-2022) of the Rio Grande and locations of selected irrigation outfall structures in the Isleta (between Isleta Diversion Dam and San Acacia Diversion Dam) and San Acacia (downstream of the San Acacia Diversion Dam) Reaches of the Middle Rio Grande, New Mexico, B) locator map, C) the Los Chavez outfall with surface flows present and D) with surface flows absent in the main channel. 15

Figure 2-Numbers of Rio Grande Silvery Minnow collected from isolated pools downstream of irrigation outfalls in the Middle Rio Grande, New Mexico. No drying occurred in the Los Chavez area in 2009, 2017, or 2019. 18

Figure 3-Relative contribution of spatial location (400-m increments) to numbers of Rio Grande Silvery Minnow stranded in isolated pools in the Middle Rio Grande, New Mexico, 2009-2022. 20

Figure 4-Relative contribution of spatial location (2.5-km increments) to numbers of Rio Grande Silvery Minnow stranded in isolated pools in the Middle Rio Grande, New Mexico, 2009-2022. 21

INTRODUCTION

Drought refuges increase the persistence of aquatic species during drought disturbances (Magoulick and Kobza 2003). Persistence of a species can be accomplished by improving resistance, the population's ability to remain unchanged by disturbance, or resilience, the ability to recover after a disturbance. Freshwater organisms may benefit from anthropogenic drought refuges, such as agricultural ponds, drainage ditches, and transport canals (Chester & Robson 2013). Water resource infrastructure, such as treated effluent or irrigation return flows may be useful for creating refuge habitat (Eppehimer et al. 2021), targeted delivery of environmental flows (Rayner et al. 2009), rehabilitation of ecosystem functions (Halliday et al. 2015; Hamdhani et al. 2020) or mitigating hypoxic events (Watts et al. 2017).

In the Middle Rio Grande (MRG), New Mexico, Rio Grande Silvery Minnow (RGS minnow, *Hybognathus amarus*) are often stranded in isolated pools during channel intermittency (Archdeacon 2016). Stranding typically results in mortality due to complete desiccation of pools within four days of formation (Archdeacon & Reale 2020). Reducing the frequency of recurrent drought disturbances is important for conservation of the species (Hatch et al. 2022). Using fish rescue (transporting fish from intermittent to perennial areas) to mitigate drought disturbances not effective in most years (Yackulic et al. 2022) because fish are exposed to stressful conditions prior to rescue and have low survival after rescue during warmer seasons (Archdeacon et al. 2020b). Reducing the annual amount of channel drying is generally a more effective option (Yackulic et al. 2022) to aid in persistence of RGS minnow. However, as in many arid-land river systems, there are limited water sources to reduce the amount of channel drying in the MRG.

Restoration and protection of sequential but discrete habitat blocks surrounded by agricultural or urban landscapes may be beneficial for protecting riparian biodiversity (Parker et al. 2014). Using irrigation infrastructure or treated effluent to create drought refuges in a "string-of-pearls" conservation approach might help protect biodiversity in the Rio Grande Basin (Landis 2012). Irrigation infrastructure in the MRG may potentially serve as drought refuge habitats for RGS minnow, and other fish species, during channel intermittency (Cowley 2003). Multiple surveys have documented RGS minnow using irrigation outfalls, albeit in small numbers and with the presence of piscivorous and non-native species (Cowley et al. 2007; Wesche et al. 2010; Archdeacon et al. 2013; SWCA 2014, 2016, 2019, 2021). Water quality (e.g., temperature and dissolved oxygen) in irrigation outfalls is generally suitable to support

RGS minnow (Van Horn et al. 2022), but evaluations on how to manage irrigation return to optimize refuge benefits for RGS minnow have not been undertaken.

Our overarching objective was to determine if irrigation infrastructure can contribute to persistence of RGS minnow in the face of extreme seasonal droughts by reducing the impacts of channel drying. As a first step, we determined if there were river channel patches with a high risk of channel drying that also supported higher RGS minnow abundance. Irrigation return flows might be used to mitigate the effects of channel drying in these areas by preventing recurrent stranding, which results in mortality (Archdeacon et al. 2020b). A first step in optimizing return flows is identifying areas of relatively higher or lower abundance as a basis for prioritization. We split this into two distinct analyses related to this objective: 1) synthesize multiple years of fish surveys within irrigation infrastructure and fishes stranded near existing infrastructure to determine how many RGS minnow occur nearby, and 2) identify areas of high RGS minnow abundance prone to suggest new areas to deliver targeted flows. We accomplished the first objective by summarizing multiple distinct investigations of the fish fauna in off-channel irrigation structures. We accomplished the second objective through examination of multiple years of fish rescue data, separating the contribution of spatial location to RGS minnow density from multiple other drivers of density and comparing locations with high average densities of RGS minnow to risk of drying location. We attempt to put these results into the context of RGS minnow life-history strategy and inform conservation actions designed to improve the persistence of the species.

METHODS

Species background

Understanding the biology and ecology of target species is important both for designing effective conservation actions and defining success when evaluating conservation actions (Crook et al. 2010). Rio Grande Silvery Minnow are a short-lived, opportunistic fish. Opportunistic fishes (sensu Winemiller 2005) are characterized by short lifespans, fast generation times, low fecundity but high reproductive effort, low parental care, and high demographic resilience. Few RGS minnow live longer than two years in the wild, with most fish living less than 18 months (Horwitz et al. 2018). The species belongs to the pelagic broadcast spawning guild (Balon 1985), a rare reproductive strategy in freshwater fishes but characteristic of a suite of minnows in sandy rivers of the western United States (Worthington et al. 2018). These fishes produce non-adhesive, neutrally buoyant eggs that drift in the current (Platania and Altenbach 1999), which is advantageous for efficiently distributing eggs among spatially and temporally shifting nursery habitats in sand-bed rivers (Hoagstrom and Turner 2015). This reproductive guild is disproportionately affected by fragmentation and flow regime changes compared to benthic or crevice-spawning species (Turner et al. 2006; Perkin et al. 2019; Nguyen et al. 2023).

Perhaps the most important trait for conservation of RGS minnow and other opportunistic species is high demographic resilience. Demographic resilience is the ability of the species to quickly recover from reductions in populations size (Capdevila et al. 2020). Traits promoting demographic resilience for RGS minnow are their high reproductive effort and short generation times. However, spawner limitation occurs when fishes are not able to recover from a disturbance, despite favorable environmental conditions, due to lack of spawning individuals. In years when spawner limitation occurs (see Yackulic et al. 2022), hatchery fish are released to compensate for lack of spawning adults, provide a demographic boost (Archdeacon et al. 2023) and maintain genetic diversity (Osborne et al. 2012; Osborne et al. under review).

Ultimately, full success of recovery actions would result in maintaining demographic resilience to end the reliance on hatchery supplementation. We would view reducing the reliance on hatchery augmentation as a partial success. Because of the initial mortality associated with releasing hatchery fish (75-91%; Yackulic et al. 2022), each wild fish surviving to autumn is conservatively worth 10 hatchery-reared fish. However, in some years as few as 3,000 individuals remain in the wild and nearly 300,000 hatchery fish are released. From both a genetic and demographic perspective, conservation of >5,000 wild individuals annually would likely reduce the reliance on hatchery fish. Conservation of <1,000 fish, within the context of demographic and genetic resilience, would not measurably lessen the need for augmentation or improve the resilience of the species. Values between 1,000 and 5,000 are likely context dependent and would require further evaluations to determine if the population is realizing any benefits to resilience.

Data collection

Flow Permanence

The MRG of central New Mexico (Figure 1) is prone to seasonal drying that varies in duration, extent, and severity each year depending on snowpack and upstream water management (Archdeacon 2016). These episodic drying events are driven by seasonal drought as snowmelt runoff dissipates (Hurd and Coonrad 2012; Chavarria and Gutzler 2018). Channel drying is exacerbated by supra-seasonal droughts resulting in less winter snowpack (Elias et al. 2015) and water abstraction for human needs (Blythe and Schmidt 2018). Historically, flow intermittence was observed during extreme drought but was uncommon prior to the 1890s (Scurlock 1998). Because there are no perennial tributaries to the MRG, fragmented areas of perennial flow due to leakage around and under dams, seepage from irrigation canals, groundwater, and irrigation return flows provide the only lasting, wetted refuge habitats for fishes in the MRG (Van Horn et al. 2022).

Beginning in 2007, the linear extent of intermittent conditions throughout the MRG were determined each day by visual observation (prior records were not recorded at the daily increment). Observations were recorded for 0.5-mi (~0.8 km) units. To calculate average annual flow permanence for a given unit, the annual flow permanence (number of days of flow divided by 365) was averaged over the years 2007-2021.

Fish Rescue

Full details of fish rescue activities are given in Archdeacon (2016). Briefly, field crews surveyed isolated pools for RGS minnow during channel intermittency. Field crews used seines of various lengths to collect RGS minnow (all seines had a mesh size of 3.2mm, generally 3.0 x 1.0 m). Depending on the size of the pool, seining continued until crews determined few or no RGS minnow were left. Most pools were small and required only a single seine haul to cover the entire area of the pool. All RGS minnow captured in an individual pool were counted and categorized as young-of-year (YOY) or adult based on size: adults are generally > 50 mm SL by June, YOY generally reach 30 mm SL by July. The location of each pool was recorded to the nearest 0.1 km reach. Fish rescue data collected with appropriate spatial data was available from 2009 – 2022.

Analysis 1–Rio Grande Silvery Minnow use of existing irrigation outfall structures

Numerous fish surveys have assessed the fish assemblage in irrigation infrastructure within the Middle Rio Grande. These surveys used a variety of different sampling gear, survey locations, designs, and timing (Table 1). Because of these differences, developing a long-term synthesis is difficult. Irrigation infrastructure surveys did not always coincide with channel drying, so we chose a variety of different comparisons. We used the largest single-collection observation of RGS minnow collected in Los Chavez and Sabinal drains during a given year. We compared this to the number of fish stranded in isolated pools in the Isleta Reach each year. In recent years (e.g., 2016-2022) the Los Chavez and Sabinal outfalls were situated where main channel areas in the Isleta Reach are prone to drying. While the largest single collection is not likely fully representative of usage and not independent of effort, this was the best measure available to compare to numbers of RGS minnow from fish rescue.

To determine if existing infrastructure could be used to improve RGS minnow persistence, we examined the number of fish rescued annually from areas below potential water return outfalls. Two locations, Los Chavez in the Isleta Reach, and the Socorro Hub in the San Acacia Reach, are located in areas that have dried multiple times since 2009. We examined the number of RGS minnow observed in isolated pools downstream of these areas. We summed all RGS minnow (wild origin, hatchery origin, adult, young-of-year, alive or dead) in 100-m sections and examined the cumulative number of RGS minnow that could be protected by increasing discharges and reducing the amount of drying in 100-m increments on an annual basis.

Analysis 2–Identifying high-density patches of Rio Grande Silvery Minnow

Several variables can affect numbers of RGS minnow stranded in isolated pools, including overall population driven by spring runoff and reach (Archdeacon 2016), date as both mortality and gear recruitment increase through a year (Archdeacon & Reale 2020), and positioning of a pool within a reach (Archdeacon et al. 2022). To accomplish objective 1, we parceled out the variability in numbers of fish stranded in isolated pools due to spatial positioning. To account for within-year temporal variation due to survival, we used days post April 1 each year for adults. We used days post July 1 and censored data prior to July 1 each year for YOY, because they do not fully recruit to seining gear until July. We used average May discharge, measured at the most upstream station within each reach, to account for among-year variation in young-of-year numbers and lagged average May discharge for adults. We did not distinguish between age-1 and older adult fish, so this may have introduced a small amount of error if older fish were not linked to the correct hatch-year discharge. However, very few age-2 fish are present in most years (Horwitz et al. 2018). We scaled the log-transformed discharge by mean and standard deviation. We included year and spatial unit (either 400 m or 2.5 km) as random effects, representing the amount of wetted habitat created from small irrigation return flows (400 m) or the average movements of adult RGS minnow (Chavez, unpublished thesis). We used a generalized linear model to predict raw counts from days post April 1 (adults) or days post July 1 (young-of year):

$$\log(Count) = \beta_0 + \beta_1(days) + \beta_2(discharge) + v_1(spatial\_unit_i)$$

Where count per pool has a negative binomial distribution with a mean of y and dispersion parameter of k:

$$\log\,(Count) \sim NB(y, k)$$

And the random effect of year or spatial unit is normally distributed with a mean of μ and variance of σ^2

$$v \sim N(\mu, \sigma^2)$$

Thus, four separate models were constructed: two spatial resolutions for two life-stages. We chose to model spatial units as random effects because some units were only sampled a few times over the 14 years and partial pooling led to better precision for these units (with the tradeoff that the effect of spatial units were biased toward the mean). We used R (R Core Team 2022 with package glmmTMB (Brooks et al. 2017)) to construct models. We used package DHARMa (Hartig 2022) for global model diagnostics, checking for model fit, influential outliers, and overdispersion.

Once appropriate models were constructed for adults and young-of-year at different scales, we extracted the random-effects estimates for each unique spatial unit. Random effects are estimated to have a mean of 0 and standard deviation of 1. The negative binomial regression model has a log-link, and effects estimates are multiplicative. That is, an estimate of 0 on the log scale is interpreted as having 1 times the expected mean number of fish per pool (e.g., no effect), whereas and estimate of -1 has only ~37% of the expected mean number of fish per pool and an estimate of 1 has ~270% of the expected mean. The effect of spatial unit could vary from little or no effect to strongly positive ("hotspots") or strongly negative ("coldspots").

RESULTS

Flow permanence

Annual flow permanence varied from ~10% to 100% from 2007-2022 (Figure 1). Several recent management actions should be considered when interpreting results: 1) the south pumping station no longer exists and future scenarios should consider this area to dry similarly to upstream areas in the San Acacia reach, 2) the north pumping station supported flows in a few years prior to 2017 and this area would dry similarly to upstream areas resulting in a section with similar flow permanence stretching from the Socorro Hub to Fort Craig, and 3) water management after 2015 has maintained surface flows in the Alejandro area and recent flow permanence (e.g., after 2015) is higher than the average flow permanence. The largest, regularly affected segment now covers ~45km of the San Acacia Reach and dries nearly annually.

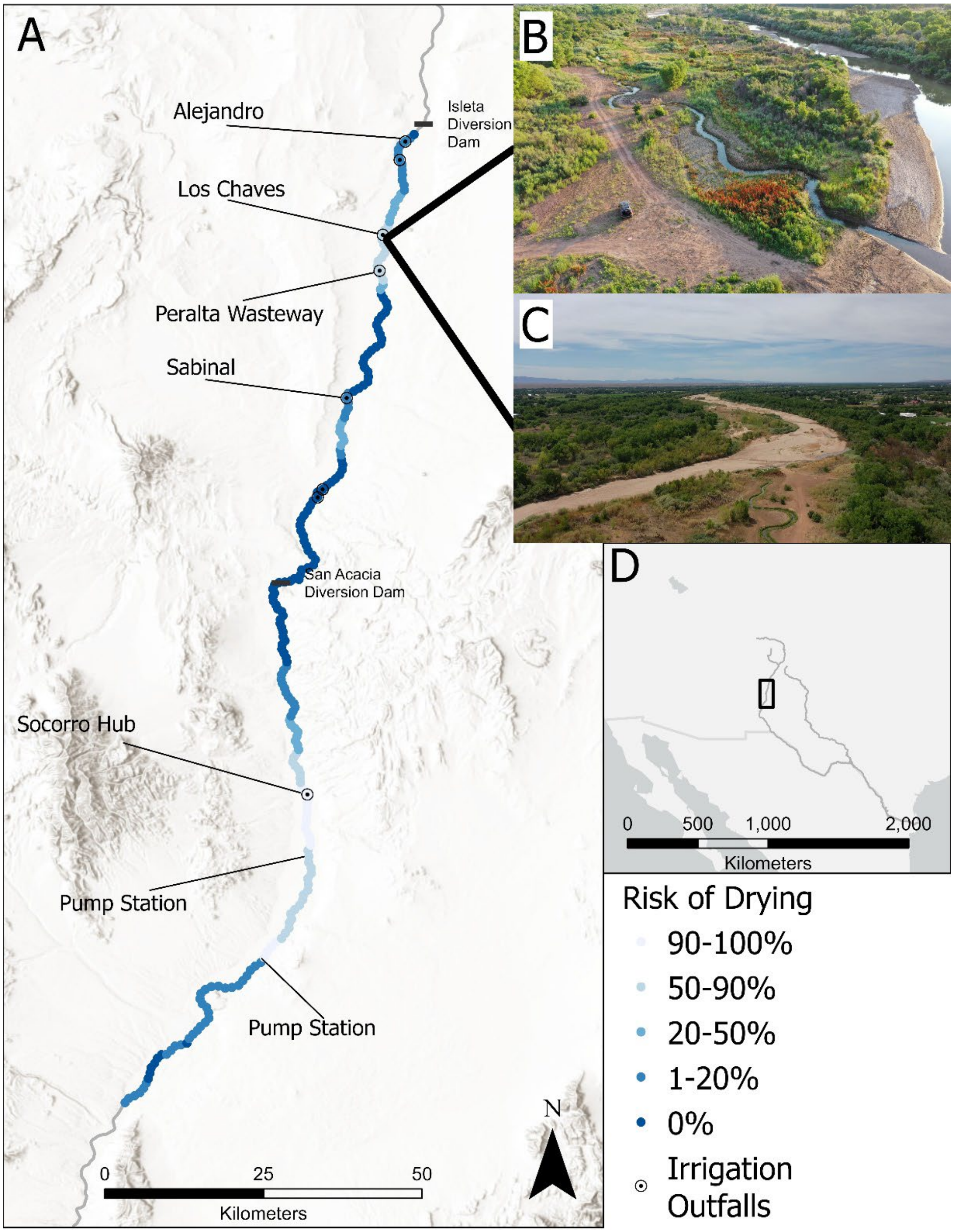


Figure 1-A) Annual flow permanence (2007-2022) of the Rio Grande and locations of selected irrigation outfall structures in the Isleta (between Isleta Diversion Dam and San Acacia Diversion Dam) and San Acacia (downstream of the San Acacia Diversion Dam) Reaches of the Middle Rio Grande, New Mexico, B) locator map, C) the Los Chavez outfall with surface flows present and D) with surface flows absent in the main channel. Photo credit: Quantina Martine, Audubon Southwest.

Fish Rescue

We surveyed 13,719 pools for adult RGS minnow from 2009-2022. Excluding pools sampled before July 1, we surveyed 9,892 pools. Although heavily driven by the 2017 cohort, we collected 89,661 live adults and 112,572 live YOY. On average, there are ~9 pools per km, with 4.8 adults per pool and 21.9 YOY per pool, but numbers of fish per pool varies greatly among years (Table 1).

Table 1-Numbers of adult and young-of-year (YOY) Rio Grande Silvery Minnow observed in isolated pools, length of stream and number of isolated pools surveyed in the Middle Rio Grande, New Mexico, during summer drying, 2007-2022. Length of segment surveyed does not necessarily represent the linear extent of drying as areas may have dried and rewet multiple times within a year. Data collected prior to July 1 each year is censored for YOY.

Year	**Length (km)**	**Pools**	**Pools per km**	**Adult per pool**	**YOY per pool**
2009	87.5	522	6	2.6	44.1
2010	217.5	1,201	5.6	4.1	5.4
2011	235.8	1,974	8.7	2.2	2.2
2012	328.3	2,863	8.4	0.9	<0.1
2013	76.3	1,058	13.5	0.1	<0.1
2014	100.7	755	7.5	<0.1	<0.1
2015	37.5	396	10.6	<0.1	2.8
2016	56.9	546	9.6	0.2	27.7
2017	57.3	285	3.9	0.7	215.0
2018	158.0	1,435	8.3	49.1	<0.1
2019	14.5	126	5.9	<0.1	7.7
2020	66.1	771	11.2	4.9	<0.1
2021	62.3	935	15.0	0.5	<0.1
2022	49.4	852	17.0	1.1	1.9
Average	111	980	8.8	4.8	21.9

Analysis 1

Rio Grande Silvery Minnow regularly occur in drain outfalls (Table 2), but in small numbers compared to numbers stranded in isolated pools. The Los Chavez and Lower Peralta 2 returns generally had more RGS minnow, but both also had years where few were observed. Trends analysis, comparisons to main channel sampling, or determining shelter-seeking behavior are not possible with existing data because of varying sampling methods and locations among surveys. As expected, numbers of fish stranded in isolated pools below irrigation outfalls was variable by year. In a few years, hundreds to thousands of RGS minnow were collected below irrigation outfalls (Figure 2), particularly following years of high recruitment. Since 2016, numbers of RGS minnow downstream of the Los Chavez outfall have declined.

Table 2-Largest single-sample collections of Rio Grande Silvery Minnow in irrigation outfalls in the Middle Rio Grande, New Mexico. Sampling gear varied by year, a = electrofishing, b = seining, c= depletion sampling with seines, d = mixed electrofishing and seining.

Location	**Year**							
	2007[a]	2008[a]	2009[a]	2013[b]	2014[b]	2015[c]	2018[d]	2020[a]
Alejandro	-	-	-	-	12	83	-	-
Los Chavez	0	-	76	-	-	-	48	47
Peralta Wasteway	14	5	5	-	-	-	-	-
Lower Peralta 2	-	-	-	1	2	49	14	131
Storey	-	-	-	-	-	-	-	35
Sabinal	-	-	-	8	0	11	0	35
San Francisco	-	-	-	-	-	-	-	16
Lower San Juan	-	-	-	2	-	-	-	-

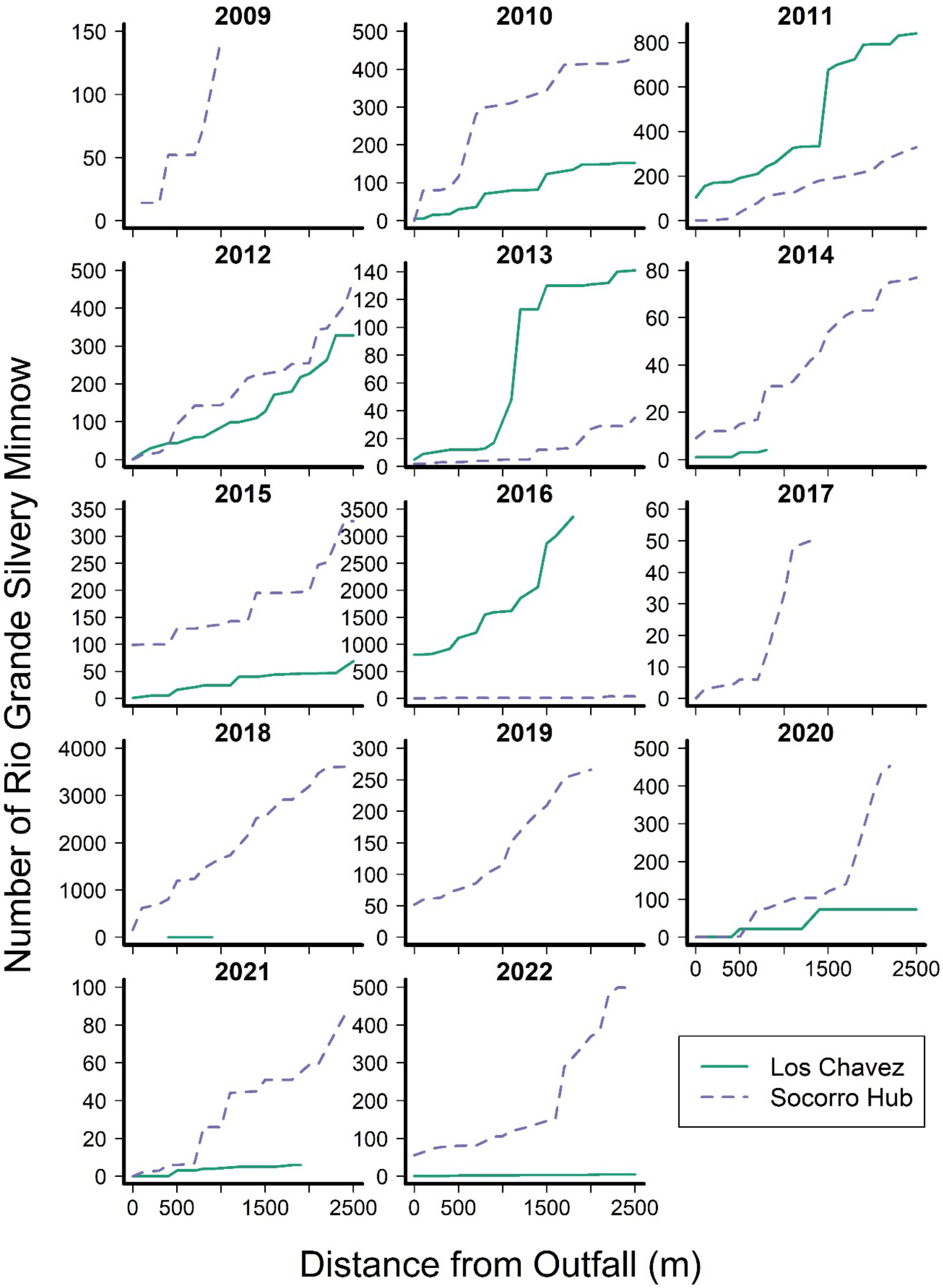


Figure 2-Numbers of Rio Grande Silvery Minnow collected from isolated pools downstream of irrigation outfalls in the Middle Rio Grande, New Mexico. No drying occurred in the Los Chavez area in 2009, 2017, or 2019.

Analysis 2

The most important factor driving variability in numbers of stranded RGS minnow is hatch-year spring runoff (Table 3). However, there are fewer RGS minnow in pools later in the year and some variability is attributable to spatial location. The contribution of spatial location varies by life stage and scale, but most areas are not significantly different than the average (Appendix A). At the finer, 400-m resolution, some higher density patches surrounded by lower density patches are evident (Figure 3). Generally, patterns observed at the 400-m resolution were similar to 2.5km resolution (Figure 4). Among areas with a high risk of drying, high-density patches of young-of-year are evident around the Los Chavez return, and notable low-density areas were found near the Sabinal return and the lower San Acacia Reach. For adults, the Socorro Hub and Los Chavez supported higher densities, and notable low-density areas were the same as for young-of-year (Figure 4).

Table 3-Untransformed fixed parameter estimates, standard errors, marginal partial pseudo-R^2 and P-values for factors driving numbers of RGS minnow rescued from isolated pools in the MRG, New Mexico, 2009-2022. Parameters were estimated from a negative binomial model (log link function), and discharge represents the river reach-specific average May discharge during the hatching year and was log-transformed and scaled. Days represents the number of days since April 1 (adults) or July 1 (YOY; young-of-year) to account for mortality.

Model	**Parameter**	**Estimate**	**SE**	**Partial R^2**	**P**
Adult, 400 m					
	Intercept	2.63	0.1067	-	<0.0001
	Discharge	1.40	0.0301	0.31	<0.0001
	Day	-0.02	0.0007	0.10	<0.0001
Adult, 2.5k m					
	Intercept	2.56	0.2011	-	<0.0001
	Discharge	1.46	0.0304	0.288	<0.0001
	Day	-0.02	0.0006	0.073	<0.0001
YOY, 400 m					
	Intercept	-0.50	0.1512	-	0.001
	Discharge	2.23	0.0618	0.507	<0.0001
	Day	-0.002	0.0022	0.007	0.0608
YOY, 2.5 km					
	Intercept	-0.75	0.3414	-	0.0272
	Discharge	2.21	0.0612	0.416	<0.0001
	Day	-0.004	0.0022	-0.100	0.0478

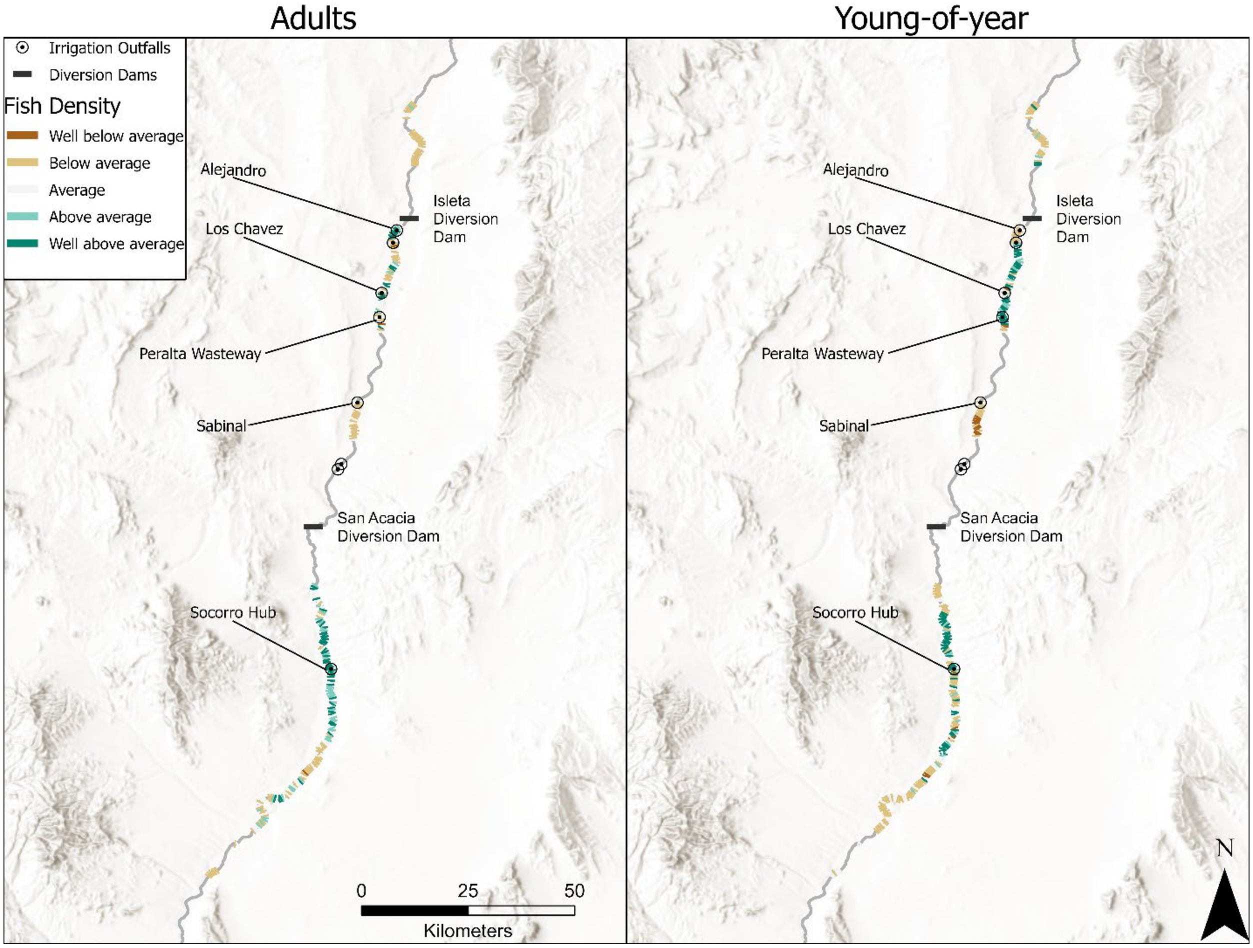


Figure 3-Relative contribution of spatial location (400-m increments) to numbers of Rio Grande Silvery Minnow stranded in isolated pools in the Middle Rio Grande, New Mexico, 2009-2022.

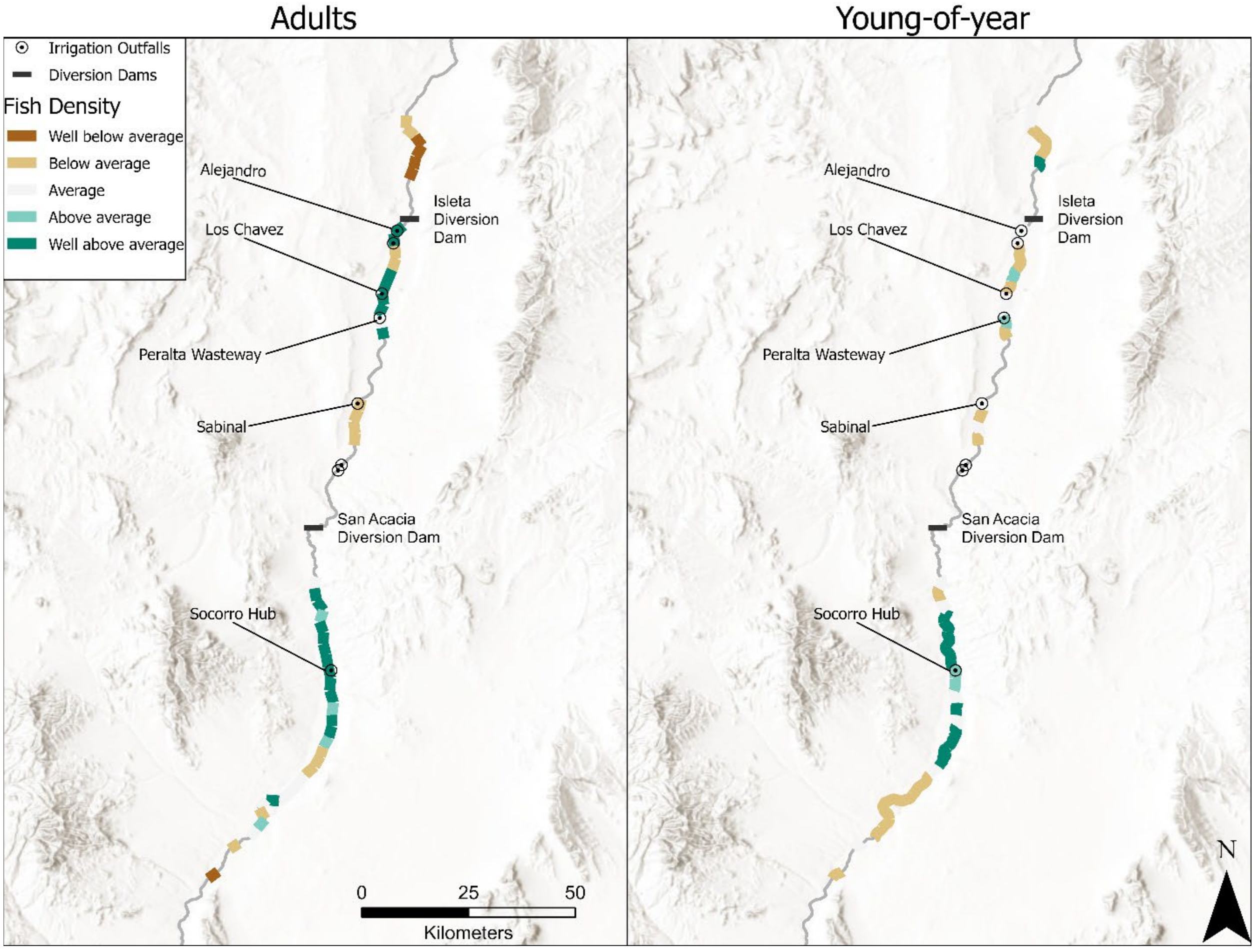


Figure 4-Relative contribution of spatial location (2.5-km increments) to numbers of Rio Grande Silvery Minnow stranded in isolated pools in the Middle Rio Grande, New Mexico, 2009-2022.

DISCUSSION

We used multiple data sources to evaluate the value of irrigation infrastructure for improving the status of RGS minnow. Mitigating the effects of climate change and habitat degradation will require careful management of available resources and thoughtful implementation and evaluations. In some years, significant (>1,000) numbers of RGS minnow are present in areas downstream of existing irrigation infrastructure. Irrigation return flows could potentially create drought refuge habitat and protect significant numbers of RGS minnow, but with important context-dependence incorporated in the decision-making processes.

Irrigation infrastructure itself (e.g., constructed, off-channel areas supported by irrigation return flows but not occurring in the main river channel) has limited benefits for RGS minnow. Although RGS minnow are regularly found within these off-channel habitats, observations have typically been of only a few fish per survey. These areas offer refuge during channel drying for fishes but are not significantly contributing to persistence of RGS minnow because too few fish use them. Future studies within irrigation infrastructure should make comparisons both to the overall catch-per-unit-effort river wide and to numbers of fish in the immediate area, prior to and during drying to help inform adaptive management strategies. Unfortunately, data obtained in 2020 in the Los Chavez outfall (SCWA 2021) suggested RGS minnow are avoiding the outfalls, as fewer fish were collected in surveys than would be expected based on numbers of stranded fish in the immediate vicinity (Archdeacon 2021).

Conversely, use of irrigation infrastructure to deliver small flows to main channel areas could be more beneficial. Hundreds to thousands of RGS minnow were collected downstream of the Los Chavez outfall and the Socorro Hub. However, recruitment flows strongly drive numbers of RGS minnow in isolated pools (and with the MRG; Yackulic et al. 2022) and benefits are context dependent. Following multiple years of low recruitment, RGS minnow numbers are low at all locations and water delivery will have limited benefits for the species during these years. Although somewhat counterintuitive, maintaining small areas of flow will be beneficial only during and following years of good reproduction, when significant numbers of RGS minnow can be protected. Until conservation actions can overcome limited recruitment in some years, the benefits of any conservation action intended to improve summer survival will be limited to years when significant numbers of RGS minnow are present.

With some flexibility in irrigation operations and infrastructure, return flows may be optimized to benefit the most RGS minnow. We were able to separate the spatial component driving variability in RGS minnow stranded in isolated pools. We observed both spatial "hot spots" and "cold spots" where RGS minnow numbers are higher (or lower) than the expected average within a specific year. These areas were not necessarily the same for adults and young-of-year fish. Nonetheless, the Socorro Hub area is of particular interest, as both young-of-year and adults have higher densities, particularly in recent years, and the area dries nearly annually. Maintaining perennial flow in this area will be far more beneficial for RGS minnow than areas further downstream in the San Acacia Reach, where the contribution of spatial location was much lower. Although we recognize there are constraints and tradeoffs in water delivery, creating refuge areas where few RGS minnow occur will not result in positive conservation outcomes.

We recognize several model limitations. Our inferences are limited to areas that have dried and been rescued. Our prioritization is limited to areas that dry regularly and we cannot compare the tradeoffs of providing flows to recognized hotspots at the cost of additional drying in new areas. We note that a few areas have only one or two years of data, particularly the upper segments of the Isleta Reach and the lower segment of the San Acacia Reach, due to specific management actions. Finally, even though many spatial units have dozens of observations over the 14-year dataset, variability in estimates makes it difficult to determine the effect on RGS minnow numbers. Despite these limitations, we were able to clearly delineate areas of both above average and below average density with a high risk of annual drying and offer recommendations for the use of irrigation return flows.

Drought refuges need to have both duration and extent that match the needs of RGS minnow. To improve persistence, drought refuges must improve the resistance or resilience of the target species. Rio Grande Silvery Minnow have low resistance to drought disturbances, as the reduction in abundance is proportional to the amount of drying in each reach, each year (Yackulic et al. 2022). These fish do not exhibit large-scale movements towards refuge areas prior to intermittency, instead choosing ecological traps (e.g., short-lived pools) where they perish (Archdeacon and Reale 2020; Archdeacon et al. 2022). Lacking directed movement towards refuges, the string-of-pearls conservation approach requires placing conservation nodes in areas of existing high density or restoration actions to create habitats that attract or retain fishes prior to intermittent conditions. Irrigation outfalls potentially could improve resilience to drought, provided enough fish can be protected to repopulate the following spring. Although some fishes in the MRG may be able to complete their life cycle in irrigation outfalls, RGS minnow are strongly tied to spring runoff and there is no evidence of spawning or successful recruitment concurrent with failed reproduction in the main channel. Thus, the string-of-pearls approach will be useful only when significant numbers of fish are present in the river and will not be useful for mitigating population bottlenecks due to low or failed reproduction.

RECOMMENDATIONS and FUTURE ANALYSES

- Off-channel habitats harbor few RGS minnow, and future evaluations should explicitly state hypotheses and use more rigorous experimental designs
- Maintaining surface flow and connectivity below dams is important
- In the San Acacia Reach, the Socorro Hub area had relatively higher densities of both adults and YOY and should be considered a priority area for maintaining surface flows
- Conversely, the area beginning about the middle of Bosque del Apache National Wildlife Refuge is relatively low density for both adults and young of year, and maintaining surface flows will have a small effect unless habitat restoration occurs
- In some years (e.g., 2014 and 2021) so few RGS minnow occurred near outfall structures that maintaining surface flows would have minimal effects on RGS minnow resistance or resilience
- Future analyses should consider an adaptive management strategy that balances benefits to maintaining surface flows during low abundance years and creating recruitment flows

ACKNOWLEDGMENTS

We thank Casey Ish and Paul Tashjian for suggesting the analyses, Mark Horner for assistance with mapping, Chad McKenna for river drying data, Charles Yackulic for assistance with statistical models, and the U.S. Bureau of Reclamation, Albuquerque Area Office for funding. We thank Paige Dunnum, Joel Lusk, Charles Yackulic, Casey Ish, and Ken Richards for comments on the report and the many U.S. Fish & Wildlife Service employees and volunteers who helped with fish rescue and data collection.

DATA AVAILABILITY

Data from fish rescue projects are available at www.doi.org/10.17632/c4j4dttksm.3

LITERATURE CITED

Archdeacon, T. P. (2016). Reduction in spring flows threatens Rio Grande silvery minnow: trends in abundance during river intermittency. Transactions of the American Fisheries Society, 145, 754-765. https://doi.org/10.1080/00028487.2016.1159611

Archdeacon, T. P., Austring, T. J., Diver, T. A., and Nolen, M. S. (2013). Fish communities of the Lower Peralta Drain #2, Lower San Juan Drain, and Sabinal Drain, New Mexico. Submitted to the U. S. Bureau of Reclamation, Albuquerque, NM. http://dx.doi.org/10.13140/RG.2.2.33850.93122

Archdeacon, T.P., Diver, T.A., and Reale, J.K. (2020b). Fish rescue during streamflow intermittency may not be effective for conservation of Rio Grande Silvery Minnow. Water, 12, 3371. https://doi.org/10.3390/w12123371

Archdeacon, T. P., Dudley, R. K., Remshardt, W. J., Knight, W., Ulibarri, M., and Gonzales, E. J. (2023). Hatchery supplementation increases potential spawning stock of Rio Grande Silvery Minnow after population bottlenecks. Transactions of the American Fisheries Society 152:187-200. https://doi.org/10.1002/tafs.10398

Archdeacon, T.P., Gonzales, E.J., Thomas, L.I., Rudolph, A.B. & Bachus, J.A. (2022). Effects of flow recession regime on stranding of Rio Grande silvery minnow suggests that conservation actions must overcome evolutionary traps. Aquatic Conservation: Marine and Freshwater Ecosystems, 32:1817– 1829. https://doi.org/10.1002/aqc.3852

Archdeacon, T. P., & Reale, J. K. (2020). No quarter: lack of refuge during streamflow intermittency results in catastrophic mortality of an imperilled minnow. Freshwater Biology, 65, 2108-2123. https://doi.org/10.1111/fwb.13607

Archdeacon, T. P. and Thomas, L. I. (2021). Rio Grande Silvery Minnow fish rescue 2020 annual report. Submitted to the U. S. Bureau of Reclamation, Albuquerque Area Office. http://dx.doi.org/10.13140/RG.2.2.29901.97766

Balon, E. K. (1975). Reproductive guilds of fishes: a proposal and definition. Journal of the Fisheries Research Board of Canada 32: 821-864. https://doi.org/10.1139/f75-110

Blythe, T. L., & Schmidt, J. C. (2018). Estimating the natural flow regime of rivers with long-standing development: the northern branch of the Rio Grande. Water Resources Research, 54: 1212–1236 https://doi.org/10.1002/2017WR021919

Brooks, M. E., K. Kristensen, K. J. van Benthem, A. Magnusson, C. W. Berg, A. Nielsen, H. J. Skaug, M. Maechler, and B. M. Bolker. (2017). glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. The R Journal, 9, 378–400.

Capdevila, P., Stott, I., Beger, M., and Salguero-Gómez, R. (2020). Towards a comparative framework of demographic resilience. Trends in Ecology & Evolution 35:776-786. https://doi.org/10.1016/j.tree.2020.05.001

Chavarria, S. B., & Gutzler, D. S. (2018). Observed changes in climate and streamflow in the Upper Rio Grande Basin. Journal of the American Water Resource Association, 54: 644–659. https://doi.org/10.1111/1752-1688.12640

Chester, E. T., & Robson, B. J. 2013. Anthropogenic refuges for freshwater biodiversity: their ecological characteristics and management. Biological Conservation 166: 64-75. https://doi.org/10.1016/j.biocon.2013.06.016

Crook D. A., Reich, P., Bond, N. R., McMaster, D., Koehn, J. D., & Lake, P. S. (2010) Using biological information to support proactive strategies for managing freshwater fish during drought. Marine and Freshwater Research 61, 379-387. https://doi.org/10.1071/MF09209

Cowley, D.E. 2003. Water requirements for endangered species - Rio Grande silvery minnow (Hybognathus amarus). 47th Annual New Mexico Water Conference, "There's No Doubt We're in a Drought", WRRI Report No. 326: 97-107. http://wrri.nmsu.edu/publish/watcon/proc47/cowley.pdf.

Cowley, D.E., Wissmar, R.C. and Sallenave, R. (2007), Fish assemblages and seasonal movements of fish in irrigation canals and river reaches of the middle Rio Grande, New Mexico (USA). Ecology of Freshwater Fish, 16: 548-558. https://doi.org/10.1111/j.1600-0633.2007.00250.x

Elias, E. H., Rango, A., Steele, C. M., Meija, J. F., & Smith, R. (2015) Assessing climate change impacts on water availability of snowmelt-dominated basins of the Upper Rio Grande basin. Journal of Hydrology: Regional Studies, 3, 525–546. https://doi.org/10.1016/j.ejrh.2015.04.004

Eppehimer, D. E., Enger, B. J., Ebenal, A. E., Rocha, E. P., & Bogan, M. T. (2021). Daily flow intermittence in an effluent-dependent river: Impacts of flow duration and recession rate on fish stranding. River Research and Applications, 37(10), 1376– 1385. https://doi.org/10.1002/rra.3850

Halliday, B.T., Matthews, T.G., Irevasi, D., Dodemaide, D.T., Pickett, P.J., Linn, M.M., Burns, A., Bail, I., Lester, R.E., 2015. Potential for water-resource infrastructure to act as refuge habitat. Ecol. Eng. 84, 136–148. https://doi.org/10.1016/j.ecoleng.2015.07.020

Hamdhani, H, Eppehimer, DE, Bogan, MT. Release of treated effluent into streams: A global review of ecological impacts with a consideration of its potential use for environmental flows. Freshwater Biology. 2020; 65: 1657– 1670. https://doi.org/10.1111/fwb.13519

Hartig, F. (2022) DHARMa: residual diagnostics for hierarchical (multi-level/mixed) regression models. R package version 0.4.5

Hoagstrom, C.W. and Turner, T.F. (2015). Recruitment ecology of pelagic-broadcast spawning minnows: paradigms from the ocean advance science and conservation of an imperilled freshwater fauna. Fish and Fisheries 16: 282-299. https://doi.org/10.1111/faf.12054

Horwitz, R.J., Keller, D.H., Overbeck, P.F., Platania, S.P., Dudley, R.K. and Carson, E.W. (2018). Age and growth of the Rio Grande Silvery Minnow, an endangered, short-lived cyprinid of the North American Southwest. Transactions of the American Fisheries Society, 147: 265-277. https://doi.org/10.1002/tafs.10012

Hurd, B. H., & Coonrad, J. (2012) Hydro-economic consequences of climate change in the Upper Rio Grande. Climate Research, 53, 103–118. https://doi.org/10.3354/cr01092.

Magoulick, D. D. and Kobza, R. M. (2003). The role of refugia for fishes during drought: a review and synthesis. Freshwater Biology 48:1186-1198. https://doi.org/10.1046/j.1365-2427.2003.01089.x

Nguyen, E., Mayes, K. B., Smith, R., Trunagle, J., and Perkin, J. S. (2023). The duality of drought: pelagic- and benthic-spawning fishes show opposing responses to drought in the southern Great Plains. North American Journal of Fisheries Management accepted article. https://doi.org/10.1002/nafm.10874

Osborne, M.J., Carson, E.W. and Turner, T.F. (2012), Genetic monitoring and complex population dynamics: insights from a 12-year study of the Rio Grande silvery minnow. Evolutionary Applications, 5: 553-574. https://doi.org/10.1111/j.1752-4571.2011.00235.x

Perkin, J. S., Starks, T. A., Pennock, C. A., Gido, K. B., Hopper, G. W., and Hedden, S. C. (2019) Extreme drought causes fish recruitment failure in a fragmented Great Plains riverscape. Ecohydrology 12:e2120. https://doi.org/10.1002/eco.2120

Platania, S. P. and Altenbach, C. S. (1998). Reproductive strategies and egg types of seven Rio Grande Basin cyprinids. Copeia 1998: 559-569. https://doi.org/10.2307/1447786

R Core Team (2018) R: A language and environment for statistical computing R Foundation Statistical Computing Vienna, Austria. Retrieved from http://wwwR-project.org

Rayner, T.S., Jenkins, K.M. and Kingsford, R.T. (2009), Small environmental flows, drought and the role of refugia for freshwater fish in the Macquarie Marshes, arid Australia. Ecohydrology 2: 440-453. https://doi.org/10.1002/eco.73

Scurlock, D. (1998) From the rio to the sierra: an environmental history of the Middle Rio Grande basin. US Department of Agriculture, Fort Collins, Colorado, USA General Technical Report RMRS-GTR-5. https://doi.org/102737/RMRS-GTR-5

SWCA (SWCA Environmental Consultants). (2014). Middle Rio Grande Conservancy District wasteway sampling – summer 2014. Report submitted to the Middle Rio Grande Conservancy District.

SWCA. (2016). Middle Rio Grande Conservancy District wasteway/drain outfalls sampling summer and fall 2015. Report submitted to the Middle Rio Grande Conservancy District.

SWCA. (2019). Middle Rio Grande Conservancy District wasteway sampling – summer/fall 2018. Report submitted to the Middle Rio Grande Conservancy District.

SWCA. (2021). Middle Rio Grande Conservancy District drain outfall sampling and analysis – summer/fall 2020. Report submitted to the Middle Rio Grande Conservancy District.

Turner, T. F., Osborne, M. J., Moyer, G. R., Benavides, M. A., and Alò, D. (2006). Life history and environmental variation interact to determine effective population to census size ratio. Proceedings of the Royal Society B 273:3065-3073. https://doi.org/10.1098/rspb.2006.3677

Van Horn, D., Reale, J. K., & Archdeacon, T. P. (2022) Water quality in three potential aquatic refugia in an arid-land river: assessing suitability to sustain populations of an endangered fish species. *Knowledge & Management of Aquatic Ecosystems*, 423, 7. https://doi.org/10.1051/kmae/2022002

Watts, R.J., Kopf, R.K., McCasker, N., Howitt, J. A., Conallin, J., Wooden, I. and Baumgartner, L. (2018). Adaptive Management of Environmental Flows: Using Irrigation Infrastructure to Deliver Environmental Benefits During a Large Hypoxic Blackwater Event in the Southern Murray–Darling Basin, Australia. Environmental Management 61, 469–480. https://doi.org/10.1007/s00267-017-0941-1

Wesche, T. A., Wesche, L. B., Broderick, S., Cowley, D. E., and Wyman, B. (2010). Development of Rio Grande Silvery Minnow refugia at drain outfalls in the Isleta Reach of the Middle Rio Grande, New Mexico. Submitted to the Middle Rio Grande Endangered Species Collaborative Program. https://webapps.usgs.gov/MRGESCP/documents/wesche-et-al-2010-development-of-rgsm-refugia-at-drain-outfalls-in-the-isleta-reach-of-the-mrg-nm

Winemiller, K. O. (2005) Life history strategies, population regulation, and implications for fisheries management. Canadian Journal of Fisheries and Aquatic Sciences, 62, 872-885. https://doi.org/10.1139/f05-040

Worthington, T. A., Echelle, A. A., Perkin, J. S., et al. (2018). The emblematic minnows of the North American Great Plains: A synthesis of threats and conservation opportunities. Fish and Fisheries 19: 271– 307. https://doi.org/10.1002/faf.12254

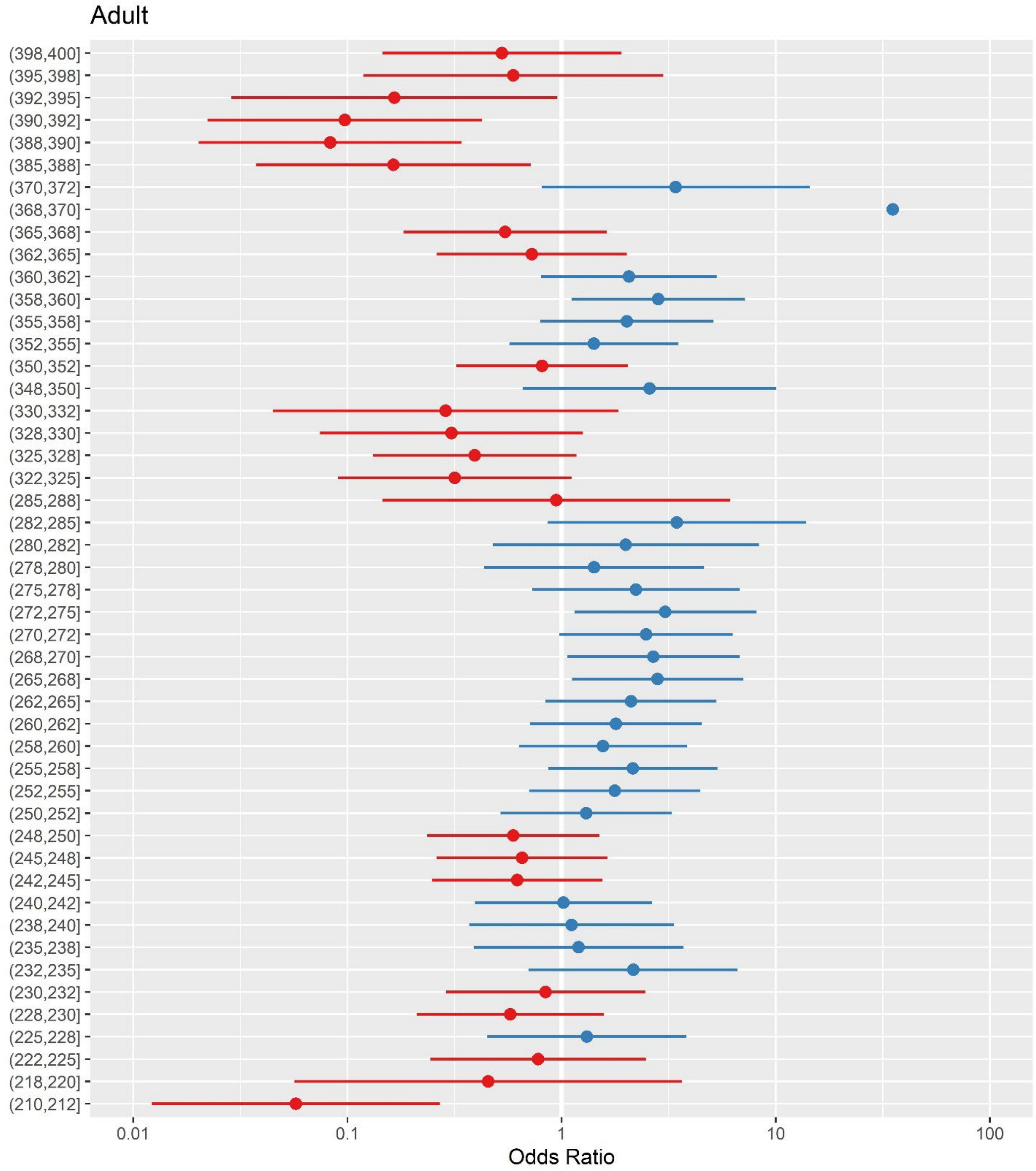
Yackulic, C. B., Archdeacon, T. P., Valdez, R. A., Hobbs, M., Porter, M. D., Lusk, J., Tanner, A., Gonzales, E. J., Lee, D. Y., and Haggerty, G. M. 2022. Quantifying flow and nonflow management impacts on an endangered fish by integrating data, research, and expert opinion. Ecosphere 13:e4240. https://doi.org/10.1002/ecs2.4240

APPENDICES

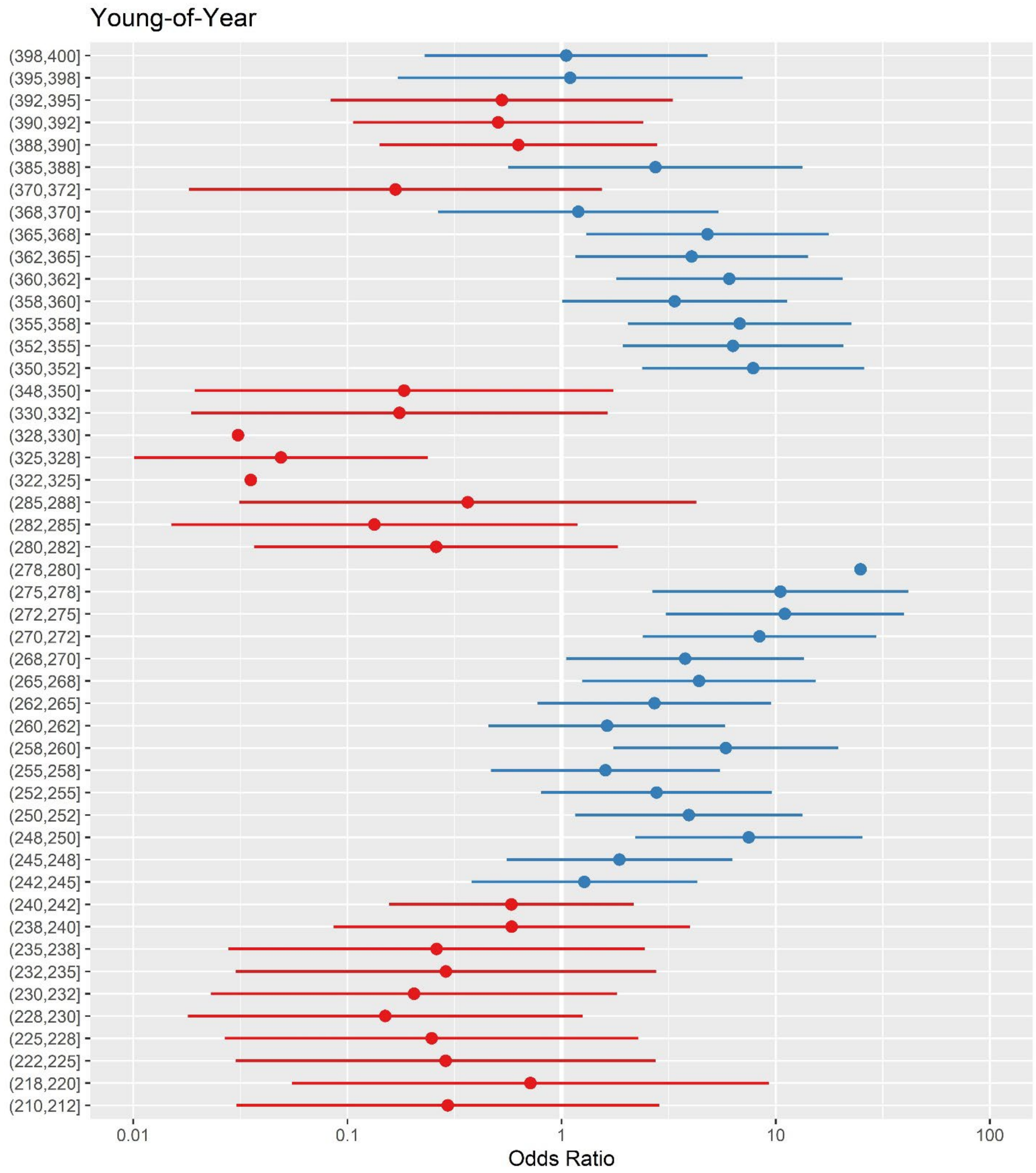
River Kilometer Location Key:

Montano-399.95
Central-393.6
Bridge-390.95
Alejandro-370.2
Los Lunas (Main Street)-363.2
Los Chavez -356.75
Peralta WW-351.35
Sabinal-331.1
Escondida/Pueblitos Road-284.25
Brown’s Arroyo-271.5
Socorro Hub-266.65
U.S. 380-263.05
North Boundary Pump Channel-258.5
South Boundary Pump Channel-240.95
San Marcial (railroad bridge)-231.8

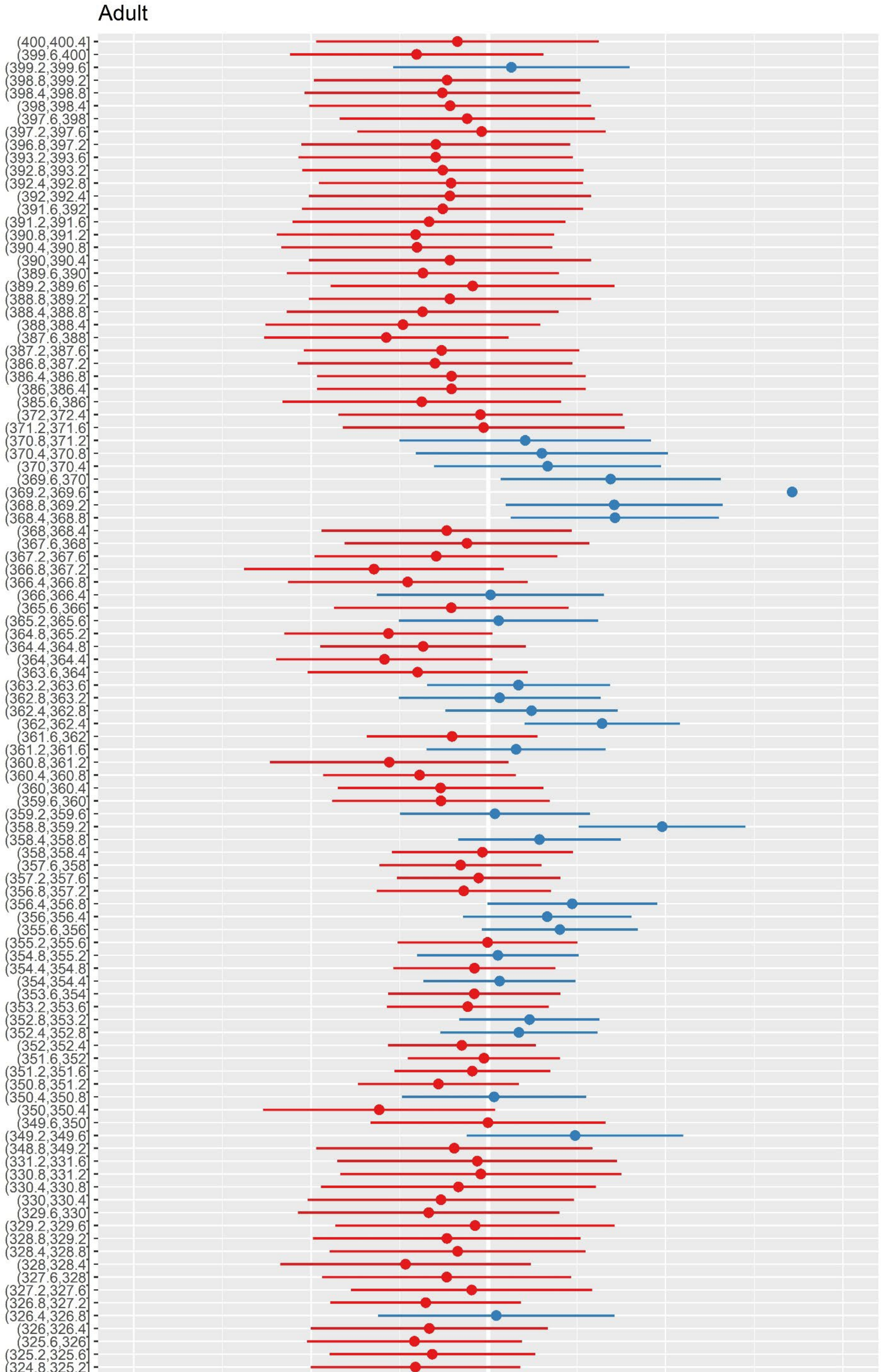
Spatial unit random effects estimates:

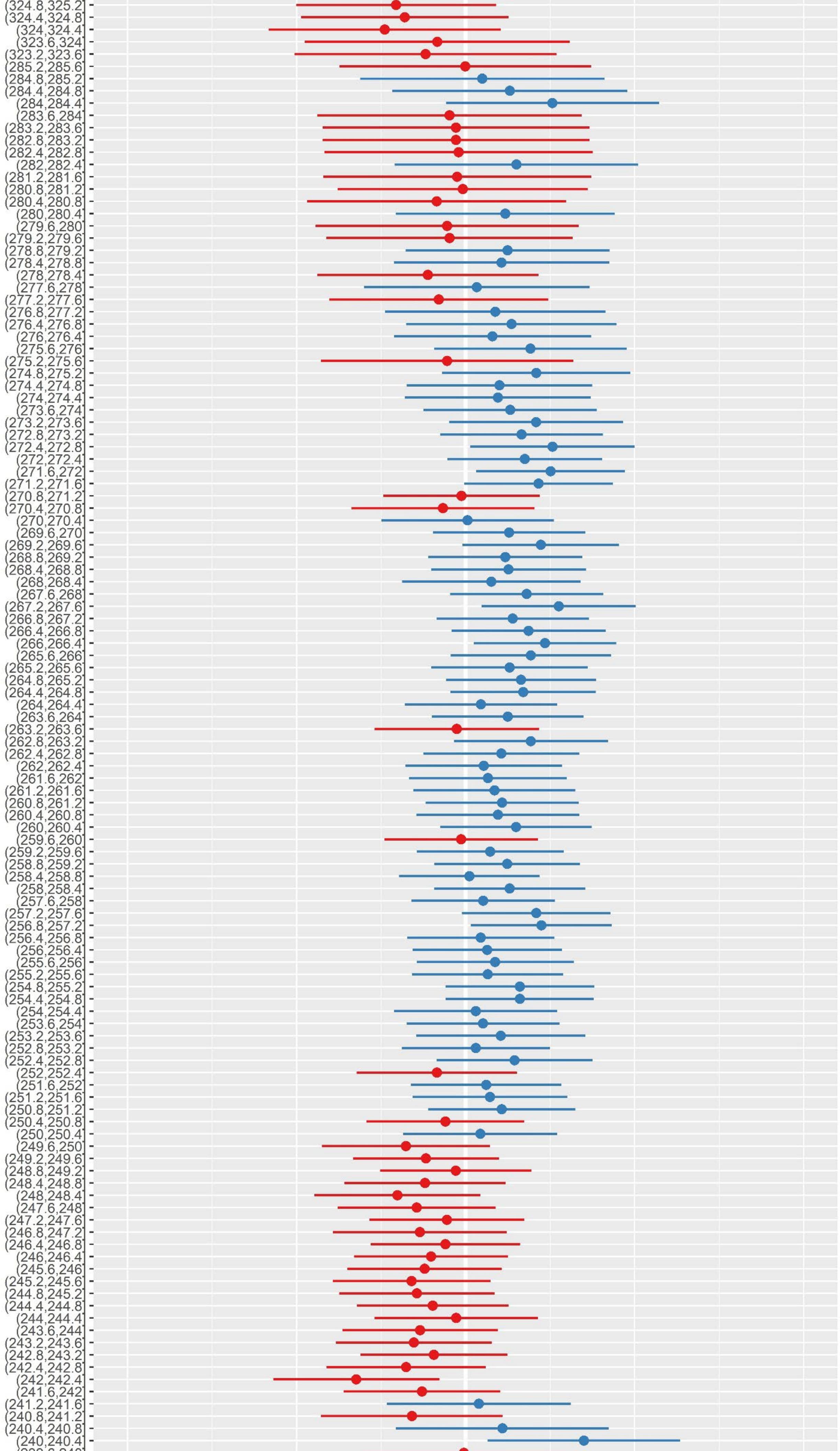


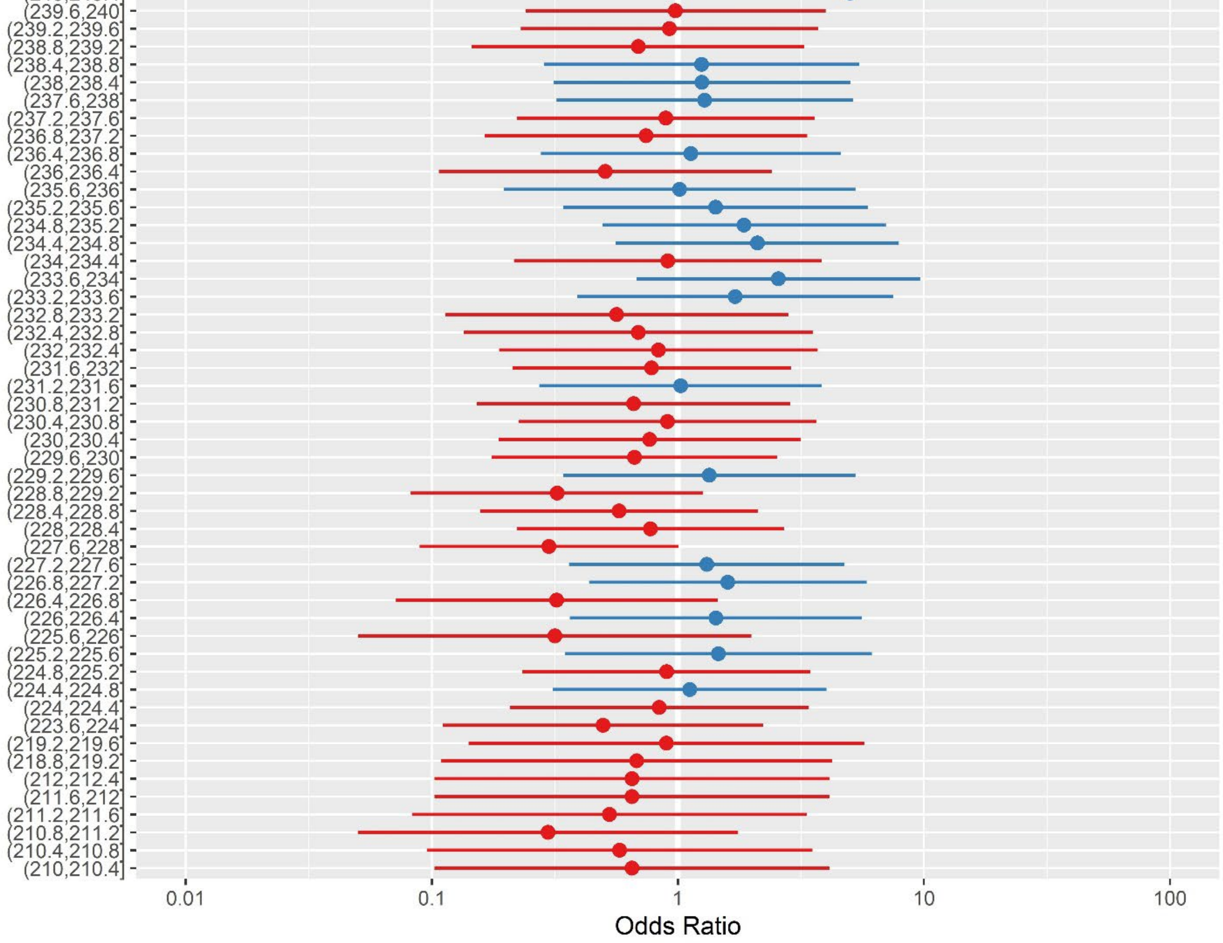
Mean and 95% confidence interval for 2.5 km spatial unit contribution to numbers of adult RGS minnow stranded in isolated pools. Odds ratio indicates the number of times the mean number, red indicates a negative effect (fewer than expected) and blue a positive effect (more than expected). Y-axis indicates the river kilometer segment.



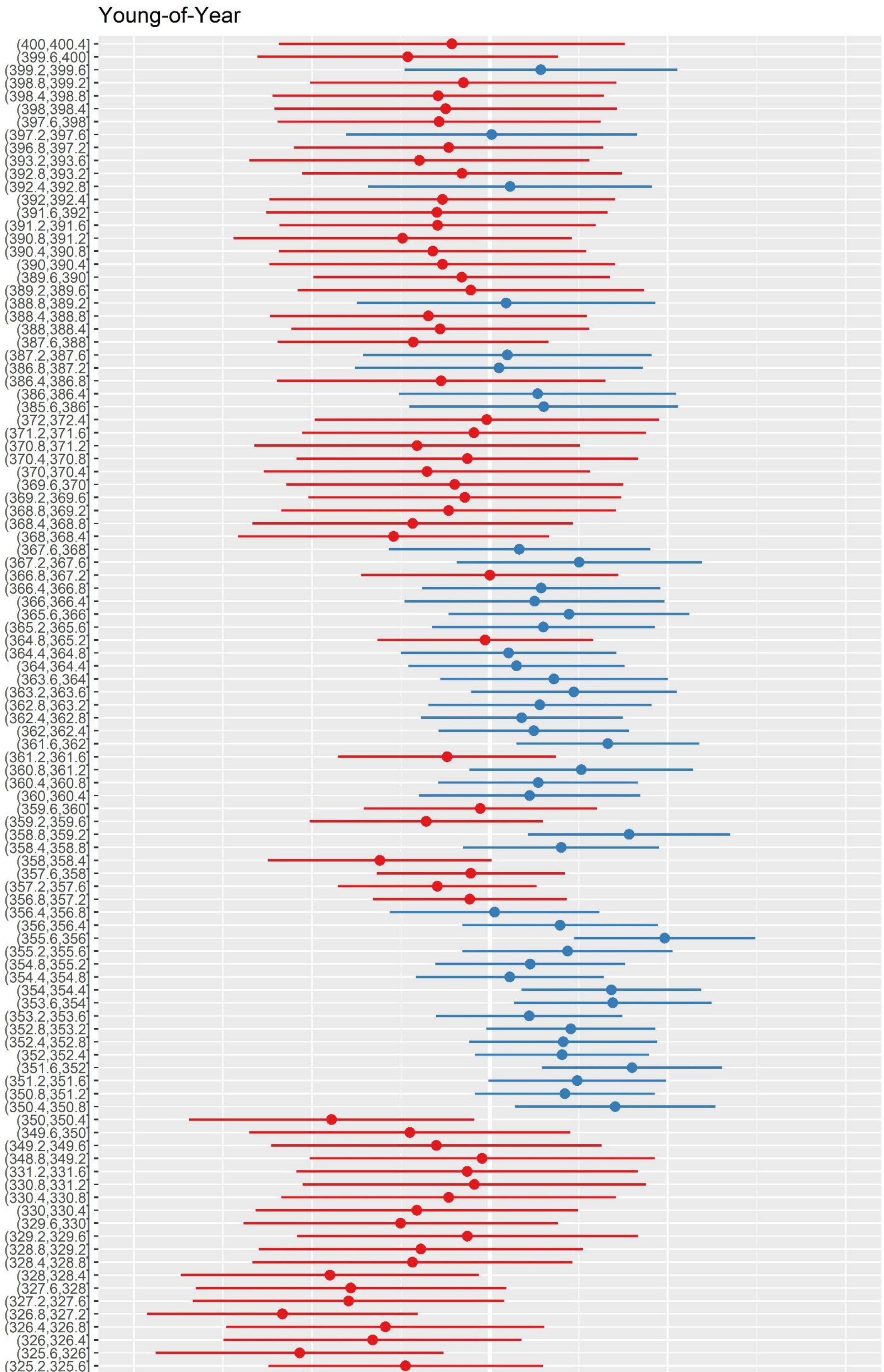
Mean and 95% confidence interval for 2.5 km spatial unit contribution to numbers of young-of-year RGS minnow stranded in isolated pools. Odds ratio indicates the number of times the mean number, red indicates a negative effect (fewer than expected) and blue a positive effect (more than expected). Y-axis indicates the river kilometer segment.

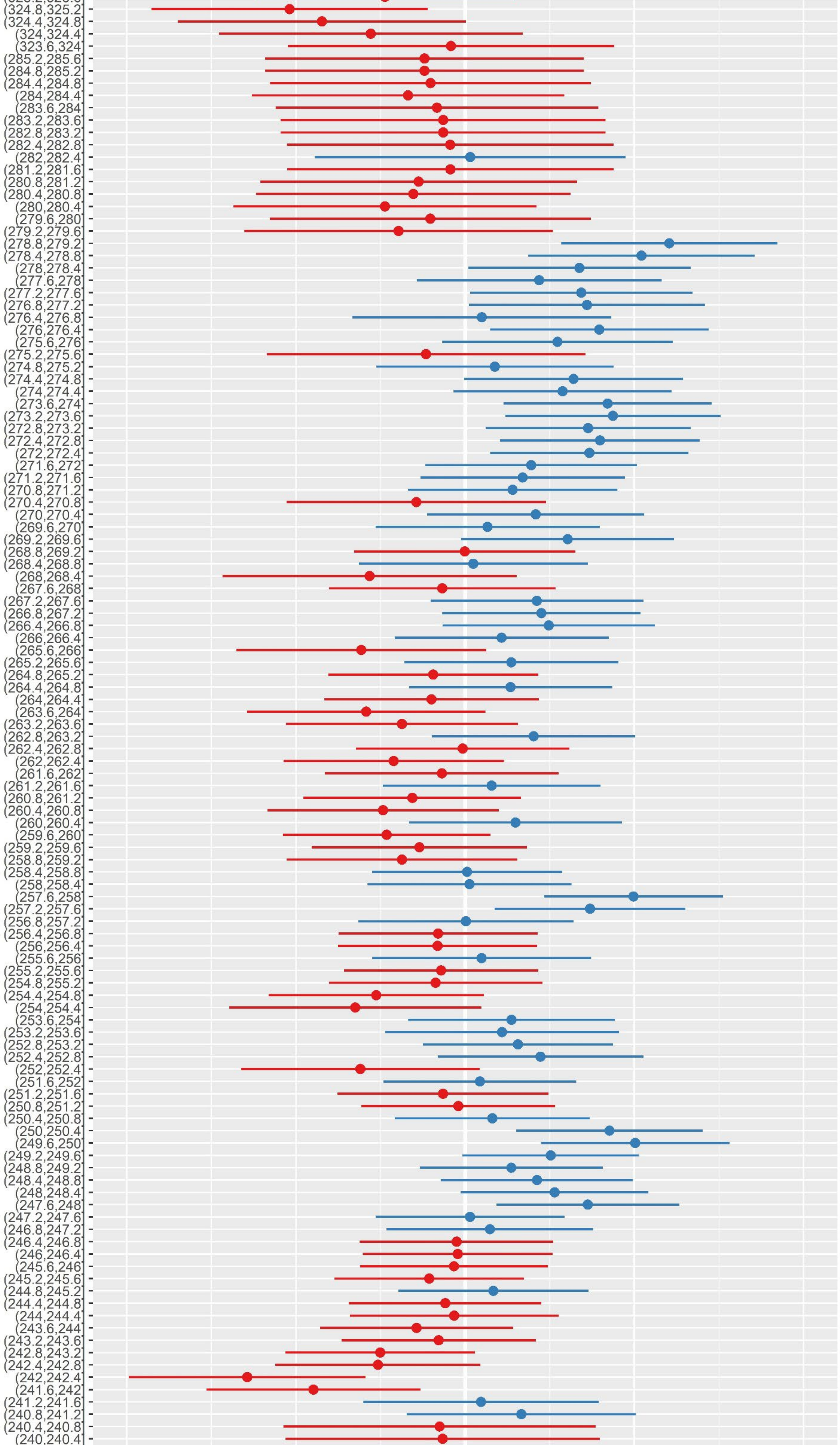

Adult
(400,400.4]
(399.6,400]
(399.2,399.6]
(398.8,399.2]
(398.4,398.8]
(398,398.4]
(397.6,398]
(397.2,397.6]
(396.8,397.2]
(393.2,393.6]
(392.8,393.2]
(392.4,392.8]
(392,392.4]
(391.6,392]
(391.2,391.6]
(390.8,391.2]
(390.4,390.8]
(390,390.4]
(389.6,390]
(389.2,389.6]
(388.8,389.2]
(388.4,388.8]
(388,388.4]
(387.6,388]
(387.2,387.6]
(386.8,387.2]
(386.4,386.8]
(386,386.4]
(385.6,386]
(372,372.4]
(371.2,371.6]
(370.8,371.2]
(370.4,370.8]
(370,370.4]
(369.6,370]
(369.2,369.6]
(368.8,369.2]
(368.4,368.8]
(368,368.4]
(367.6,368]
(367.2,367.6]
(366.8,367.2]
(366.4,366.8]
(366,366.4]
(365.6,366]
(365.2,365.6]
(364.8,365.2]
(364.4,364.8]
(364,364.4]
(363.6,364]
(363.2,363.6]
(362.8,363.2]
(362.4,362.8]
(362,362.4]
(361.6,362]
(361.2,361.6]
(360.8,361.2]
(360.4,360.8]
(360,360.4]
(359.6,360]
(359.2,359.6]
(358.8,359.2]
(358.4,358.8]
(358,358.4]
(357.6,358]
(357.2,357.6]
(356.8,357.2]
(356.4,356.8]
(356,356.4]
(355.6,356]
(355.2,355.6]
(354.8,355.2]
(354.4,354.8]
(354,354.4]
(353.6,354]
(353.2,353.6]
(352.8,353.2]
(352.4,352.8]
(352,352.4]
(351.6,352]
(351.2,351.6]
(350.8,351.2]
(350.4,350.8]
(350,350.4]
(349.6,350]
(349.2,349.6]
(348.8,349.2]
(331.2,331.6]
(330.8,331.2]
(330.4,330.8]
(330,330.4]
(329.6,330]
(329.2,329.6]
(328.8,329.2]
(328.4,328.8]
(328,328.4]
(327.6,328]
(327.2,327.6]
(326.8,327.2]
(326.4,326.8]
(326,326.4]
(325.6,326]
(325.2,325.6]
(324.8,325.2]

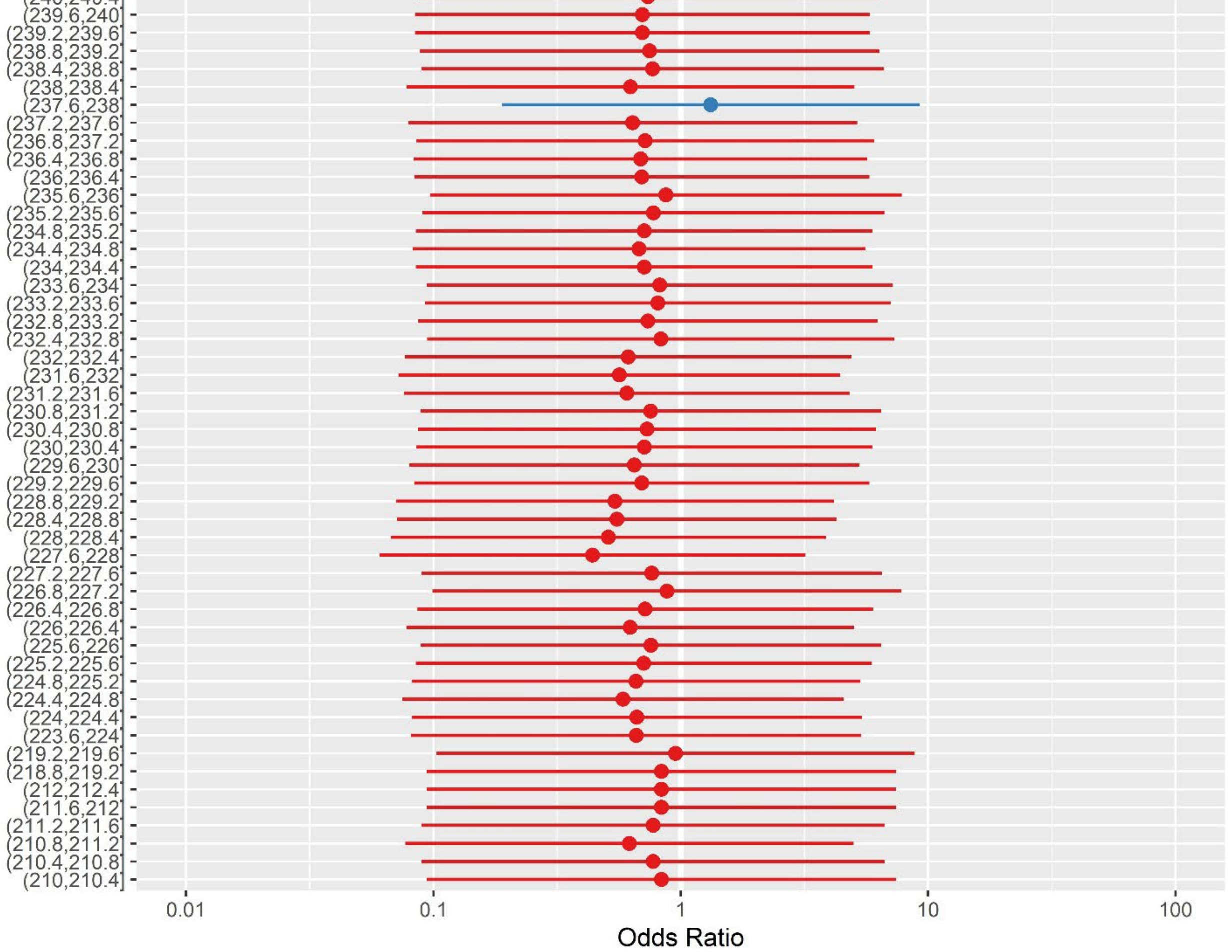

(324.8,325.2]
(324.4,324.8]
(324,324.4]
(323.6,324]
(323.2,323.6]
(285.2,285.6]
(284.8,285.2]
(284.4,284.8]
(284,284.4]
(283.6,284]
(283.2,283.6]
(282.8,283.2]
(282.4,282.8]
(282,282.4]
(281.2,281.6]
(280.8,281.2]
(280.4,280.8]
(280,280.4]
(279.6,280]
(279.2,279.6]
(278.8,279.2]
(278.4,278.8]
(278,278.4]
(277.6,278]
(277.2,277.6]
(276.8,277.2]
(276.4,276.8]
(276,276.4]
(275.6,276]
(275.2,275.6]
(274.8,275.2]
(274.4,274.8]
(274,274.4]
(273.6,274]
(273.2,273.6]
(272.8,273.2]
(272.4,272.8]
(272,272.4]
(271.6,272]
(271.2,271.6]
(270.8,271.2]
(270.4,270.8]
(270,270.4]
(269.6,270]
(269.2,269.6]
(268.8,269.2]
(268.4,268.8]
(268,268.4]
(267.6,268]
(267.2,267.6]
(266.8,267.2]
(266.4,266.8]
(266,266.4]
(265.6,266]
(265.2,265.6]
(264.8,265.2]
(264.4,264.8]
(264,264.4]
(263.6,264]
(263.2,263.6]
(262.8,263.2]
(262.4,262.8]
(262,262.4]
(261.6,262]
(261.2,261.6]
(260.8,261.2]
(260.4,260.8]
(260,260.4]
(259.6,260]
(259.2,259.6]
(258.8,259.2]
(258.4,258.8]
(258,258.4]
(257.6,258]
(257.2,257.6]
(256.8,257.2]
(256.4,256.8]
(256,256.4]
(255.6,256]
(255.2,255.6]
(254.8,255.2]
(254.4,254.8]
(254,254.4]
(253.6,254]
(253.2,253.6]
(252.8,253.2]
(252.4,252.8]
(252,252.4]
(251.6,252]
(251.2,251.6]
(250.8,251.2]
(250.4,250.8]
(250,250.4]
(249.6,250]
(249.2,249.6]
(248.8,249.2]
(248.4,248.8]
(248,248.4]
(247.6,248]
(247.2,247.6]
(246.8,247.2]
(246.4,246.8]
(246,246.4]
(245.6,246]
(245.2,245.6]
(244.8,245.2]
(244.4,244.8]
(244,244.4]
(243.6,244]
(243.2,243.6]
(242.8,243.2]
(242.4,242.8]
(242,242.4]
(241.6,242]
(241.2,241.6]
(240.8,241.2]
(240.4,240.8]
(240,240.4]



Mean and 95% confidence interval for 400 m spatial unit contribution to numbers of adult RGS minnow stranded in isolated pools. Odds ratio indicates the number of times the mean number, red indicates a negative effect (fewer than expected) and blue a positive effect (more than expected). Y-axis indicates the river kilometer segment.


Young-of-Year
(400,400.4]
(399.6,400]
(399.2,399.6]
(398.8,399.2]
(398.4,398.8]
(398,398.4]
(397.6,398]
(397.2,397.6]
(396.8,397.2]
(393.2,393.6]
(392.8,393.2]
(392.4,392.8]
(392,392.4]
(391.6,392]
(391.2,391.6]
(390.8,391.2]
(390.4,390.8]
(390,390.4]
(389.6,390]
(389.2,389.6]
(388.8,389.2]
(388.4,388.8]
(388,388.4]
(387.6,388]
(387.2,387.6]
(386.8,387.2]
(386.4,386.8]
(386,386.4]
(385.6,386]
(372,372.4]
(371.2,371.6]
(370.8,371.2]
(370.4,370.8]
(370,370.4]
(369.6,370]
(369.2,369.6]
(368.8,369.2]
(368.4,368.8]
(368,368.4]
(367.6,368]
(367.2,367.6]
(366.8,367.2]
(366.4,366.8]
(366,366.4]
(365.6,366]
(365.2,365.6]
(364.8,365.2]
(364.4,364.8]
(364,364.4]
(363.6,364]
(363.2,363.6]
(362.8,363.2]
(362.4,362.8]
(362,362.4]
(361.6,362]
(361.2,361.6]
(360.8,361.2]
(360.4,360.8]
(360,360.4]
(359.6,360]
(359.2,359.6]
(358.8,359.2]
(358.4,358.8]
(358,358.4]
(357.6,358]
(357.2,357.6]
(356.8,357.2]
(356.4,356.8]
(356,356.4]
(355.6,356]
(355.2,355.6]
(354.8,355.2]
(354.4,354.8]
(354,354.4]
(353.6,354]
(353.2,353.6]
(352.8,353.2]
(352.4,352.8]
(352,352.4]
(351.6,352]
(351.2,351.6]
(350.8,351.2]
(350.4,350.8]
(350,350.4]
(349.6,350]
(349.2,349.6]
(348.8,349.2]
(331.2,331.6]
(330.8,331.2]
(330.4,330.8]
(330,330.4]
(329.6,330]
(329.2,329.6]
(328.8,329.2]
(328.4,328.8]
(328,328.4]
(327.6,328]
(327.2,327.6]
(326.8,327.2]
(326.4,326.8]
(326,326.4]
(325.6,326]
(325.2,325.6]


(324.8,325.2]
(324.4,324.8]
(324,324.4]
(323.6,324]
(285.2,285.6]
(284.8,285.2]
(284.4,284.8]
(284,284.4]
(283.6,284]
(283.2,283.6]
(282.8,283.2]
(282.4,282.8]
(282,282.4]
(281.2,281.6]
(280.8,281.2]
(280.4,280.8]
(280,280.4]
(279.6,280]
(279.2,279.6]
(278.8,279.2]
(278.4,278.8]
(278,278.4]
(277.6,278]
(277.2,277.6]
(276.8,277.2]
(276.4,276.8]
(276,276.4]
(275.6,276]
(275.2,275.6]
(274.8,275.2]
(274.4,274.8]
(274,274.4]
(273.6,274]
(273.2,273.6]
(272.8,273.2]
(272.4,272.8]
(272,272.4]
(271.6,272]
(271.2,271.6]
(270.8,271.2]
(270.4,270.8]
(270,270.4]
(269.6,270]
(269.2,269.6]
(268.8,269.2]
(268.4,268.8]
(268,268.4]
(267.6,268]
(267.2,267.6]
(266.8,267.2]
(266.4,266.8]
(266,266.4]
(265.6,266]
(265.2,265.6]
(264.8,265.2]
(264.4,264.8]
(264,264.4]
(263.6,264]
(263.2,263.6]
(262.8,263.2]
(262.4,262.8]
(262,262.4]
(261.6,262]
(261.2,261.6]
(260.8,261.2]
(260.4,260.8]
(260,260.4]
(259.6,260]
(259.2,259.6]
(258.8,259.2]
(258.4,258.8]
(258,258.4]
(257.6,258]
(257.2,257.6]
(256.8,257.2]
(256.4,256.8]
(256,256.4]
(255.6,256]
(255.2,255.6]
(254.8,255.2]
(254.4,254.8]
(254,254.4]
(253.6,254]
(253.2,253.6]
(252.8,253.2]
(252.4,252.8]
(252,252.4]
(251.6,252]
(251.2,251.6]
(250.8,251.2]
(250.4,250.8]
(250,250.4]
(249.6,250]
(249.2,249.6]
(248.8,249.2]
(248.4,248.8]
(248,248.4]
(247.6,248]
(247.2,247.6]
(246.8,247.2]
(246.4,246.8]
(246,246.4]
(245.6,246]
(245.2,245.6]
(244.8,245.2]
(244.4,244.8]
(244,244.4]
(243.6,244]
(243.2,243.6]
(242.8,243.2]
(242.4,242.8]
(242,242.4]
(241.6,242]
(241.2,241.6]
(240.8,241.2]
(240.4,240.8]
(240,240.4]



Mean and 95% confidence interval for 400 m spatial unit contribution to numbers of adult RGS minnow stranded in isolated pools. Odds ratio indicates the number of times the mean number, red indicates a negative effect (fewer than expected) and blue a positive effect (more than expected). Y-axis indicates the river kilometer segment.